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Context-dependent repetition effects on recognition memory

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A B S T R A C T

One widely acknowledged way to improve our memory performance is to repeatedly study the to be learned material. One aspect that has received little attention in past research regards the context sensitivity of this repetition effect, that is whether the item is repeated within the same or within different contexts. The predictions of a neuro-computational model (O'Reilly & Norman, 2002) were tested in an experiment requiring participants to study visual objects either once or three times. Crucially, for half of the repeated objects the study context (encoding task, background color and screen position) remained the same (within context repetition) while for the other half the contextual features changed across repetitions (across context repetition). In addition to behavioral measures, event-related potentials (ERP) were recorded that provide complementary information on the underlying neural mechanisms during recognition. Consistent with dual-process models behavioral estimates (remember/know-procedure) demonstrate differential effects of context on memory performance, namely that recognition judgements were more dependent on familiarity when repetition occurs across contexts. In accordance with these behavioral results ERPs showed a larger early frontal old/new effect for across context repetitions as compared to within context repetitions and single presentations, i.e. an increase in familiarity following repetition across study contexts. In contrast, the late parietal old/new effect, indexing recollection did not differ between both repetition conditions. These results suggest that repetition differentially affects familiarity depending on whether it occurs within the same context or across different contexts.

1. Introduction

One key function of declarative memory, the conscious memory for facts and events (Cohen & Eichenbaum, 1993; Tulving, 1972), is to support recognition of stimuli that were previously encountered and to discriminate such stimuli from those that are novel. According to dual-process models of recognition memory, the ability to discriminate between items encountered at study and items only presented at test is supported by two independent processes, recollection and familiarity (Mecklinger, 2000; Wilding & Rugg, 1996; Yonelinas, 2002). Recollection refers to conscious retrieval of contextual details of the original study episode in which an item occurred. Thus recollection provides information both about the prior occurrence of an item and the context of that occurrence. By contrast familiarity based recognition is not accompanied by information from specific study episodes and therefore provides no means for making discriminations on the basis of contextual information. A critical assumption of most dual-process models is that recollection and familiarity are independent retrieval processes, i.e. recognition can be based solely on recollection without evoking recognition based on familiarity and vice versa (Rugg & Yonelinas, 2003; Yonelinas, 2001).

Dual-process accounts of recognition memory receive support from a number of different sources. In addition to findings from a body of behavioral and patient studies (for a comprehensive review, see Yonelinas, 2002) there is also an extensive amount of research demonstrating that event-related potentials (ERP) are sensitive to dissociate the contribution of familiarity and recollection to recognition memory (e.g., Curran, 2000; Friedman & Johnson, 2000; Rugg et al., 1998a). The ERP old/new effect is estimated from the difference between the ERPs associated with correct responses to old and new test items and comprise relatively more positive-going ERPs for old than for new test items. Based on their spatio-temporal characteristics and sensitivity to experimental manipulations this difference can be subdivided into at least two subcomponents. For the present purposes, the most important effects are an early frontal old/new effect (300–500 ms) and a later effect (400–800 ms) maximal over (left) parietal regions. Importantly, evidence suggests that the two ERP effects are dissociable on both topographic (e.g. see Mecklinger, 2000) and functional grounds (Jäger, Mecklinger, & Kipp, 2006; Rhodes & Donaldson, 2007). Within dual-process accounts of recognition memory these ERP effects are taken to dissociate the contribution of familiarity and recollection (e.g., Curran, 2000; Friedman & Johnson, 2000; Opitz & Cornell, 2006), with the

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early frontal old/new effect reflecting familiarity and the late parietal old/new effect linked to recollection.

A common finding of many studies of recognition is a memory improvement when information is repeatedly presented for studying (Baddeley, Vargha-Khadem, & Mishkin, 2001; Curran, Tepe, & Piatt, 2006; van Strien, Hagenbeek, Stam, Rombouts, & Barkhof, 2005). As an example, using a continuous recognition paradigm van Strien et al. (2005) have shown that subjects discriminated old from new stimuli faster and more accurate the more often old stimuli were repeated. It has been assumed that augmented recognition memory is achieved by strengthening the item-context bindings through repeated item presentations during the study episode. Norman and O'Reilly (2003, see also O'Reilly and Norman, 2002) have developed a biologically plausible neuro-computational model[1] suggesting that sparse neural coding within the hippocampus leads to distinct (pattern-separated) representations of arbitrary item-context bindings irrespective of their contextual similarity. In contrast, the medial temporal lobe cortex (MTLC) assigns similar representations to similar input using overlapping representations to code for the shared structure of events. By this means item representations become sharper over repeated exposures across different contexts. That is, the first presentation of an item weakly activates a large number of MTLC units, whereas repeated and thus familiar stimuli strongly activate a smaller number of units. At test, the presentation of a studied test probe initiates a set of processes that may be described as a comparison between the short-lived representation of the actual stimulus and the sharpened representation in the MTLC. Consequently, a scalar signal is provided that tracks the global similarity between the test probe and the studied items (Hintzman, 2001).

