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Adapting to changing memory retrieval demands: Evidence from event-related potentials

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ABSTRACT

This study investigated preparatory processes involved in adapting to changing episodic memory retrieval demands. Event-related potentials (ERPs) were recorded while participants performed a general old/new recognition task and a specific task that also required retrieval of perceptual details. The relevant task remained either constant or changed (predictably or randomly) across trials. Responses were slowed when participants switched from the specific to the general task but not vice versa. Hence, asymmetrical switch costs were observed, suggesting that retrieval preparation is dependent not only on the current retrieval goal but also influenced by recent retrieval attempts. Consistently, over posterior scalp regions ERPs associated with advance preparation were modulated by the preceding task, reflecting increased attentional selection requirements for the general task, and by the foreknowledge about the task sequence. When retrieval demands remained constant, frontal slow-waves elicited by retrieval-cues were more positive going for the specific task, indicating full implementation of a retrieval orientation that allows more efficient retrieval of perceptual details.

1. Introduction

Remembering details of one's own past can be a controlled and goal-directed activity. That is, rather than being a reflexive act, episodic memory retrieval is a voluntarily initiated search process that people engage in for meeting the changing demands of current situations (cf., Moscovitch, 1995). In recent years, processes mediating the retrieval of detailed information and their neural correlates have been investigated by several studies (e.g., Dobbins & Wagner, 2005; Ranganath, Johnson, & D'Esposito, 2000; Rugg & Wilding, 2000; Simons, Gilbert, Owen, Fletcher, & Burgess, 2005). In particular, Rugg and Wilding (2000) proposed that controlled memory retrieval is fostered by the implementation of *retrieval orientations*. These are suggested to be tonically maintained cognitive modes that constrain processing of a retrieval-cue to efficiently retrieve specific episodic information. Neural correlates of retrieval orientations can best be observed by examining trials of correctly rejected new items (Rugg & Wilding, 2000). That is, these trials are not confounded by processes associated with retrieval success that were also shown to be modulated by specific retrieval demands (Johansson, Stenberg, Lindgren, & Rosén, 2002; Senkfor & Van Petten, 1998; Van Petten, Senkfor, & Newberg, 2000).

In a functional imaging study, Ranganath, Johnson, and D'Esposito (2000) reported greater recruitment of rostral prefrontal cortex for a condition requiring recollection of perceptual features of a study episode than for mere old/new recognition. Importantly, this was also the case for new items. The effect of retrieval task on brain activation thus did not merely reflect task differences in the quantity or quality of retrieved information, or monitoring processes that operate on retrieved information. Employing an analogues task with event-related potentials (ERP), Ranganath and Paller (2000) observed a difference in slow-wave activity for the two memory retrieval tasks time-locked to retrieval-cue onset. In accordance with the aforementioned neuroimaging data, this effect was located at frontal recording sites and was present for trials of correctly rejected new items.

Similar ERP retrieval orientation effects, though varying in scalp topography (with some reporting central maxima), have been observed in different memory tasks. Some reported these effects for conditions requiring the recollection of contextual information compared to simple old/new recognition tasks (Stenberg, Johansson, & Rosén, 2006; Dzulkifli, Sharpe, & Wilding, 2004; Ranganath & Paller, 1999). Others found similar effects for comparing old/new recognition tasks following either different encoding operations (Rugg, Allan, & Birch, 2000), or format changes of the studied mate-

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rial (Herron & Rugg, 2003; Hornberger, Morcom, & Rugg, 2004; Robb & Rugg, 2002). All of these studies manipulated retrieval operations across blocks or between subjects, suggesting sustained *implementation* of a particular retrieval orientation for a period of time. Accordingly, ERP retrieval orientation effects appear to be restricted to those contexts, in which retrieval demands are relatively consistent. Specifically, these effects are generally not observed in conditions requiring frequent switching between episodic retrieval tasks within a test phase (Johnson & Rugg, 2006; Herron & Wilding, 2006; Werkle-Bergner, Mecklinger, Kray, Meyer, & Düzel, 2005). These results suggest that the full implementation of a retrieval orientation is contingent upon prolonged engagement in the same episodic memory task.

In addition to maintenance of a specific cognitive mode, most everyday situations require flexible *adaptation* to changing task demands. The cognitive system, therefore, has to be constantly reconfigured in order to cope with currentl situations (e.g., Monsell, 2003). Thus, an understanding of controlled episodic memory retrieval is incomplete without knowledge about the processes that enable flexible adaptation to changing memory retrieval demands. Since a retrieval orientation is conceptualized as a tonically maintained cognitive mode for specific, goal-directed memory retrieval, its implementation would seem to interfere with this ability.

The main goal of this study was thus to investigate processes involved in the preparation for an upcoming retrieval attempt. Particularly, we examined the extent to which the adaptation for specific episodic retrieval demands is influenced by the preceding retrieval goals. To investigate electrophysiological correlates of retrieval preparation, we asked participants to switch between two retrieval tasks, which were previously associated with an ERP retrieval orientation effect at frontal recording sites (Werkle-Bergner et al., 2005). In particular, participants engaged in two recognition memory tasks: an item recognition task that required mere old/new decisions for words (*general task*), and a relational recognition task that also required to indicate whether the test stimulus was associated with a specific aspect of the study event (i.e., words' font; *specific task*). While participants constantly performed either the general or the specific task in continuous blocks, they switched between the two tasks in mixed blocks. Employing a similar paradigm, Werkle-Bergner et al. (2005) reported faster responses when participants performed the same memory task as in the preceding trial (*non-switch trials*) compared to switched to the alternate task (*switch trials*). Thus, episodic memory retrieval appears to be more efficient, if the sought-for information has not changed since the last retrieval attempt. A similar pattern of performance decrement has frequently been associated with the requirement to switch between simple task sets (e.g., stimulus–response mappings), and has been termed *specific switch costs* (e.g., Kray & Lindenberger, 2000; for reviews see Logan, 2003; Monsell, 2003). These costs are either thought to reflect time consumed by the implementation of the currently relevant task set (e.g., de Jong, 2000; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001) or interference from the task set that was relevant on the preceding trial (e.g., Allport, Styles, & Hsieh, 1994). However, these two accounts are not mutually exclusive (cf., Meiran, Chorev, & Sapir, 2000; see also Monsell 2003; Wylie & Allport, 2000).

To investigate preparatory processes in the domain of episodic memory retrieval, we examined ERPs elicited by task-cues which instructed for the currently relevant task on a trial-by-trial basis. We take these ERPs to reflect processes involved in preparation for an upcoming retrieval demand, which are not confounded by actual retrieval attempts. Furthermore, recent behavioral studies observed that specific switch costs are eliminated after one completed trial (i.e., on non-switch trials) when the task sequence is predictable. In contrast, switch costs decline more gradually over the consecutive engagement in a given task for at least two trials, if the nature of the upcoming task is unpredictable (Milán, Sanabria, Tornay, & González, 2005; Monsell, Sumner, & Waters, 2003; see also Koch, 2005). These findings suggest that even though the task set participants recently engaged in is more activated, both competing task sets remain in a comparable 'state of readiness' in random blocks (Monsell et al., 2003; see also Kray, 2006). We aimed at examining whether electrophysiological correlates of retrieval preparation are also modulated by the foreknowledge about the task sequence by introducing two mixed block types. In *predictable* blocks, participants alternated between the tasks on every second trial, whereas the currently relevant task changed unpredictably across trials in *random* blocks.

Two electrophysiological correlates of the preparation for imminent changes of basal task sets have frequently been observed at posterior recoding sites, namely a modulation of the P3b and a difference in slow potential activity. First, preparation for switch trials is associated with increased P3b amplitude (e.g., Barceló, Perianez, & Knight, 2002; Kieffaber & Hetrick, 2005; Moulden et al., 1998; Nicholson, Karayanidis, Poboka, Heathcote, & Michie, 2005; Rushworth, Passingham, & Nobre, 2005; Tieges, Snel, Kok, Plat, & Ridderinkhof, 2007). The effect was suggested to reflect the extent to which attentional resources are allocated to the now-relevant task set (e.g., Kieffaber & Hetrick, 2005; see also Barceló, Munoz-Cespedes, Pozo, & Rubia, 2000). This interpretation is in agreement with the "context updating" account of the P3b (e.g., Donchin & Coles, 1988, 1998), proposing that P3b amplitude is proportional to the amount of working memory revision that is required for task performance (Fabiani & Donchin, 1995). If similar mechanisms are involved in adapting to changing retrieval demands as in switching between more basal task sets, we expected larger P3b amplitude on switch than on non-switch trials. Moreover, in accordance with the proposed role of the P3b in context updating, we predicted enhanced P3b amplitude in random compared to predictable blocks, since task-cues are more informative in the former block type. Secondly, a sustained slow potential that emerges later in time than the P3b was also observed to be modulated by the requirement to switch task sets (e.g., Brass, Ullsperger, Knoesche, von Cramon, & Phillips, 2005; Goffaux, Phillips, Sinai, & Pushkar, 2006; Karayanidis, Coltheart, Michie, & Murphy, 2003; Nicholson et al., 2005; Rushworth, Passingham, & Nobre, 2002, 2005; Swainson, Jackson, & Jackson, 2006; Wylie, Javitt, & Foxe, 2003). Particularly, this ERP component manifests over posterior scalp regions and is more positive going for switch than for non-switch trials. It has been suggested to reflect competition for activation between both task sets and/or enhanced attentional selection requirements in preparation for the less activated task set (Wylie et al., 2003). Since specific switch costs are assumed to index these attentional selection requirements (e.g., Allport et al., 1994), we accordingly predicted putative switch cost differences for the two tasks to be reflected by differences of this posterior slow-wave effect during the task-cue interval.

The requirement to switch between two tasks is not only associated with specific switch costs. In addition, performance is also generally slower in mixed blocks than in continuous blocks (e.g., Goffaux et al., 2006; Mayr, 2001). This performance cost has been labeled *general switch cost* (cf., Kray & Lindenberger, 2000). Werkle-Bergner and colleagues observed an ERP correlate of this performance decrement, i.e., an anterior-frontal slow-wave elicited by retrieval-cues that was more positive going for predictable than for continuous blocks. It was taken to reflect the general *dual-task* requirement of maintaining both task sets active in working memory while performing the actual retrieval task and/or *sequencing* processes engaged by the regularity of the task order and the monitoring of the position within the task sequence. We aimed at delineating these two accounts by using mixed blocks with random and predictable sequences. If the anterior slow-wave pattern reflects sequence monitoring, we expected different slow-wave patterns for the two mixed block types, since participants can only engage in sequencing processes in predictable blocks. In contrast, if this ERP effect indexes more general dual-task requirements, a similar slow-wave pattern was predicted for both random and predictable blocks.

To summarize, the aims of this study were twofold: First, we examined ERP correlates of retrieval preparation, i.e., the processes set in train by the task-cue. Particularly, we expected effects of the preceding retrieval task on the preparation for the upcoming retrieval attempt over posterior scalp regions. Secondly, we aimed at scrutinizing the functional characteristics of the anterior-frontal slow-wave that was shown to be an electrophysiological correlate of general switch costs (Werkle-Bergner et al., 2005). Specifically, we examined whether this effect reflected "sequencing", i.e., monitoring of the current position within the task sequence. Analyses of ERPs time-locked to retrieval-cue onset focused on those elicited by correctly rejected new items, since these trials are not confounded by processes associated with retrieval success, such as the monitoring and verification of retrieved information (Ranganath & Paller, 1999; Rugg & Wilding, 2000; Werkle-Bergner et al., 2005).

2. Materials and methods

2.1. Participants

Twenty-three volunteers from Saarland University participated in this experiment. They all were right-handed, had normal or corrected-to-normal vision, and reported good health with no known history of neurological or psychiatric illness. At the beginning of the experimental session, they gave written informed consent. All participants received € 20 reimbursement. Of the 23 participants, 7 had to be excluded from further analysis due to excessive eye movement artifacts, technically unsatisfactory recordings, or chance performance. Thus, 16 participants (8 females; mean age = 24.12 years, age range = 20–27 years) were included in the analyses.

2.2. Stimuli

The study and test material comprised 480 concrete German nouns selected from the CELEX data base (Baayen, Piepenbrock, & van Rijn, 1993). The words consisted of two or three syllables with a normed frequency of 1–7 per million within the CELEX corpus. Each noun was presented in one of two fonts (times new roman bold [tmsrb.fon 200]; helvetica bold [helvb.fon 200]), where half of the words within each study or test block was presented in either font type. During test phases, a rectangle and an ellipse served as task-cues, indicating which retrieval task had to be performed next (see Fig. 1). The assignment of task-cue type to retrieval task was counterbalanced across subjects. Visual stimuli were presented in white on a black background at the center of a 19″ monitor. Stimulus presentation and behavioral data collection were controlled by ERTS software (BeriSoft Cooperation; Beringer, 1992).

2.3. Procedure

The experiment consisted of alternating study and test phases. In a study phase, participants had to memorize a list of 30 words. In addition, they were instructed to indicate whether a given word contained the letter "a" by pushing one of two buttons. This task was introduced to constrain the variability of mnemonic encoding strategies and to ensure appropriate encoding of the words and their respective fonts. Each study trial started with the presentation of a fixation cross for 300 ms. Then, a word was presented for 2000 ms, which was followed by a blank screen for 100 ms (see Fig. 1).

In a test phase, participants received a list of 40 words, which had either just been studied ("old") or had not yet been presented in the experiment ("new"). The old words were presented either in the same font as during study ("old/same") or in the alternative font ("old/different"). In each trial, participants engaged in one of two retrieval tasks. The *general task* (G) required old/new decisions for words irrespective of the font type. That is, participants had to decide "old" for both old/same and old/different words, whereas a "new" response was required for new words only. In contrast, the *specific task* (S) additionally required to retrieve each word's study font. That is, participants had to indicate "old" only for old/same but "new" for both old/different and new words. Each trial started with the presentation of a blank screen for 200 ms (see Fig. 1). Thereafter, a task-cue was presented that indicated which of the retrieval tasks had to be performed. 1000 ms after task-cue onset, a word (i.e., the retrieval-cue) appeared in the center of the task-cue. Both retrieval-cue and task-cue remained for another 1700 ms, followed by a blank screen for 300 ms.

Responses were registered by a four button response-box. The keys were arranged in a square, whereby each task (i.e., general or specific retrieval instruction) was assigned to a row. For each retrieval instruction, one button corresponded to "old" and another one to "new" responses. Assignment of the rows to retrieval type instruction and of the left and right buttons to response type was counterbalanced across participants. Participants were instructed to respond as accurately and quickly as possible.

Moreover, participants performed both retrieval tasks (general and specific) under different block conditions. In continuous blocks, they maintained the same retrieval orientation. In *continuous–general* blocks, participants solely engaged in the general re-

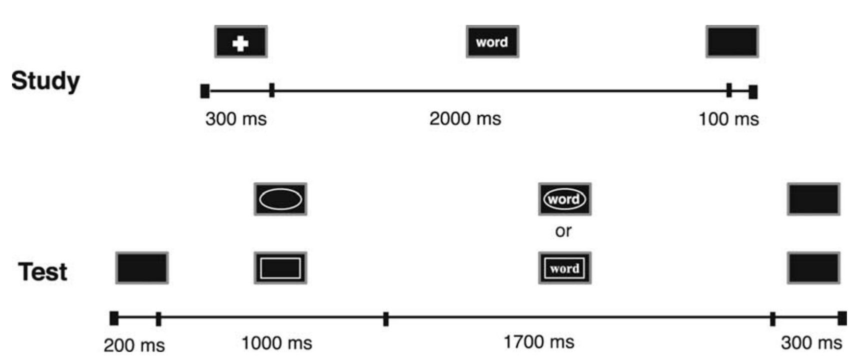

Fig. 1. Illustration of timing and stimuli of study- (upper row) and test trials (lower row). During test trials ellipses and rectangles served as task-cues, indicating the type of retrieval task to be performed.

trieval task and in the *continuous–specific* blocks they exclusively performed the specific retrieval task. In contrast, in mixed blocks, participants switched between the retrieval tasks, i.e., they had to perform both tasks within a block of trials. In *predictable mixed* blocks, the general and the specific tasks alternated on every second trial (e.g., GGSSGG), whereas in *random mixed* blocks, the tasks alternated pseudo-randomly (e.g., GSSSGS). The probability of a task switch was 50% in this latter block type. After the conclusion of a study phase, an instruction was presented for 5 s, indicating the nature of the upcoming test block type (e.g., *continuous–general*). This instruction was followed by an "alerting screen", which remained for 2 s and indicated the start of the test phase 3 s later. Thus, study and test phases were separated by a 10 s delay.

The experimental session comprised two blocks each of the continuous–general and the continuous–specific block type and four blocks of each of the mixed block types. The order of old/same, old/different, and new words within a test block was random. The proportions of these word types were adapted for the general and the specific task to equate the number of words requiring 'old' responses. Specifically, "old" was the correct response for half of the presented words for each task type in each block type. Therefore, there were 40 old/same, 40 old/different, and 80 new words in the general task, and 80 old/same, 40 old/different, and 40 new words in the specific task across the twelve study-test cycles. At the beginning of the session, participants practiced each block type to familiarize with the stimulus–response mappings and the fonts.

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 (Jasper, 1958), including left and right mastoids. Data were acquired using a left mastoid reference and 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. Vertical and horizontal electro-ocular activity was recorded bipolarly from two electrode pairs placed on the infra- and supra-orbital ridges of the right eye or on the outer canthi of the two eyes, respectively. Electrode impedances were kept below 5 k.