Repeated item presentations within the context of the same study episode will add contextual detail to the representation of this study episode, thereby strengthening the item-context bindings. This in turn will lead to a highly distinct hippocampal representation, whereas in MTLC units, a blurred representation will emerge as a large number of units is weakly activated by the item and its study context. During test, when the item is presented as a test probe the hippocampus is able to reconstruct the entire studied pattern, i.e. the item bound to its context (pattern completion, O'Reilly & Rudy, 2001), thereby enabling the retrieval of contextual information. From the dual process perspective, this binding of an item to its study context entails enhanced recollection (cf. Yonelinas & Parks, 2007). In contrast, given the blurred representation in the MTLC, i.e. the inability to sufficiently differentiate the representations of different events owing to the relatively low learning rate, only a weak familiarity signal should be elicited by items repeated within the same context. This proposed increase in recollection is corroborated by a recent study asking the participants to memorize words that were presented either once (weak words) or three times (strong words) during a study phase (Finnigan, Humphreys, Dennis, & Geffen, 2002). At test, correct old decisions after the presentation of strong words elicited a stronger left parietal old/new effect, indexing recollection, as compared to correct old decisions after the presentation of weak words.

Despite converging evidence that recognition of items repeatedly presented within the same study context is mainly based on recollection it is still unknown how repetition affects recognition memory if an item is repeated across different study contexts. This is often the case in real life where a particular event (e.g. the final goal of the soccer championship) is repeatedly encountered in different contexts, e.g. seen on the television and beeing told by a friend. Moreover, it has been speculated that this form of repetition leads to decontextualized factual knowledge about the world (Craik, 2006; Eichenbaum, 2006). According to the model proposed by Norman and O'Reilly (2003) the repetition of items across different contexts gives rise to a small overlap of contextual features resulting in separate but weak hippocampal representations. However, the sharpening mechanism in the MTLC operates faster and much more efficiently as compared to a situation when items are repeated within the same context in that only the item without contextual features is represented by MTLC units. At test, the test probe is compared against this sharpened representation of the item alone in the MTLC and a larger familiarity signal is provided, whereas the recollection of studied contexts is less likely because of the use of a shared structure to represent similar events preventing the binding of an item to an arbitrary context. While the MTLC model cannot support recollection of details from specific events owing to its relatively low learning rate it well supports familiarity judgments based on the sharpness of representations in MTLC. Consistent with this neuro-computational model I argue that item representations become sharper over repeated exposures across different contexts, thereby supporting recognition based on familiarity. In contrast, repetition within the same context should foster item-context bindings which lead to recollection.

The present experiment explored these hypotheses employing visual objects that were studied either once or three times. Crucially, for half of the repeated objects the study context remained the same (within context repetition) while for the other half the contextual features changed across repetitions (across context repetition). Beside the independent remember/know-procedure the putative ERP correlates of familiarity and recollection were used. Thus, an early frontal old/new effect and a late parietal old/new effect should be observed during the retrieval of items repeated across and within context, respectively.

2. Methods

2.1. Subjects

A total of 30 students from Saarland University participated in this study and were paid for their participation. The data from two participants were discarded due to malfunction of the recording equipment. The data from further two participants were excluded from all analyses because they exhibited excessive EOG artifacts. Of the remaining 26 participants (aged 21–29 years, 14 male) all were right handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971).

2.2. Materials

Stimuli consisted of 252 colored pictures from the revised Snodgrass and Vanderwart's object pictorial set (Snodgrass & Vanderwart, 1980; Rossion & Pourtois, 2004) that were divided into 6 lists of 42 objects each. Three lists were used as study lists, the three remaining constituted the new distractor items during the recognition test. The study test assignment of the six lists was counterbalanced across participants so that each list (and therefore each object) appeared equally often in study and test lists. All pictures subtended a horizontal visual angle of 2.5° and a vertical angle of 1.75°.

2.3. Experimental procedure

Each participant performed an intentional recognition memory task. The study phase was divided into three different blocks con-

[1] It should be noted that this so-called 'complementary learning systems' (CLS) framework was initially developed to account for the differential contributions of the hippocampus and the surrounding neocortex to learning and memory in general. However, the underlying computational principles can be well applied to recognition memory. In this sense the CLS model belongs to the long tradition of dual-process models (O'Reilly & Norman, 2002).

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stituting three different study contexts. Each study context was defined by three properties (cf. Fig. 1): background color (being either black, dark gray, or white), position on the screen (either left, center, or right) and study task assigned at the beginning of each block. Subjects were asked to indicate by button press in one block whether the picture showed an animate object or not, in another block whether it is mainly used indoor and in a third block whether the object fits in a shoe box. Approximately half of the pictures in each block required a yes response. Each picture was presented for 500 ms with an inter stimulus interval (ISI) of 1000 ms. Objects of one of the study lists were presented once during study, evenly distributed across the different study contexts. Objects of the second list were presented three times, once in each context, constituting across context repetitions. Finally, objects of the third list were repeated within the same context, one third in each of the three study contexts. This even distribution of items across the different encoding blocks ensures an equal mean retention interval for all three conditions.

During the test phase participants saw pictures of objects (all previously encountered objects and the three lists of unstudied distractors) for 1000 ms at a central screen position on light gray background. Although the use of central presentation constitutes a repetition of a contextual detail from the study phase, this affects only a few items from all conditions. As central presentation is very common in ERP research to avoid unnecessary eye movements, this procedure was also adopted in the present experiment. Participants made an old/new recognition judgment. The instructions for the old/new decision equally emphasized speed and accuracy. In case an item was judged old a remember(R)/know(K) judgment followed 1500 ms after stimulus onset. Instructions for these judgments were adopted from Gardiner and Richardson-Klavehn (2000). A R-response should be given when participants mentally re-experienced the previous presentation of a picture, that is, recollect some specific contextual information pertaining to the study episode (e.g. background color, screen position or study task) whereas a K-response was required when they knew the object was seen in the previous study episode but could not recollect any contextual detail about its previous occurrence. The next trial started 1000 ms after the R- and K-response was made.