2.5. Data analysis

2.5.1. Behavioral analysis

Behavioral analyses focused on those items that required the same response in both tasks, i.e., on old/same and new words, thus paralleling the ERP analysis (see below). Specifically, we examined response times (RT) for hits to old/same and correct rejections to new words, correct rejection rates for new words and unbiased Pr-values (Snodgrass & Corwin, 1988). Pr-values provide an estimate of true memory judgments by subtracting the false alarm rate for new (unstudied) words (as an estimate of guessing) from the hit rate for old/same words.

2.5.2. ERP analysis

For the task-cue interval, ERPs were computed separately for each electrode, condition, and subject with a 200 ms baseline prior to task-cue onset and a length of 1000 ms, i.e., lasting until word (retrieval-cue) onset. For the retrieval-cue interval, ERPs were similarly averaged with a 200 ms baseline prior to retrieval-cue presentation and a length of 1700 ms. Prior to averaging, trials exhibiting excessive eye movements or muscle artifacts were rejected from further analysis using a pre-set criterion (standard deviation > 40 μV; within a sliding window of 200 ms). Blink artifacts were corrected using a modified linear regression technique (Gratton, Coles, & Donchin, 1983) implemented in EEProbe [A.N.T. Software BV], the software used for EEG analysis.

To control for processes of retrieval success that are likely to occur for old items (Rugg & Wilding, 2000), ERPs time-locked to retrieval-cue onset were averaged across trials of correctly rejected new items only (e.g., Werkle-Bergner et al., 2005). The mean trial number (and range) for these ERPs were 27.9 (19–36; continuous block type), 28.1 (21–36; predictable block type), and 26.9 (19–34; random block type) in the general task, and 16.1 (13–19), 15.5 (11–20), and 14.1 (10–19) for the respective blocks in the specific task. ERPs in the task-cue interval were averaged across trials that were later classified as hits to old/same and correct rejections to new words to increase the signal-to-noise ratio. The mean number of trials (and range) forming the ERPs in the predictable blocks were 18.6 (13–24; switch) and 21.4 (16–29; non-switch) for the general task, and 18.3 (12–28; switch) and 19.4 (14–25; non-switch) for the specific task. For the random block type, the mean trial numbers were 17.2 (13–22; switch) and 21.4 (14–27; non-switch) in the general task, and 17.7 (13–23; switch) and 18.3 (10–29; non-switch) in the specific task.

All data were analyzed by repeated measures analysis of variance (ANOVA) with a significance level of $\alpha = 0.05$. Whenever appropriate, Greenhouse and Geisser (1959) corrections were used to adjust for nonsphericity. Statistical analyses of the electrophysiological data were conducted on regions-of-interests (ROI). In particular, effects of retrieval preparation in the task-cue interval were examined over close-to-midline parieto-occipital electrodes (e.g., Barceló et al., 2002; Moulden et al., 1998). Based on previous studies in which the effects of the task manipulation were most pronounced at bilateral frontal recording sites (Ranganath & Paller, 1999; Werkle-Bergner et al., 2005), and the effects of the block factor were prominent at frontal and fronto-polar recording sites (Werkle-Bergner et al. 2005), the effects of the task and block manipulations were assessed at frontal or frontal and fronto-polar recording sites, respectively. To cover large cortical surface areas and to avoid a loss of statistical power due to inclusion of an inflated number of (electrode) factor levels (Oken & Chiappa, 1986), electrodes located at short distances in between other electrodes (e.g., F1 and F5) were skipped from statistical analyses. These electrodes were also not included in the analyses of the aforementioned studies.

3. Results

3.1. Behavioral results

We first present behavioral effects associated with the block type manipulation (i.e., general switch costs), before we turn to the effects of actually switching between retrieval tasks (i.e., specific switch costs) in the second section. Behavioral analyses are based on new and old/same words, thus paralleling the focus of the ERP analyses.

3.1.1. Block comparison: general switch costs

Behavioral data are summarized in Table 1. To examine recognition accuracy, Pr-values were analyzed by an ANOVA with the factors task type (general and specific) and block type (continuous, predictable, and random). This test revealed a main effect of task type ($F[1,15] = 5.29$; $p < .05$), reflecting lower recognition performance for the specific than for the general task. The main effect of block type was also significant ($F[2,30] = 10.52$; $p < .001$). Comparing the Pr-values directly for the three levels of block type yielded lower recognition accuracy for random blocks than for both continuous ($F[1,15] = 16.80$; $p < .001$) and predictable ($F[1,15] = 5.98$; $p < .05$) blocks.

Table 1
Means (M) and standard error of the mean (SEM) of Pr-values, percent-correct values for new, old/same, and old/different words, and response times (RT) in ms for hits to old/same and correct rejections (CR) to new words as a function of block type (continuous, predictable, and random) and task type (general and specific).

Block type	Task type	Pr		% Correct						Response times			
				New		Old/same		Old/different		$Hit_{old/same}$		CR_{new}	
		M	SEM	M	SEM	M	SEM	M	SEM	M	SEM	M	SEM
Continuous	General	0.72	0.03	86.1	2.7	85.9	2.1	79.1	2.8	849	53.3	891	57.9
	Specific	0.66	0.03	92.8	1.8	72.7	2.7	52.3	3.7	1062	62.8	964	68.3
Predictable	General	0.66	0.04	88.1	2.0	77.5	3.1	64.8	4.0	1044	60.1	1009	64.1
	Specific	0.63	0.04	87.3	3.3	75.5	2.7	46.7	5.6	1124	66.7	1014	73.8
Random	General	0.58	0.04	82.6	2.7	74.7	3.5	63.4	4.1	1040	61.5	988	63.4
	Specific	0.53	0.04	84.1	2.7	68.8	3.3	42.8	4.7	1138	69.9	1021	67.2

Performing a similar ANOVA on the CR-rates (i.e., percent correct for new words) revealed a main effect of block type ($F[2,30] = 6.54$; $p < .005$), indexing a lower CR-rate for the random blocks (vs. continuous: $F[1,15] = 12.49$; $p < .005$; vs. predictable: $F[1,15] = 6.28$; $p < .05$). Moreover, also the interaction between block type and task type was significant ($F[2,30] = 3.5$; $p < .05$). However, follow-up analyses showed reliable effects of block type for both the general ($F[2,30] = 4.45$; $p < .05$) and the specific task ($F[2,30] = 5.57$; $p < .05$).

Finally, RTs were submitted to an ANOVA with the additional factor response type (hits, CR). The main effects of task type ($F[1,15] = 20.32$; $p < .0005$) and response type ($F[1,15] = 10.23$; $p < .001$) reached significance, reflecting shorter RTs for the general task and for CR. Furthermore, the main effect of block type was significant ($F[2,30] = 7.66$; $p < .005$). Follow-up contrasts revealed faster responses in continuous blocks than in both predictable ($F[1,15] = 12.98$; $p < .005$) and random blocks ($F[1,15] = 9.9$; $p < .01$), whereas the contrast of predictable and random blocks was not significant ($F[1,15] = 0.01$; $p > .9$). Hence, in both predictable and random blocks responses were slower than in continuous blocks, indicating reliable *general switch costs*.[1]

In addition, all two-way interactions as well as the three-way interaction between block type, task type, and response type were significant (all F-values > 4.6; all p-values < 0.05). To elucidate the nature of these interactions, ANOVAs with the factors block type and response type were computed separately for each task. For the general task, there was an effect of block type ($F[2,30] = 16.04$; $p < .0001$), and an interaction between block and response type ($F[2,30] = 10.15$; $p < .005$). This interaction reflected faster hits than correct rejections for the continuous blocks but a reverse pattern for the mixed blocks. However, follow-up contrasts revealed effects of block type for both hits ($F[2,30] = 22.44$; $p < .0001$) and CR ($F[2,30] = 7.67$; $p < .005$), suggesting reliable general switch costs for both response types. In contrast, for the specific task only the response type effect was significant ($F[2,30] = 17.14$; $p < .001$), indicating faster responses for correct rejections.

3.1.2. Trial comparison: specific switch costs

In a next step, the effects of actually switching between retrieval demands on task performance were analyzed. Behavioral data are summarized in Table 2. Pr-values were submitted to an ANOVA with the factors block type (predictable and random), task type (general and specific), and trial type (switch and non-switch). This analysis revealed an effect of block type ($F[1,15] = 6.04$; $p < .05$), reflecting higher Pr-values for predictable blocks. For CR-rates (i.e., percent correct for new words) the effect of block type was also significant ($F[1,15] = 7.16$; $p < .05$), indicating greater CR-rates for predictable blocks. Furthermore, there was a reliable interaction between task type and trial type ($F[1,15] = 7.42$; $p < .05$) that was due to an effect of trial type for the specific task only ($F[1,15] = 8.43$; $p < .05$).