2.4. Data acquisition

Electroencephalograms (EEG) were continuously recorded from 59 Ag/AgCl scalp electrodes mounted in an elastic cap and labeled according to the extended 10–20 system (Sharbrough et al., 1990). The EEG from all sites was recorded with reference to the left

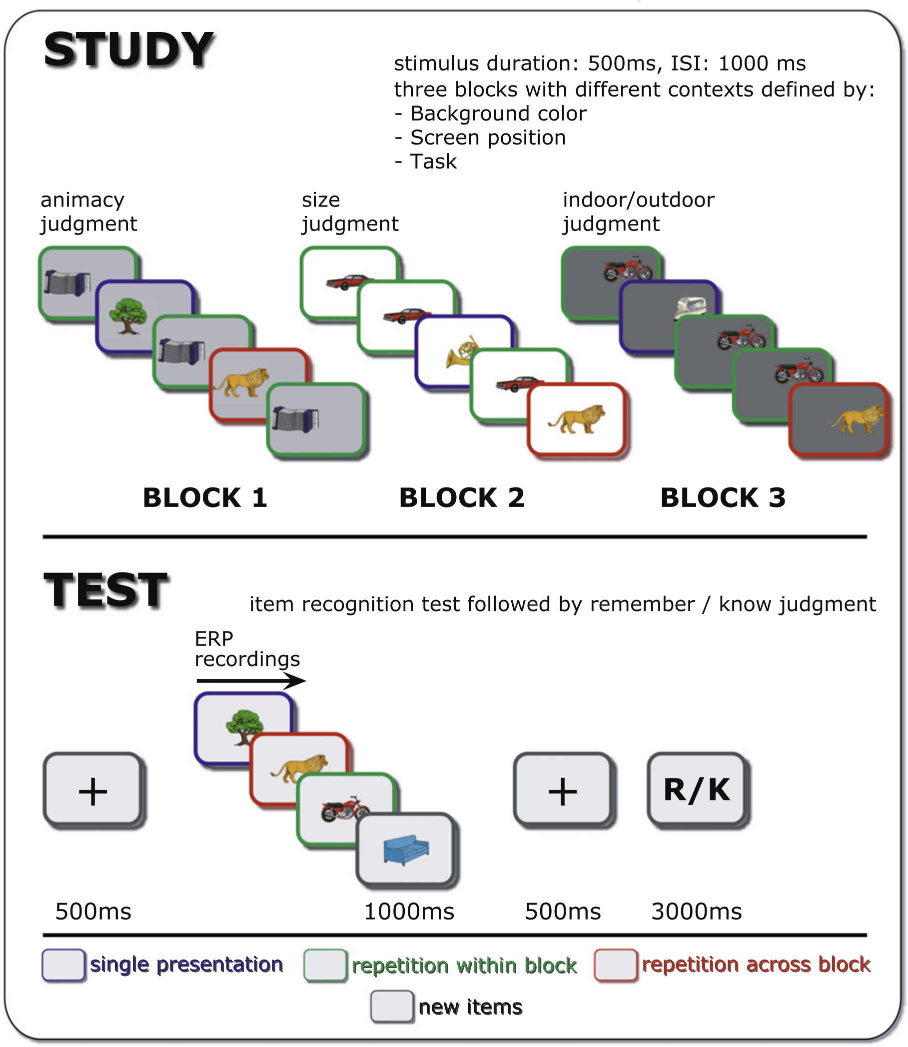

Fig. 1. Trial structure of the study phase and the test phase. Note that the frames are for illustrative purposes and were not presented during the experiment. During study pictures were presented either once (dashed frame) or were repeated two times. Half of the repetitions occurred within the same study context (bold line), the other half across different study context (thin line). The study context was defined by background color, screen position and study task. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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mastoid electrode. An additional channel recorded EEG from the right mastoid, allowing the scalp recordings to be re-referenced off-line to linked mastoids. Vertical and horizontal electrooculograms were recorded with additional electrodes located above and below the right eye and outside the outer canthi of both eyes. All channels were amplified with a band-pass from DC to 70 Hz and A/D converted with 16 bit resolution at a rate of 500 Hz. Inter electrode impedances were kept below 5 kΩ. Further off-line data processing included a digital high-pass filter set to 0.1 Hz (−3 dB cutoff) to eliminate low frequency signal drifts. Recording epochs including eye movements were corrected using a linear regression approach (Gratton, Coles, & Donchin, 1983) and epochs with other recording artifacts were rejected prior to averaging whenever the standard deviation in a 200 ms time interval exceeded 30 μV in any channel. This procedure yielded about 34 trials per condition (single: 27, across: 39, within: 37) accepted for averaging including about 11 trials (single: 9, across: 13, within: 12) corrected for eye movements.

2.5. Data analysis

Data were analyzed with repeated-measures analyses of variance (ANOVA, alpha level = .05). The Greenhouse–Geisser adjustment for nonsphericity was used whenever appropriate and the corrected *p* values are reported together with the uncorrected degrees of freedom.

2.5.1. Behavioral data

The mean proportion of old responses were calculated separately for the three old item conditions (hits) and for new items (false alarms) and subjected to a one-way ANOVA. In case of a significant main effect of condition the following planned contrasts were calculated. First, to assess the old/new effect false alarms were compared with hits collapsed across all old items. Second, the effect of stimulus repetition during study was estimated by contrasting the proportion of hits to single presentations with the mean hit rate of both repeated presentations. Third, the effect of study context was revealed by comparing hits to items repeated across different contexts with hits to items repeated within the same context. Subsequently, all hits were further classified as objects given an R-judgment and objects given a K-judgment. Following to the assumption that recollection and familiarity operate independently K-responses were corrected to reflect a pure familiarity estimate as previously suggested (Yonelinas & Jacoby, 1995). Reaction times to correct responses were analyzed in an identical manner except for the remember/know distinction.