Response times were analyzed by an ANOVA including the additional factor of response type (hits, CR). The main effects of task type ($F[1,15] = 8.32$; $p < .05$), trial type ($F[1,15] = 14.69$; $p < .001$), and response type ($F[1,15] = 14.52$; $p < .001$) were significant. Moreover, this analysis revealed several reliable interactions. The interaction between task and response type was significant ($F[1,15] = 14.69$; $p < .001$), although follow-up analyses showed that responses were faster for correct rejections for both the general ($F[1,15] = 5.17$; $p < .05$) and the specific task ($F[1,15] = 19.22$; $p < .001$).

Importantly, also the interactions between task and trial type ($F[1,15] = 6.36$; $p < .05$) and response and trial type ($F[1,15] = 13.76$; $p < .005$) reached significance, indicating that the effect of actually switching between retrieval tasks varied with both task type and response type (see Fig. 2). Following-up these two-way interactions revealed slower responses on switch compared to non-switch trials for both hits ($F[1,15] = 10.85$; $p < .005$) and CR ($F[1,15] = 16.14$; $p < .005$). However, contrasting RTs in switch and non-switch trials separately for both tasks revealed an effect for the general task ($F[1,15] = 24.71$; $p < .0005$) but not for the specific task ($F[1,15] = 2.95$; $p > .1$). Thus, reliable specific switch costs were obtained for the general but not for the specific task.

To summarize, recognition accuracy was reduced for random blocks compared to both continuous and predictable blocks. Furthermore, general switch costs on RTs were present for both types of mixed blocks, though they were only reliable for the general task. As expected, the general task was associated with better recognition accuracy and shorter RTs than the specific task. Moreover, specific switch costs on response speed were substantially larger for the general task. Thus, switching towards the easier to perform task (i.e., the general retrieval task) was associated with greater specific switch costs. Hence, consistent with previous studies

[1] An anonymous reviewer suggested another potential difference between the block types: Since the correct response to old/different words changes across trials in mixed blocks, these words might induce a response conflict that is not present in continuous blocks. To address this issue, we exploratively analysed response times for correct responses to the three word types (i.e., old/same, old/different, new). Specifically, we examined whether the effect of word type or its potential interaction with task type (general, specific) varied as a function of the block type. That is, response conflict for old/different words would be expected in the mixed blocks, thus leading to especially prolonged response times for old/different words compared to the other two word types. In contrast, the correct response to old/different words does not change in continuous blocks. Thus, the response times would be expected to be more similar to the other word types in this condition. An ANOVA with the factors block type (continuous, predictable, random), word type, and task type merely revealed a trend for an interaction between word type and block type ($F[4,60] = 2.55$; $p > .05$). Comparing response times of the word types separately for each block type yielded significant effects for all blocks (continuous: $F[2,30] = 6.68$; $p < .01$; predictable: $F[2,30] = 20.73$; $p < .0001$; random: $F[2,30] = 16.74$; $p < .0001$). Thus, there is not much evidence for a selectively enhanced response conflict for old/different trials in mixed blocks.

Table 2
Means (*M*) and standard error of the mean (SEM) of Pr-values, percent-correct values for new, old/same, and old/different words, and response times (RT) in ms for hits to old/same and correct rejections (CR) to new words as a function of block type (predictable and random), task type (general and specific), and trial type (non-switch and switch).

Block type	Task type	Trial type	Pr		% Correct						Response times			
					New		Old/same		Old/different		$Hit_{old/same}$		CR_{new}	
			M	SEM	*M*	SEM	*M*	SEM	*M*	SEM	*M*	SEM	*M*	SEM
Predictable	General	Non-switch	0.65	0.05	86.9	2.4	78.6	3.6	70.6	4.8	991	57.1	975	64.0
		Switch	0.66	0.04	89.3	1.9	75.9	3.7	60.6	4.5	1105	67.4	1047	66.7
	Specific	Non-switch	0.62	0.07	83.6	5.2	78.6	3.2	47.9	6.0	1074	64.1	1006	78.3
		Switch	0.63	0.05	91.3	2.9	71.6	3.4	43.5	6.9	1177	74.8	1023	75.2
Random	General	Non-switch	0.66	0.04	86.6	3.0	79.5	3.6	60.3	6.2	1002	65.6	962	62.5
		Switch	0.47	0.07	79.3	3.3	67.2	5.4	65.6	4.0	1122	67.9	1013	66.8
	Specific	Non-switch	0.52	0.05	81.6	3.0	70.3	3.7	46.0	6.6	1128	67.8	1036	66.5
		Switch	0.54	0.06	86.2	4.3	67.4	4.3	38.0	6.1	1154	71.2	1023	71.9

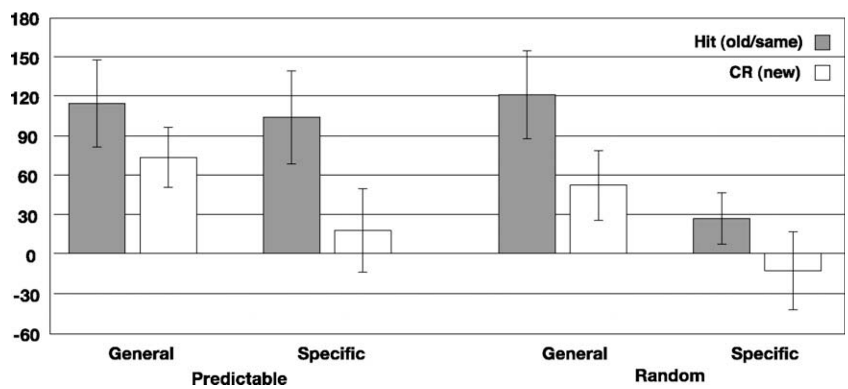

Fig. 2. Specific switch cost [RT switch trials – RT non-switch trials] in ms as a function of block type (predictable, random) and task type (general, specific), separately for hits to old/same words and correct rejections (CR) to new words. Error bars indicate the standard error of the mean.

(e.g., Allport et al., 1994, Experiment 5; Meuter & Allport, 1999), we observed asymmetrical switch costs in the behavioral data.

3.2. Electrophysiological results

The presentation of results is organized in two sections. In the first section, we focus on the task-cue interval and report ERP correlates of retrieval preparation over posterior scalp regions. In the second section, we then present ERP effects for the task and block manipulations during the retrieval-cue interval at anterior electrodes.

3.2.1. Task-cue interval

ERPs are displayed in Fig. 3a as a function of block type (predictable and random), task type (general and specific), and trial type (non-switch and switch). Visual inspection of the data revealed that effects of task switching were present over posterior scalp regions and most pronounced at parieto-occipital recording sites. Three subsequent effects were obtained in the time period between 250 ms and 900 ms after task-cue onset (see Fig. 3b). First and consistent with our predictions, P3b amplitude (270–370 ms) was larger for switch than for non-switch trials for both the general and the specific task. The P3b was also more pronounced for random than for predictable blocks. Secondly, in immediate succession a slow potential (SP1; 370–570 ms) was found to be more positive going for switch than for non-switch trials in random blocks only. This effect was present for both tasks. Finally, the later part of the slow potential (SP2; 570–870 ms) yielded a positive deflection for switch relative to non-switch trials for the general but not for the specific task, irrespective of the block type. The effect on SP2, therefore, parallels the observed behavioral pattern of asymmetrical switch costs, as an ERP difference between switch and non-switch trials was only present when participants switched to the general task that was associated with greater specific switch costs.

As all aforementioned effects were most pronounced over close-to-midline parieto-occipital sites, the statistical analyses concentrated on data obtained from this scalp region (see Barceló et al., 2002; Moulden et al., 1998; for similar analysis strategies). Mean amplitudes for the three components (P3b, SP1, SP2) were initially analyzed by an ANOVA with the factors component, trial type (switch and non-switch), block type (predictable and random), task type (general and specific), and laterality (left [PO3], middle [POZ], right [PO4]). This analysis revealed significant main effects of both trial type ($F[1,15] = 16.06$; $p < .005$) and block type ($F[1,15] = 12.42$; $p < .005$), reflecting greater positivity for switch trials and for random blocks. In addition, the interaction between component, trial type, and task type was significant ($F[2,30] = 10.90$; $p < .001$). Moreover, there were trends for the interactions between component, trial type, and block type ($F[2,30] = 3.22$; $p < .07$), and trial type, block type, task type, and laterality ($F[4,60] = 2.7$; $p < .08$). The effect of trial type thus appeared to vary across the three components and with both task type and block type. Hence, we further explored the interactions by separate ANOVAs for each of the three components with the factors block type, task type, trial type, and laterality.

Analysis of P3b amplitude revealed a main effect of block type, reflecting greater amplitudes for random than for predictable blocks ($F[1,15] = 7.78$; $p < .05$). Moreover, the main effect of trial type was significant ($F[1,15] = 12.20$; $p < .005$), indicating that P3b was more pronounced for switch than for non-switch trials.

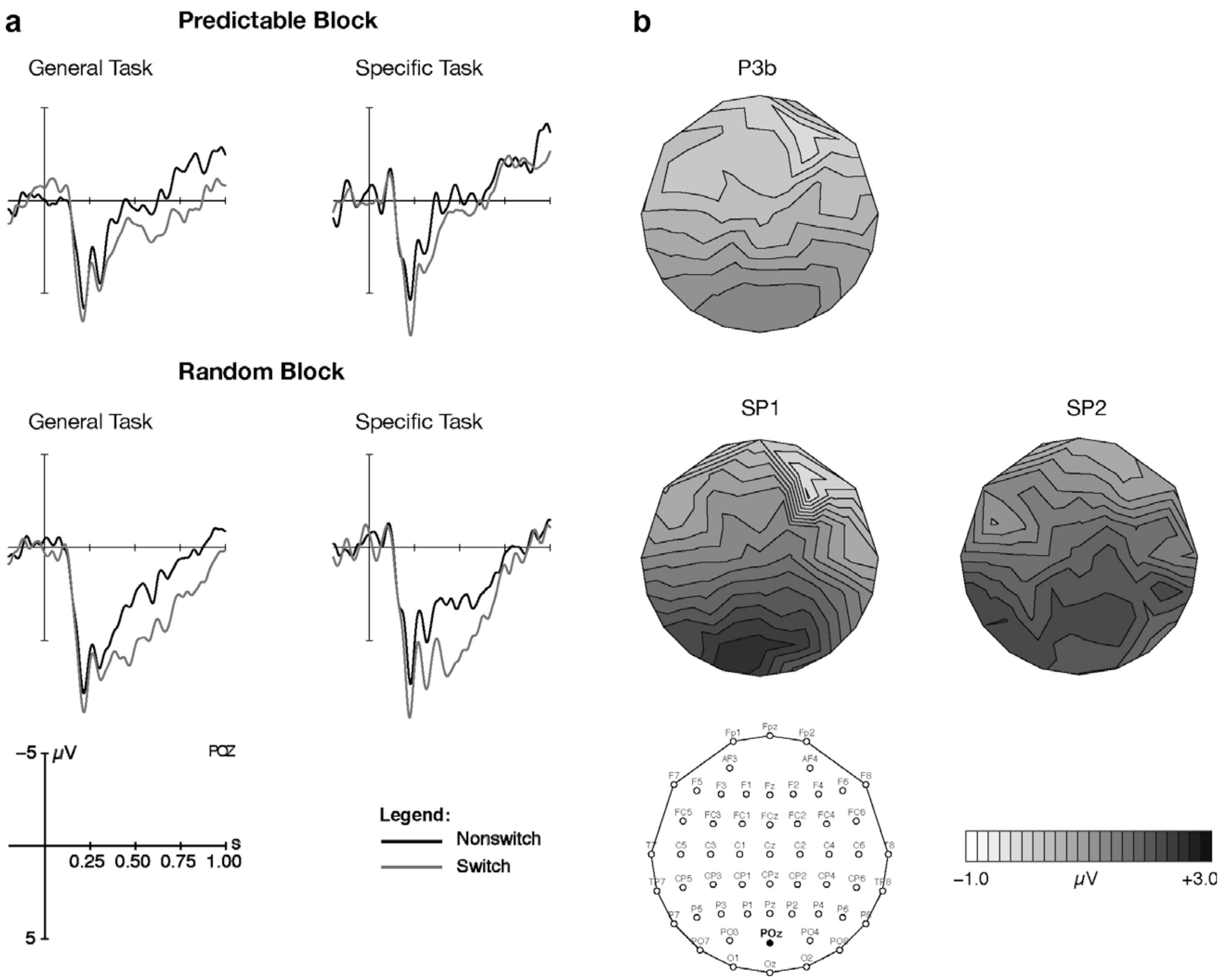

Fig. 3. Switch effects during the task-cue interval. (a) ERPs for switch (thin lines) and non-switch (bold lines) trials at POZ as a function of block type (predictable, random) and task type (general, specific); and (b) scalp distributions of the P3b effect (switch–non-switch across block types and task types; 270–370 ms), the SP1 effect (switch–non-switch for random blocks across task types; 370–570 ms), and the SP2 effect (switch–non-switch for the general task across block types; 570–870 ms).

For the early slow potential (SP1), again both main effects of block type ($F[1,15] = 13.65$; $p < .005$) and trial type ($F[1,15] = 12.85$; $p < .005$) were significant. In addition, the interaction between block type and trial type reached significance ($F[1,15] = 4.77$; $p < .05$), indicating that the slow potential was larger for switch than for non-switch trials in random blocks ($F[1,15] = 5.61$; $p < .05$) but not in predictable blocks ($F[1,15] > 0.8$; $p > .3$).

Finally, analysis of the late slow potential (SP2) yielded main effects of block type ($F[1,15] = 13.83$; $p < .005$), trial type ($F[1,15] = 11.36$; $p < .005$), and task type ($F[1,15] = 5.12$; $p < .05$). These main effects were accompanied by an interaction between task type and trial type ($F[1,15] = 5.96$; $p < .05$), indicating that SP2 was larger for switch than for non-switch trials in the general task ($F[1,15] = 17.55$; $p < .001$) but not in the specific task ($F[1,15] = 0.97$; $p > .3$). Thus, switch effects on SP2 were only obtained for the general task, which was also associated with greater behavioral specific switch costs.

Taken together, retrieval preparation was associated with three functionally dissociable components. First, P3b amplitude was invariantly larger for switch than for non-switch trials. Secondly, the early part of the subsequent slow potential (SP1) was more positive going for switch trials in random blocks only. Finally, the later positive slow potential (SP2) was only more pronounced on switch trials of the general task, which was also associated with larger specific switch cost.

3.2.2. Retrieval-cue interval

3.2.2.1. Task effects. Visual inspection of the waveforms revealed that ERPs time-locked to retrieval-cue onset for the general and specific task started to differ at around 400 ms at frontal sites (see Fig. 4). As expected, and consistent with our hypotheses, these differences were most prominent at frontal sites and took the form of more positive going slow-wave activity for the specific task that lasted until about 800 ms after stimulus onset. This effect appeared to be more pronounced for the continuous than for the two mixed block types.

An ANOVA was conducted on the mean amplitudes with the factors task type (general and specific), block type (continuous, predictable, and random), electrode position (F7, F3, FZ, F4, and F8), and time window (400–600 ms, 600–800 ms). This analysis revealed a main effect of task type ($F[1,15] = 12.38$; $p < .005$). Also the interaction between task type, block type, electrode, and time window was significant ($F[8,120] = 2.92$; $p < .05$), suggesting that task effects varied as a function of block type, electrode position, and time window. To examine whether task effects reliably differed between continuous blocks and either mixed block type,