2.5.2. ERP data

ERP data in the test phase were computed for each participant at all recording sites with a duration of 1200 ms commencing 200 ms pre-stimulus baseline. Average ERPs were computed for correct responses to old and new items separately for all conditions. For statistical analysis, a hypothesis-driven approach was chosen. Thus, the present analysis focuses on the ERP effects of familiarity and recollection. Based on visual inspection of the grand average waveform, the mean amplitudes in two different time windows were used for the quantification of the ERP old/new effects related to familiarity and recollection. The early frontal old/new effect was examined in a time window between 300 and 450 ms, whereas the parietal old/new effect was expected to be maximal between 550 and 700 ms. Electrode sites, exhibiting the largest effects (based on visual inspection) were pooled to two topographical ROIs: an anterior ROI (F3, F1, FZ, F2, F4) and a left posterior region (CP5, CP3, CP1, P5, P3). Both, time windows and ROIs were in accordance with the results of prior studies examining ERP old/new effects in recognition memory tasks (Curran & Hancock, 2007; Opitz & Cornell, 2006; Rhodes & Donaldson, 2007).

For each time window and ROI, an initial repeated-measures ANOVA with the four-level factor condition (3 old, new) was performed. Identical to the analysis of the behavioral data planned contrasts were subsequently calculated to evaluate (1) the old/new effects (ERPs to new items were compared to the mean ERP response to all correctly recognized old items), (2) the effects of single and repeated presentation during study (i.e. ERPs to recognized items presented once during study vs. ERPs to all repeated hits) and (3) the effect of study context (hits from the across context condition vs. hits from the within context repetition condition) on the ERP correlates of familiarity and recollection. Measures of effect size (ω^2, indicating the amount of variance that is accounted for by a particular effect in the population) for the single effects are reported in combination with main effects of repetition condition. In order to specifically test the predictions derived from dual-process models an analysis of ERPs for R- and K-responses was performed. ERPs were quantified in the same time windows and for the same ROIs as in the analysis of the old/new effect.

Scalp potential maps were generated using a two-dimensional spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989) and a radial projection from Cz, which respects the length of the median arcs.

Table 1
Reaction times (ms) of correct responses and mean probability of an old response (±SEM) for the initial old/new judgment and the respective R- and K-responses. Corrected know refers to K-responses that were corrected according to the assumption that recollection and familiarity operate independently and thus reflects a pure familiarity estimate (Yonelinas & Jacoby, 1995).

	Old items			New items
	Single	Across	Within	
Reaction time	718 (18)	657 (14)	671 (17)	710 (18)
Proportion old	0.63 (.03)	0.91 (.14)	0.88 (.02)	0.16 (.02)
Remember	0.30 (.04)	0.41 (.07)	0.45 (.06)	0.06 (.01)
Know	0.33 (.03)	0.50 (.07)	0.43 (.06)	0.10 (.02)
Corrected know	0.45 (.04)	0.85 (.04)	0.76 (.05)	0.11 (.02)

3. Results

3.1. Behavioral data

Table 1 shows the mean reaction times of correct responses and the probability of an old judgment to old and new items and the proportion of subsequent R- and K-responses. The ANOVA performed on these measures revealed significantly more old responses for old as compared to new items ($F_{1,25} = 566.3$, $p < .001$). In addition, it was revealed that repeated items were better recognized than items presented once during study ($F_{1,25} = 95.1$, $p < .001$) and that the study context also had an effect on recognition performance in that items repeated across different contexts were slightly better recognized than items repeated within the same context (.91 vs. .88, $F_{1,25} = 12.5$, $p < .01$). This is corroborated by the analysis of the reaction times. As revealed by planned contrasts subjects responded faster to repeated items than non repeated items ($F_{1,25} = 18.3$, $p < .0001$) whereas no differences were observed between both repetition conditions ($F_{1,25} = 3.58$, $p = .08$). The recollection and familiarity (i.e. corrected know[2]) estimates derived from the R- and K-responses to items repeated across different contexts or within the same context were subjected to repeated-measures ANOVA with

[2] Corrected know refers to K-responses that were corrected according to the assumption that recollection and familiarity operate independently using the formula *corrected know* = $K/(1 - R)$. Thus corrected know responses reflect a pure familiarity estimate (Yonelinas & Jacoby, 1995).