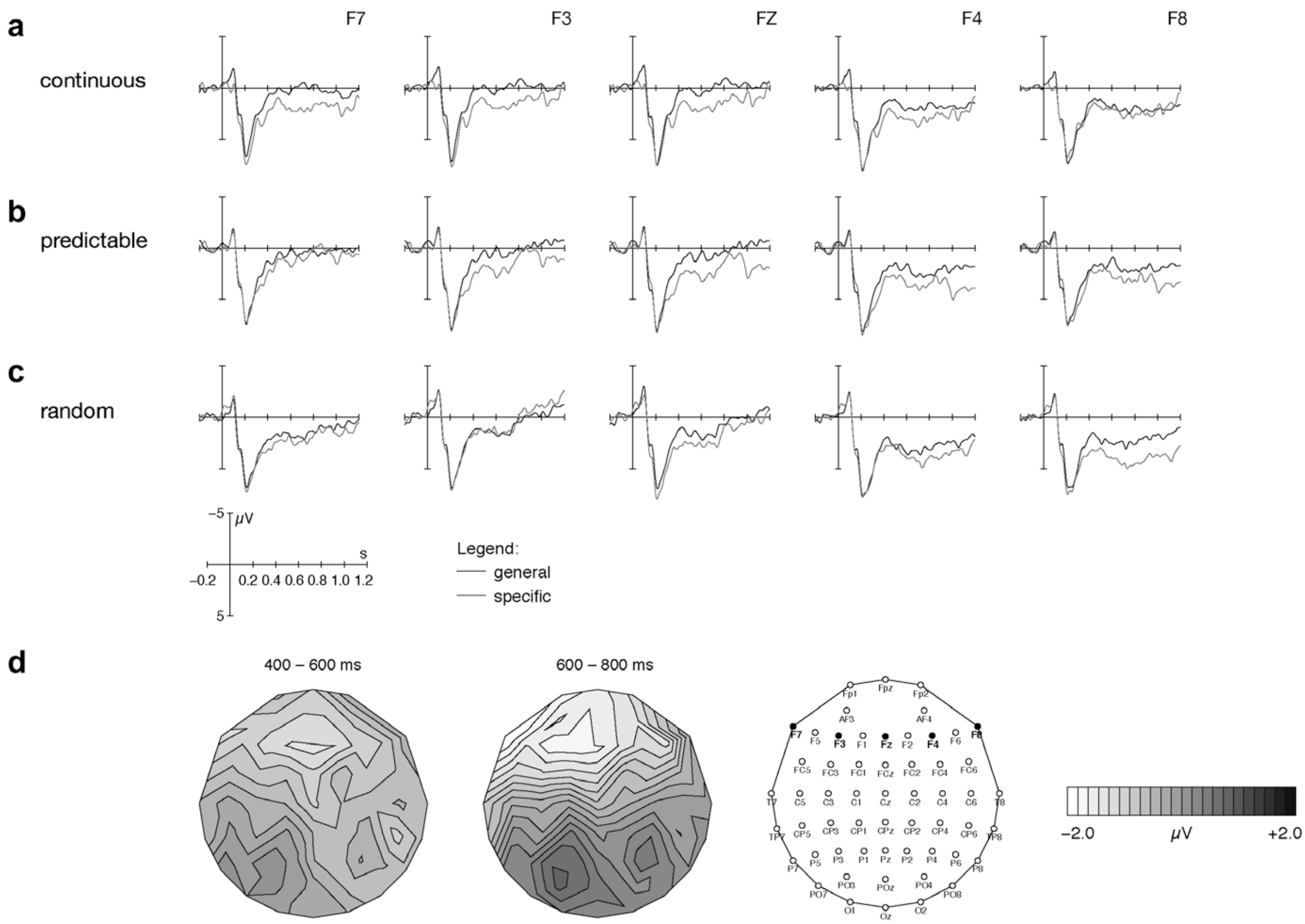

Fig. 4. Task effects during the retrieval-cue interval. ERPs time-locked to retrieval-cue onset for correct rejections in the general task (bold lines) and the specific task (thin lines) for (a) continuous, (b) predictable, and (c) random blocks; (d) scalp distribution of the task effect (general–specific) of the continuous blocks for two time windows (400–600 ms; 600–800 ms).

four-way ANOVAs were computed that included only continuous blocks and one mixed block type (i.e., predictable or random) at a time. The analysis including predictable blocks revealed both the task type effect ($F[1,15] = 7.85$; $p < .05$) and an interaction between block type, electrode, and time window ($F[4,60] = 3.79$; $p < .05$). Importantly, also the interaction between block type, task type, electrode, and time window ($F[4,60] = 4.02$; $p < .05$) was significant. The ANOVA that included continuous and random blocks similarly yielded a task effect ($F[1,15] = 7.56$; $p < .05$) and the interaction between block type, task type, electrode, and time window ($F[4,60] = 3.92$; $p < .05$). Thus, the task effect differed between the continuous blocks and both mixed block types and also varied as a function of both, electrode and time window. To further understand the nature of the aforementioned interactions, three-way ANOVAs were computed separately for each block type. No effect including the task factor reached significance for the predictable or random blocks, due to smaller mean amplitude differences between the two task conditions in the mixed blocks. In contrast, the main effect of task type ($F[1,15] = 5.73$; $p < .05$) as well as the interaction between task type, electrode position, and time window ($F[4,60] = 3.34$; $p < .05$) were significant for the continuous blocks. Hence, consistent with previous reports (e.g., Werkle-Bergner et al., 2005), ERP correlates of having adapted a retrieval orientation were observed for continuous blocks only.[2]

The three-way interaction for the continuous blocks was followed-up by direct comparisons of the ERPs of the general and specific task for each combination of the factors time window and electrode (see Table 3). For the early time window (400–600 ms), significant task effects were observed at the central electrodes (F3: $p < .05$; FZ: $p < .05$; F4: $p < .01$). In addition, there was a trend for this effect at F7 ($p < .09$). For the later time window (600–800 ms), the task effect reached significance at both F7 ($p < .05$) and F3 ($p < .05$) and was marginally significant at FZ ($p < .08$) and

Table 3
Significant effects ($p < .05$; bold) and trends ($p < .1$) for the contrast of the general task and the specific task in continuous blocks at frontal electrode sites for two consecutive time windows (400–600 ms; 600–800 ms) ($df = 1,15$).

Electrode	Time window			
	400–600 ms		600–800 ms	
	F	*p*	*F*	*p*
F7	3.47	0.082	6.01	**0.027**
F3	6.55	**0.022**	5.25	**0.037**
FZ	6.18	**0.025**	3.78	0.071
F4	9.35	**0.008**	3.83	0.069
F8	0.96	>0.1	0.47	>0.1

[2] An anonymous reviewer suggested that including the factor time window might have lead to underestimation of a putative task effect in the predictable blocks that is more extended in time. To test this idea, we calculated a series of two-way ANOVAs on the mean amplitudes between 400 and 800 ms with the factors task type and electrode. The results were similar to the ones obtained with the factor time-window. That is, only the continuous but neither mixed block type was associated with any effect including task type (all $F[1,15] < 2.84$, all $p > .11$).

F4 ($p < .07$). Hence, consistent with our prediction, there were significant task effects at left and central frontal sites for the continuous blocks.

3.2.2.2. Block effects. ERPs time-locked to retrieval-cue onset in continuous, predictable, and random blocks are displayed in Fig. 5, separately for the general and the specific retrieval task. Visual inspection suggested that ERPs of the mixed blocks deviated from those of the continuous block between 400 and 800 ms at fronto-polar and frontal sites. To examine the reliability of these effects at these scalp locations, we conducted a series of ANOVAs with the factors of block type (continuous, predictable, and random) and task type (general and specific) on mean amplitudes of two time windows (400–600 ms, 600–800 ms) for fronto-polar and frontal electrodes (FP1, FPZ, FP2; F7, FZ, and F8). No interaction including the block type factor reached significance. The analyses revealed only trends for a block type effect at left frontal electrodes (400–600 ms: $F[2,30] = 3.10$; $p < .07$; 600–800 ms: $F[2,30] = 2.59$; $p < .1$). Thus, in contrast to our hypotheses, we only observed marginal block effects at frontal electrodes and no slow-wave differences between predictable and random blocks were obtained.

4. Discussion

The goal of this study was to investigate electrophysiological correlates of adapting to varying retrieval demands. Participants engaged in two episodic memory retrieval tasks. The general task required old/new judgments for test words, whereas the specific task asked for the retrieval of the words' study font. By introducing both continuous blocks in which participants constantly performed the same task and mixed blocks in which they alternated between the tasks, we were able to examine electrophysiological correlates in predictable and unpredictable task sequences. Specifically, comparing ERPs in the task-cue interval for switch and non-switch trials allowed assessing correlates of retrieval preparation as a function of the previous retrieval demand.

4.1. Behavioral results: asymmetrical switch costs

The specific task was more difficult than the general task as indicated by lower recognition accuracy and slower responses, reflecting the requirement to retrieve the words' study font. Moreover, recognition accuracy was generally reduced for random blocks compared to both continuous and predictable blocks. Analyses of response times revealed general switch costs for both mixed block types. These costs, however, were only reliable for the general task.

Consistent with other studies (e.g., Rogers & Monsell, 1995; Wylie & Allport, 2000), task performance was worse on switch than on non-switch trials. In particular, switch trials were associated with slowed responses for both correct rejections and hits. Thus, adapting to changing retrieval demands was associated with specific switch costs.

Furthermore, specific switch costs were substantially larger for the general task, which was associated with faster response speed. We therefore observed a pattern of asymmetrical switch costs, i.e., switching to the easier task yielded greater specific switch cost. This effect cannot simply index the remapping of stimulus–response associations, since these were of equal complexity for both tasks (i.e., one key each for "old" and "new" responses). Thus, this switch cost asymmetry is likely to reflect the different memory retrieval demands. According to Allport et al. (1994), the less frequently performed and more difficult task needs to be more strongly imposed to successfully compete with the more fre-