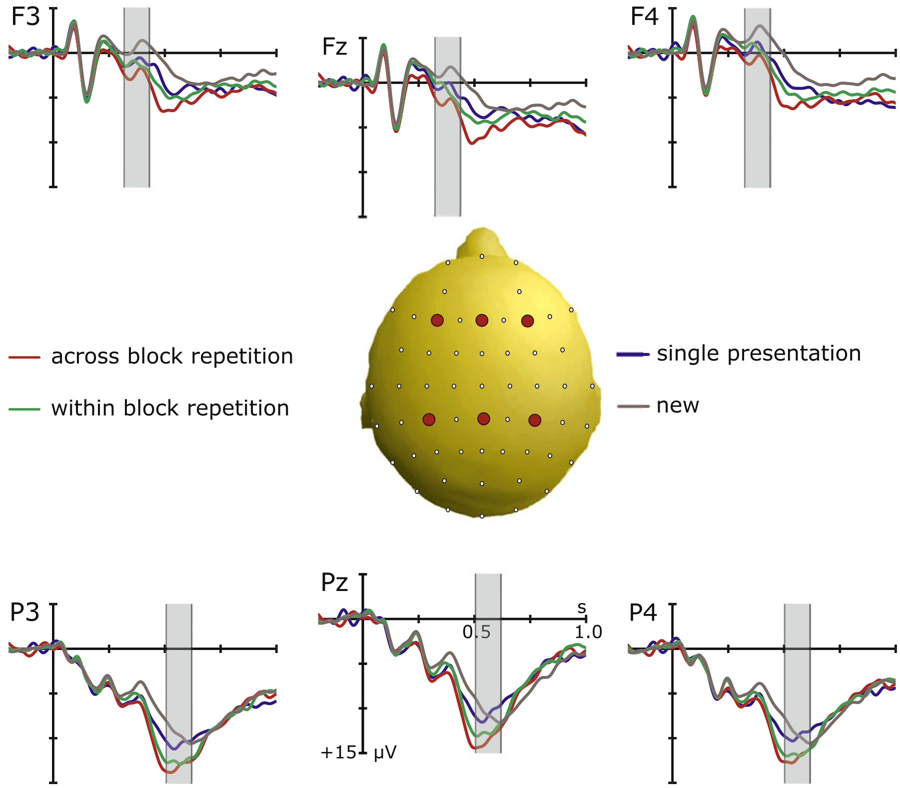

Fig. 2. Grand average ERPs elicited by correctly judged old (black traces) and new (gray trace) items depicted at selected electrodes. The respective location of the electrodes is indicated on the schematic head. Gray bars indicate the time windows used to analyze the early and late old/new effects.

the factors study context (within context vs. across context) and parameter estimate (recollection vs familiarity). As indicated by a significant study context × parameter estimate interaction ($F_{1,25} = 15.9$, $p < .001$) the contribution of familiarity and recollection differed as a function of study context. In accordance with the hypothesis subsequent paired *t*-tests indicated that the contribution of familiarity to the recognition of items repeated across contexts was significantly greater as compared to items repeated within the same context ($t_{25} = 3.62$, $p < .001$) whereas recollection did not differ as a function of study context ($t_{25} < 1$).

3.2. ERP data

Grand averages for correct responses to old and new items are depicted in Fig. 2. As expected, correctly recognized old items elicited more positive-going ERPs than correctly rejected new items, beginning approximately 200 ms post stimulus onset for all three conditions. Importantly, the scalp distribution and the temporal characteristics of these effects correspond well with the old/new effects found in a number of recent recognition memory studies and which have been taken as ERP correlates of familiarity and recollection (Ecker, Zimmer, & Groh-Bordin, 2007; Azimian-Faridani & Wilding, 2006; Rugg & Curran, 2007; Woodruff, Hayama, & Rugg, 2006). A mid-frontal old/new effect that occurred early in time (around 400 ms) as well as a left parietal effect evident around 600 ms were observed.

To examine whether differential old/new effects were observable for the three conditions an omnibus ANOVA with the repeated-measures factors condition (3 old, 1 new), time window (early vs. late), and ROI (frontal vs. parietal) was conducted. This analysis revealed a significant main effect of condition ($F_{3,75} = 10.31$, $p < .001$), a significant condition by time window interaction ($F_{3,75} = 3.93$, $p < .05$), and a three-way interaction condition × time window × ROI ($F_{3,75} = 4.85$, $p < .01$). Consistent with the behavioral results this indicates a differential contribution of familiarity and recollection to item recognition as a function of stimulus repetition and study context (cf. Fig. 3). Thus, based on the interactions described above separate tests for each time window were conducted in order to statistically evaluate the effects of single and repeated presentation during study on the electrophysiological correlates of familiarity and recollection, respectively.

3.2.1. The 300–450 ms interval

Correctly classified old items elicited an early frontal old/new effect as indicated by repeated-measures ANOVAs contrasting the mean ERP to old items from the three conditions with the ERP elicited by correct rejections ($F_{1,25} = 48.04$, $p < .001$). Further analyses showed that this effect was elicited by all three old conditions (single presentation: $F_{1,25} = 18.20$, $p < .001$, $\omega^2 = .389$; across block repetition: $F_{1,25} = 34.12$, $p < .001$, $\omega^2 = .648$; within block repetition: $F_{1,25} = 11.76$, $p < .01$, $\omega^2 = .336$). As indicated by the effect size, this early frontal old/new effect was largest for items repeated across different contexts and was smallest for items repeated within the same context. To further corroborate this result, ERPs elicited by the recognition of items presented once during study were compared to ERPs to hits collapsed across both repetition conditions and no difference of the early frontal old/new effect as a function of repetition was obtained ($F_{1,25} < 1$). In contrast when evaluating the effect of study context, i.e. when comparing ERPs to hits from the across context condition with ERPs to hits from the within context condition a significant influence of the differential study context on the early frontal old/new effect was obtained (main effect of condition: $F_{1,25} = 4.73$, $p < .05$).

3.2.2. The 550–700 ms interval

In this latency range, a significant old/new effect was only evident for both repetition conditions (across block repetition: $F_{1,25} = 16.57$, $p < .001$, $\omega^2 = .400$; within block repetition:

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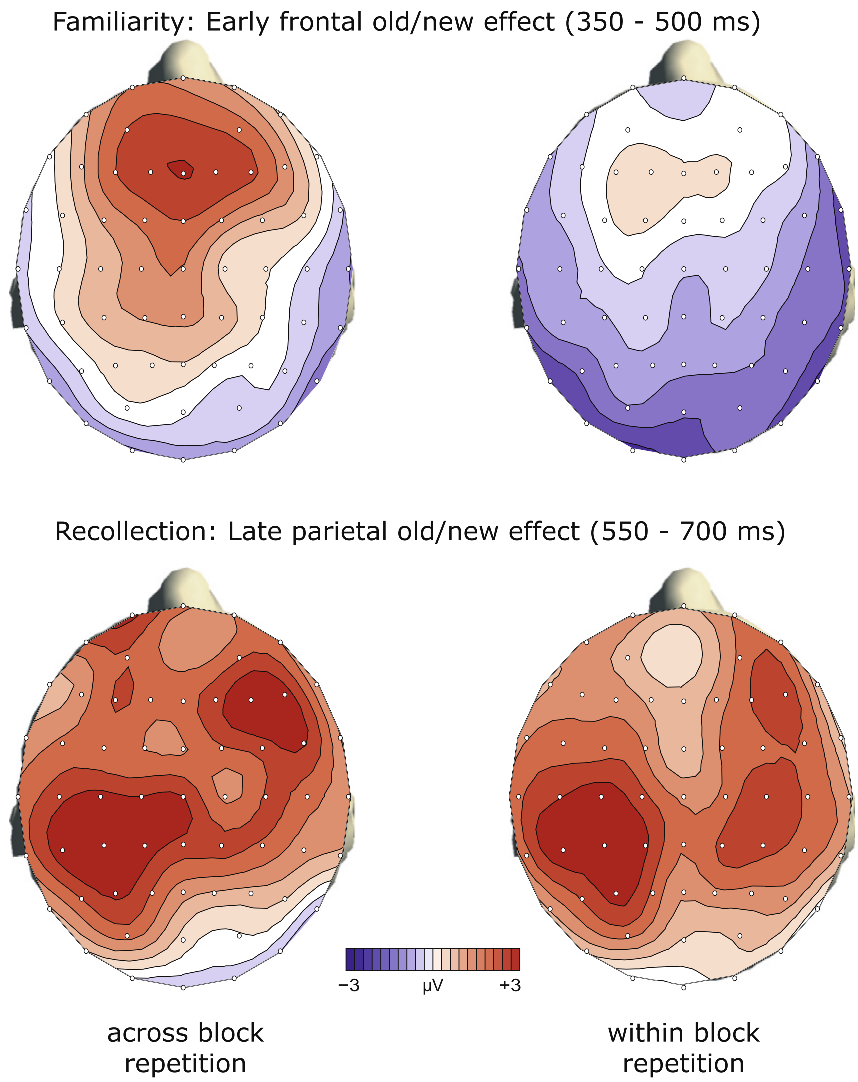

Fig. 3. Scalp distribution of the old/new effects in the early (top row) and the late (bottom row) time windows used in the analyses. The left column depicts the difference maps between old items repeated across contexts and new items, whereas the right column shows the difference maps for items repeated within the same context and new items. Note the selective effect of study context on the familiarity component.

$F_{1,25} = 5.27$, $p < .05$, $\omega^2 = .187$), while items presented once during study did not elicit a late parietal old/new effect ($F_{1,25} < 1$). Moreover, this ERP waveform was also less positive relative to the mean of both repetition conditions ($F_{1,25} = 15.07$, $p < .001$), suggesting that repeated presentation during study led to a pronounced late parietal old/new effect, indexing recollection. As opposed to the early time window, no significant differences between items repeated across different contexts (M = 10.98 μV, SD = 4.63) and items repeated within the same context (M = 10.11 μV, SD = 5.11) were obtained ($F_{1,25} = 2.77$, $p > .1$).

3.2.3. *Remember/know-analysis*

In order to better delineate the processes underlying the frontal and parietal old/new effects hits were further subdivided into R- and K-responses. In order to achieve an acceptable signal-to-noise ratio R- and K-responses were collapsed across conditions. Nevertheless, seven subjects failed to provide at least 15 artifact free trials to ensure an acceptable signal-to-noise ratio and were excluded from the statistical analysis. The ERPs elicited by K- and R-responses were compared using the same time window and the same ROIs as in the analysis used before. This analysis revealed a significant a main effect of response type ($F_{1,18} = 5.77$, $p < .05$), a significant response type × ROI interaction ($F_{1,18} = 4.92$, $p < .05$) and a significant response type × time window interaction ($F_{1,18} = 5.80$, $p < .05$). The triple interaction response type × time window × ROI approached significance ($F_{1,18} = 3.35$, $p < .08$), indicating that R- and K-responses elicited different frontal and parietal old/new effects. A closer inspection of this interaction showed that R-responses elicited a larger late parietal old/new effect as compared to K-responses ($F_{1,18} = 9.0$, $p < .01$, $\omega^2 = .286$, cf. Fig. 4), whereas no differences between response types were observed at the frontal electrode sites ($F_{1,18} = 1.14$, $p > .24$).