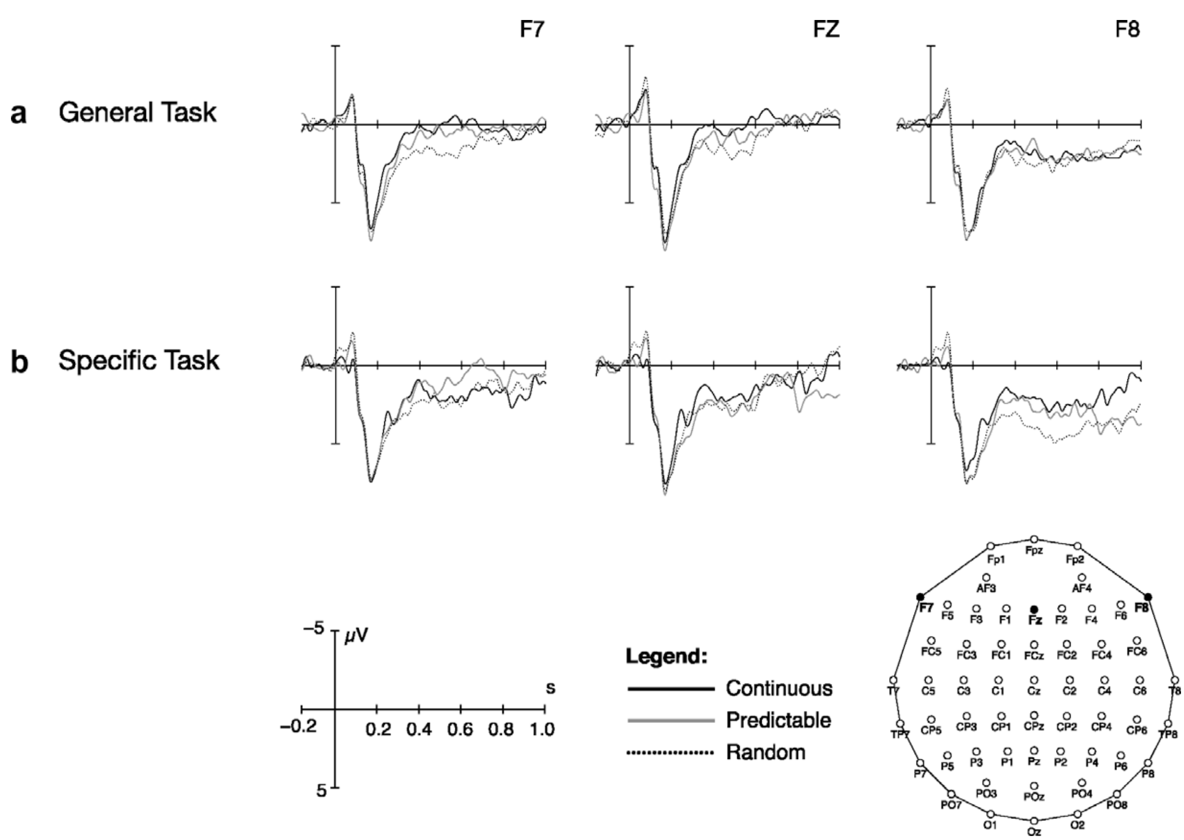

Fig. 5. Block effects during the retrieval-cue interval. ERPs time-locked to retrieval-cue onset for continuous (bold lines), predictable (thin lines), and random (dotted lines) block types, separately for the (a) general task and the (b) specific task.

quently performed, easier task. When participants switched to the general task the activation of the strongly imposed (specific) task set carried over from the preceding trial. Hence, enhanced attentional control was required to overcome these 'task set inertia', leading to large specific switch cost when switching to the general task. In contrast, since retrieval operations involved in the general task are more frequently performed than those required by the specific task, the general task set does not have to be as strongly imposed as the specific task set.

The response times provide further support for this interpretation. That is, in continuous blocks, hits were faster than correct rejections for the general task, whereas the pattern was reversed for the specific task. Similar findings have previously been interpreted as reflecting more time-consuming memory retrieval processes in tasks like source memory tasks that require the retrieval of associative information (Johansson et al., 2002; Van Petten et al., 2000). Intriguingly, when performed in mixed blocks, also the general task showed this response time pattern that is characteristic for the specific task (i.e., faster correct rejections than hits). This suggests that participants did not completely disengage the specific task set when switching to the general task.[3]

Asymmetrical switch costs have also been observed for tasks such as shifting between color naming and reading with incongruent stroop stimuli (e.g., Allport et al., 1994, Experiment 5) or switching between naming numerals in the dominant and a second language (Meuter & Allport, 1999). Our findings extend this asymmetrical pattern to the domain of episodic memory retrieval, implying that similar mechanisms may be involved in adapting to changing retrieval demands as in task switching more generally. Importantly, these results suggest that retrieval preparation is dependent not only on the current retrieval goal but also influenced by the history of recent retrieval attempts.

4.2. ERP results

4.2.1. Preparatory processes in the task-cue interval

We observed three subsequent ERP components (P3b, SP1, and SP2) over posterior scalp regions that were differentially modulated by the adaptation to changing retrieval tasks. First, P3b amplitude was larger for random than for predictable blocks and also larger for switch than for non-switch trials. In line with the postulated role of the P3b in 'context updating' (Donchin & Coles, 1988, 1998; Fabiani & Donchin, 1995), the block effect might be due to the unpredictability of the upcoming task in the random blocks. P3b amplitude was also greater for switch than for non-switch trials. This effect has been previously reported in several studies investigating electrophysiological correlates of task switching (Barceló et al., 2000, 2002; Kieffaber & Hetrick, 2005; Moulden et al., 1998; Nicholson et al., 2005; Rushworth et al., 2005). Consistent with the context updating hypothesis, it may reflect the amount of working memory revision that is necessary for reconfiguring the now-relevant task set on switch trials (Barceló et al., 2002; Kieffaber & Hetrick, 2005). Since P3b amplitude was not modulated by task type, this effect might specifically index those reconfiguration processes that are common to both tasks, such as remapping of stimulus–response associations. In contrast, preparation processes indexed by the subsequent slow potential were modulated by either the foreknowledge about the task sequence (SP1) or the nature of the task (SP2). Thus, these effects are unlikely to merely reflect adjustments of stimulus–response mappings, since these were of similar complexity for both tasks and constant across the block types.

The early part of the slow potential (SP1) was more positive going for switch than for non-switch trials only in random but not in predictable blocks. A similar result was recently obtained by Swainson et al. (2006), who observed greater posterior slow-wave activity for switch than for non-switch trials time-locked to task-cue onset. In accordance with the current findings, this effect was only present for random but not for predictable task sequences. A possible explanation of the processes reflected by SP1 can be derived from the recent proposal that task set reconfiguration is to some degree dependent on the expectation of a further task switch on the following trial (Monsell et al., 2003; see also Kray, 2006; Milán et al., 2005). Whereas participants always engage in the same task for two subsequent trials in predictable blocks, they may have to switch tasks in immediate succession in random blocks. Therefore, fully reconfiguring task sets would be inefficient in the latter condition, since the discarded task set may again be needed in the next trial. Thus, competing task sets remain in a relatively comparable 'state of readiness' in random task sequences, leading to high competition on both switch and non-switch trials.[4]

If both task sets are in a comparable state of readiness under unpredictable task sequences, a mismatch between the relatively-more activated task set and the task-cue would have to be detected to initialize an attentional shift towards the cued task set. When, however, behavior is contingent upon a predictable task sequence, participants have foreknowledge about the upcoming requirement to switch task sets. Hence, detection of a mismatch between relatively-more activated task set and cued task is primarily required in random but not in predictable blocks. Since a similar component has been implicated in conflict processing (cf., West, 2003), the more pronounced SP1 for random blocks may accordingly reflect such a detection mechanism. Moreover, actual conflict between the relative activation of both task sets and the task-cue is present on switch trials of random blocks, since the task-cue instructs for a shift away from the slightly more activated task set. The detection of this behaviorally relevant conflict may be reflected by the largest SP1 amplitude for these trials.

Finally, the later part of the slow potential (SP2) was modulated by the requirement to switch task sets only for the general retrieval task, irrespective of the predictability of the task sequence. Hence, SP2 was larger on switch trials of the task that was also associated with greater specific switch costs. This component was, therefore, apparently sensitive to the magnitude of the attentional selection requirements. Whereas asymmetrical switch costs on performance have repeatedly been reported, this is, to our knowledge, the first observation of an electrophysiological correlate of this effect. The 'task set inertia' hypothesis proposes that asymmetrical switch costs arise from the necessity to overcome persisting activation of the strongly imposed task set and prior suppression of the weakly imposed, easier task set (e.g., Allport et al., 1994). Accordingly, SP2 may reflect the greater attentional selection requirements for the general task set to win competition against the activation of the strongly imposed specific task set. In particular, this mechanism might specify the aspects of the upcoming retrieval-cue that are going to be processed in order to guide memory retrieval. Alternatively, attention might be reallocated towards internal information, such as stored items in the memory set. In either case the data suggests that rather than being fully deter-

[3] We thank an anonymous reviewer for this observation.

[4] As pointed out by an anonymous reviewer, the two mixed block types might also differ in the degree that participants engage in cue-related preparation processes. Paradoxically, they might actually prepare less when they have foreknowledge about the task sequence. However, since recognition accuracy was overall better under the predictable task sequence, we would suggest that the current data more likely reflects stronger competition between task sets in random blocks rather than less preparation in predictable blocks.

mined by current retrieval demands, retrieval preparation is also influenced by discarded retrieval goals.