4. Discussion

Behavioral and electrophysiological measures were used to examine the subprocesses mediating recognition memory for items repeated within the same context or across different contexts. Consistent with the hypothesis the behavioral results indicated more accurate and faster recognition of repeated items as compared to items presented once during study. This is in agreement with a number of previous results demonstrating superior memory performance after repeated presentation during study (Baddeley et al., 2001; Finnigan et al., 2002; van Strien et al.,

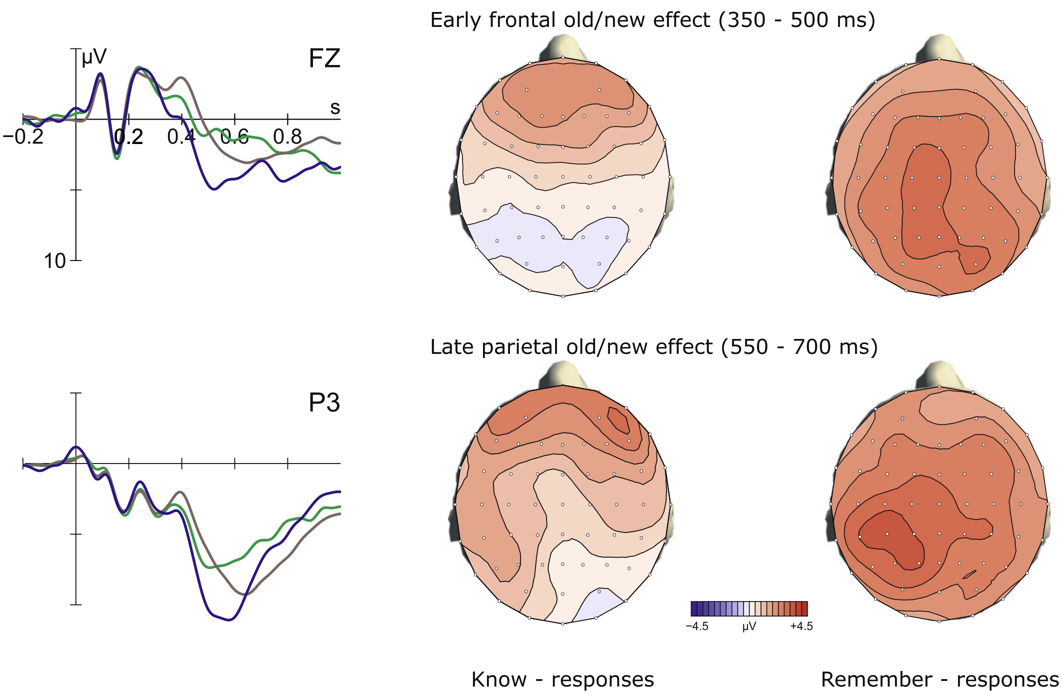

Fig. 4. ERPs (left panel) evoked by R- (bold line) and K-responses (thin line) and by correct rejections (dashed line) collapsed across conditions. A larger late parietal effect was observed for R-responses. In the right panel the scalp distribution of the respective old/new effects in the early (top row) and the late (bottom row) time windows are depicted.

2005). Moreover, this enhanced memory performance for items repeatedly studied was accompanied by increased R-responses indicative of recollection-based recognition. Although, the hit rate did not differ between both repetition conditions a greater contribution of familiarity to the recognition of items repeated across different contexts was observed in the analysis of R- and K-responses. However, the contribution of recollective processes to memory performance did not differ as a function of study context which might be caused by the generally low proportion of recollection-based responses. Although single process models can account for context effects in recognition memory (Ratcliff, Zandt, & McKoon, 1995), the present results seem difficult to interpret in similarity-based frameworks. As an example the Search of Associative Memory (SAM) theory originally proposed by Raaijmakers and Shiffrin (1992, see also Gillund and Shiffrin, 1984) assumes that information is represented in memory traces that contain item, associative, and contextual features. Whether an item is retrieved at test or not depends on the overall strength (i.e. familiarity) of the test item to the memory trace. Crucially, a second (or third) presentation of the same item during study will add new information to the existing memory trace in case this item can be retrieved at the second (third) study presentation. Otherwise, a new trace is formed. The likelihood of retrieving a particular item at the second (third) presentation during study depends on the contextual overlap between the two (or three) presentations and is, therefore, much larger the more similar the two study contexts are (Raaijmakers, 2003). Consequently, the strength values (i.e. the familiarity) at test of items repeated within context should be much larger as compared to items repeated across contexts, conflicting with the present results.

Contrary, the present data are consistent with the framework of dual-process models. The finding of an increased proportion of K-responses for items repeated across contexts conforms to the hypothesis of greater involvement of familiarity based recognition in the across contexts condition. This is also in line with recent R- and K-experiments on context variability (Cook, Marsh, & Hicks, 2006). Similar to changes in study context implemented in the present study context variability in the previous experiments referred to the number of pre-experimental contexts in which a given concept is experienced. Low context variability was associated with greater recollection, and high context variability was associated with greater familiarity, consistent with the present results. In a similar vein, it has been demonstrated that exact repetition of study material enhances recollective processes but had no reliable effect on familiarity. In contrast, the repetition of the semantic category influenced recognition by enhancing familiarity as indicated by increased proportion of K-responses (Dewhurst & Anderson, 1999). One interpretation of the present findings would, therefore, suggest that within context repetition during learning evokes more specific and, perhaps, idiosyncratic associations between an item and its context and that these item-context associations support recognition based on recollection. By contrast, repetition of an item across different contexts (similar to high context variability) leads to decontextualization, i.e. a relatively context free representation of the commonalities among sets of similar events (Craik, 2006).

The ERP results in the test phase confirmed the pattern of behavioral results: Both repetition conditions exhibited larger parietal old/new effects as compared to single presentations whereas no effect of item repetition on the early frontal old/new effect was observed. This finding is consistent with the dual-process account in that repeated item presentations during the study episode in general augment recognition memory by enhancing recollection rather than familiarity reflected in an increased late parietal old/new effect (Johnson, Kreiter, Russo, & Zhu, 1998; Nessler, Friedman, Johnson, & Bersick, 2007; Segalowitz, Roon, & Dywan, 1997). In addition, using the response-signal delay technique Jones (2005) provided further empirical evidence for recollection-based processes underlying repetition effects in recognition memory tasks. Support for the dual-process view is also provided by the results of the remember/know-analysis, demonstrating that the parietal old/new effect is larger when recognition is based upon

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remembering rather than knowing, whereas the frontal old/new effect was elicited by both response types. However, some caution in interpreting this finding is appropriate. As has been previously demonstrated that inter-item latency jitter can result in reduced amplitude ERPs (Spencer, Abad, & Donchin, 2000). In this study it was demonstrated that correcting for variance in peak latency between R- and K-trials eliminated the $R > K$ difference in late parietal old/new effect. This is especially the case for markedly different numbers of trials making up the ERP in both conditions. However, this was not the case in the present experiment. Another factor known to affect latency jitter is greater confidence (and supposedly less latency jitter) in responding to items repeated across different contexts. As reaction times did not differ for both repetition conditions, one can assume, that responses were given with comparable confidence across repetition conditions. Thus, latency jitter might have only a minor contribution to the different late parietal old/new effects observed for R- and K-responses. In sum, the present results add to the evidence that the early frontal old/new effect might reflect familiarity and the parietal old/new effect can be associated with recollection by replicating previous remember/know ERP results (Curran, 2004; Düzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Rugg, Schloerscheidt, & Mark, 1998b; Vilberg, Moosavi, & Rugg, 2006).

In contrast to the finding that repetition per se increases the parietal old/new effect and, hence, affects recollective processes, repetition in varying contexts increases the early frontal old/new effect as compared to repetitions within the same context. Given an involvement of the hippocampus in recollection and of the surrounding cortex in familiarity (cf. Aggleton & Brown, 2006; Montaldi, Spencer, Roberts, & Mayes, 2006) these data suggest that the recognition of decontextualized representations is partly due to an increased familiarity signal in the MTLC. This is supported by recent studies demonstrating that subjective and objective indices of familiarity correlate with the activity in the MTLC (Davachi, 2006; Henson, Cansino, Herron, Robb, & Rugg, 2003). Specifically, during encoding of words in the context of either a size or an animacy judgment, activity in perirhinal cortex has been shown to correlate with later item familiarity irrespective of what task was performed with the word during encoding (Ranganath et al., 2004). This view is also in accordance with the neuro-computational model proposed by Norman and O'Reilly (2003) showing that over repeated exposures to a given input pattern its representation becomes sharper, i.e. the difference in activity between units representing that input and the surrounding units within the MTLC increases which in turn gives rise to a heightened familiarity signal in the MTLC. Given the small overlap of contextual features the repetition of items across different contexts induces a sharpened representation in MTLC, thereby supporting recognition based on familiarity.

Contrary to the hypothesis of larger involvement of recollective processes in recognition memory for items repeated within the same context, behavioral and electrophysiological measures of recollection did not differ between both repetition conditions. One possible explanation of this unexpected finding could be derived from a difference in the repetition lag between conditions. Despite an comparable retention interval the between the first and subsequent presentations is larger (about 60 intervening items) for items repeated in varying contexts than for items repeated within the same context (about 10 intervening items) due to the blocked presentation of contexts. As was previously demonstrated spaced as compared to massed repetition increased R-responses during recognition (Parkin, Gardiner, & Rosser, 1995; Parkin & Russo, 1993). Accordingly, increased performance in a free recall task was observed with increased spacing between items irrespective of constant or changing repetition context (Verkoeijen, Rikers, & Schmidt, 2004; Verkoeijen & Delaney, 2008). In light of these findings one could speculate that the larger repetition lag for items repeated across different contexts might have fostered recollection based recognition.

Alternatively, it seems conceivable that both repetition conditions differ by the depth-of-processing they induce. As in the across contexts condition three different tasks were performed upon presentation of a particular stimulus, three different aspects of that stimulus, namely animacy, size, and usage were processed. In comparison to the within context repetition, where only one task was performed, this might have caused deeper or semantically-cued encoding processes in the across contexts condition. It has been previously demonstrated that deep encoding would augment recognition by enhancing recollection, i.e. the parietal old/new effect (e.g. Paller & Kutas, 1992; Rugg et al., 1998a; Ullsperger, Mecklinger, & Müller, 2000). In the study by Rugg and colleagues a levels-of-processing manipulation required subjects to study words with either a semantically deep or shallow encoding task. The late parietal old/new effect was greater for correctly recognized words following deep than shallow encoding, but the frontal old/new effect did not differentiate between shallow and deep conditions. Thus, although the depth-of-processing might have fostered the parietal old/new effect for items repeated across different contexts, the exact nature of the effects of study context on recollection remains to be elucidated in further studies.

Taken together, both behavioral and ERP results are consistent with the idea that repetition within the same context and across varying contexts leads to different effects at retrieval. Consistent with the dual process view of recognition memory repetition across different contexts leads to decontextualized representations of features common to a number of specific instances by virtue of a sharpening mechanism in the perirhinal cortex. Given an involvement of the MTLC in familiarity, one might speculate that the recognition of decontextualized representations is partly due to an increased familiarity signal in the medial temporal lobe cortex.

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