The interpretation of SP2 as reflecting higher cognitive control demands is indirectly supported by an ERP study that made use of a predictable task sequence and manipulated the duration of the preparation interval (Karayanidis et al., 2003). The authors observed a positive deflection for switch as compared to non-switch trials over posterior electrodes that was more pronounced for short than for long preparation intervals. This effect might partly reflect greater cognitive control requirements for the now-relevant task set in the case of less preparation time, since activation of a discarded task set dissipates passively over time (e.g., Meiran et al., 2000). A similar result was obtained by Nicholson et al. (2005), who made us of a random task sequence. Rushworth et al. (2002) observed a similar posterior positive slow-wave effect elicited by task-cues after a series of consecutive trials. Dipole modeling revealed a source in the ventromedial occipito-temporal cortex for this effect. However, considering the ambiguity inherent in any dipole analysis (cf., Opitz, 2003), this identified region can only be taken as an approximation of the generating neural source. Several neuroimaging studies reported that activation within the intraparietal sulcus (IPS) was greater for switch than for non-switch trials (e.g., Brass & von Cramon, 2002, 2004; Dove, Pollmann, Schubert, Wiggins, & von Cramon, 2000; Ruge et al., 2005). In particular, Ruge et al. (2005) investigated hemodynamic changes during the preparation interval. A region within the IPS was shown to be activated for both switch and non-switch trials. The authors manipulated the duration of the preparation interval and reported increased activation for switch compared to non-switch trials in this region for the shorter preparation interval only. These hemodynamic results nicely mirror the electrophysiological effect reported by Karayanidis et al. (2003) and Nicholson et al. (2005), suggesting that the IPS may be of high relevance for attentional selection. The possible link between enhanced attentional selection requirements, late posterior slow potential, and IPS is also supported by fMRI studies showing this brain region's involvement in the advance preparation for shifts of visual attention (e.g., Hopfinger, Buonocore, & Mangun, 2000). Moreover, our suggestion is compatible with the hypothesis that the IPS together with the frontal eye field constitutes a dorsal attention system that is involved in preparing and applying attentional sets (Corbetta & Shulman, 2002).

Taken together, the preparation for a switch of retrieval demand was associated with P3b and slow-wave effects that were similar to those reported for switching between stimulus–response mappings (e.g., Kieffaber & Hetrick, 2005) or processing of different perceptual features (e.g., Wylie et al., 2003). Hence, we conclude that retrieval preparation is fostered by similar neural mechanisms as shifting between these less complex task sets. Moreover, in agreement with previous studies (e.g., Brass et al., 2005; Goffaux et al., 2006; Karayanidis et al., 2003; Nicholson et al., 2005; Rushworth et al., 2005; Swainson et al., 2006; Wylie et al., 2003), the posterior slow potential was more positive going for switch than for non-switch trials. To the best of our knowledge this is the first report of a functional fractionation of this posterior slow-wave pattern. We suggest that it reflects two dissociable processes. The earlier part may be associated with a conflict detection mechanism signaling attentional shift requirements, whereas the later one may be related to actual attentional selection processes.

To date, only few studies have investigated electrophysiological correlates of retrieval preparation. Herron and Wilding (2006), for instance, reported sustained ERP differences elicited by task-cues that indicated different source judgments. This effect was taken to reflect initial stages of retrieval orientation implementation. However, only late preparation effects (starting 800 ms after task-cue onset) were statistically analyzed, while processes of retrieval preparation already occurred at around 250 ms in this study. A more similar electrophysiological pattern was reported by Johnson and Rugg (2006). Participants had to either retrieve whether an item had been presented as a word or as a picture during study. Switch trials were associated with a positive deflection from 150 to 800 ms after task-cue onset over parietal sites. However, these effects were not modulated by the retrieval task that participants were preparing for. Since no asymmetrical switch costs were reported, preparation for both tasks might have required comparable engagement in cognitive control processes. Moreover, the tasks always alternated unpredictably. Therefore, the present study extends the knowledge about parietal ERP correlates of retrieval preparation by demonstrating that the indexed processes can be modulated by the nature of the retrieval goal, both of the current and the former trial, and the predictability of the task sequence.

4.2.2. Retrieval-cue processing

Examining ERPs elicited by correctly rejected new words, we observed a sustained slow-wave that was more positive going for the specific than for the general task over frontal scalp regions. This task effect was only reliable for continuous blocks and lasted from 400 to 800 ms after retrieval-cue onset. In accordance with previous studies (e.g., Dzulkifli et al., 2004; Herron & Rugg, 2003; Hornberger et al., 2004; Robb & Rugg, 2002; Rugg et al., 2000; Werkle-Bergner et al., 2005), we suggest that this effect indicates the sustained implementation of different retrieval orientations in both tasks.

A retrieval orientation is thought to reflect pre-retrieval processing of retrieval-cues in order to optimize the likelihood of successful retrieval (Rugg & Wilding, 2000). In particular, it is beneficial to focus processing of a given retrieval-cue to those aspects that could potentially be shared with the sought-for memory representation. Werkle-Bergner et al. (2005) concluded that more positive going ERPs for the specific task reflect control processes in the service of retrieving specific perceptual attributes. Consistently, a similar frontal slow-wave has been observed for the retrieval of objects' aspect ratios compared to mere old/new recognition (Ranganath & Paller, 1999).

Consistent with our expectation and previous findings (Herron & Wilding, 2006; Johnson & Rugg, 2006; Werkle-Bergner et al., 2005), we did not observe reliable ERP retrieval orientation effects for predictable or random blocks. On the one hand, implementing a tonically maintained cognitive mode, such as a retrieval orientation, might interfere with the ability to adapt to constantly changing task requirements (see also Monsell et al., 2003). Relying on less efficient retrieval processes, therefore, may permit adaptation to varying retrieval demands. On the other hand, it has been suggested that adoption of a retrieval orientation requires prolonged engagement in a specific task (e.g., Johnson & Rugg, 2006). This proposal is supported by the more general suggestion that a given task has to be executed more than once before its task set is fully implemented (Monsell, Yeung, & Azuma, 2000). Applying these interpretations to the current data, however, warrants caution. First, it is possible that the absence of task effects for the mixed blocks reflects engagement of the specific retrieval orientation for both task types. This interpretation would be supported by the response time results, showing a pattern for the general task when performed in mixed blocks (i.e. correct rejections faster than hits) that is characteristic for the specific task. Secondly, since ERPs of the mixed blocks were averaged across both switch and non-switch trials, it is conceivable that an ERP retrieval orientation effect for predictable and/or random blocks was restricted to either one of these trial types. While due to signal-to-noise consideration it was not possible to explore this possibility for the current data, previous studies did not observe an ERP retrieval effect for either switch or non-switch trials (Herron & Wilding, 2006; Johnson & Rugg, 2006).

4.2.3. Absence of anterior-frontal block effects

In contrast to our predictions, we did not observe any significant block effect at anterior-frontal electrodes in the retrieval-cue interval. Employing a similar paradigm, Werkle-Bergner et al. (2005) reported a sustained slow-wave at anterior-frontal electrodes that was more positive going for predictable than for continuous blocks, reflecting either dual-task requirements or engagement in sequencing in the predictable blocks. In the current study, dual-tasking was required in both mixed block types. In contrast, only the predictable blocks could have been associated with sequencing. One explanation for the absence of any reliable anterior-frontal slow-wave effect in the present study can be derived from the different preparation intervals in both studies. The interval between task-cue and retrieval-cue onset was considerably longer in the present (1000 ms) than in Werkle-Bergner and colleagues' study (300 ms). By this, it might have been adaptive to reconfigure to the now-relevant task set already before task-cue onset (i.e., immediately after a response was given on the previous trial) in the latter study. This advance preparation would have required the engagement in sequencing. In contrast, the preparation interval exceeded 600 ms in the present study, which was reported to be the asymptotic duration for preparation effects (e.g., Arbuthnott & Frank, 2000; Rogers & Monsell, 1995). Thus, ample time was given to engage in reconfiguration processes after task-cue onset, and there was, consequently, no need to engage in sequencing. In support of this view, specific switch costs for hits were enhanced by 63 and 71 ms (for the general and specific task) in Werkle-Bergner and colleagues' data as compared to the present study. Further research is required to determine the exact nature of the processes indicated by the reported anterior-frontal slow-wave pattern.

4.3. Summary and conclusions

The present study revealed different ERP correlates of processes contributing to either preparation for varying retrieval demands or maintenance of a retrieval orientation. On the one hand, maintaining distinct retrieval orientations was associated with a difference in slow-wave activity over middle and left frontal scalp regions. This ERP retrieval orientation effect was reliable only when participants continuously engaged in the same retrieval task throughout a block. On the other hand, preparing for an upcoming switch of retrieval demands was associated with modulations of three subsequent ERP components over posterior scalp regions. First, P3b amplitude was larger for switch than for non-switch trials as well as increased for random compared to predictable blocks. In contrast, SP1 yielded a switch effect only for the random blocks, maybe reflecting a conflict detection mechanism. Finally, SP2 was only more positive going for switch trials of the general task. Since this task was also associated with greater specific switch cost on response speed, we argued that this ERP effect might reflect enhanced attentional selection requirements for the relatively weaker imposed task set. Rather than being fully determined by the current retrieval goal, retrieval preparation is therefore also influenced by the context of recent retrieval attempts.

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