Cognitive Brain Research 10 (2001) 283–301

COGNITIVE BRAIN RESEARCH

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Research report

Event related brain potentials and illusory memories: the effects of differential encoding

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Accepted 25 July 2000

Abstract

This study investigates event related potentials (ERP) elicited by true and false recognition using words from different semantic categories. In Experiment 1, ERPs for true and false recognition were more positive than for correctly rejected NEW words starting around 300 ms after test word presentation (old/new ERP effects). ERP waveforms for true and false recognition revealed equal early (300–500 ms) fronto-medial old/new ERP effects, reflecting similar familiarity processes, but smaller parietal old/new ERP effects (500–700 ms) for false relative to true recognition, suggesting less active recollection. Interestingly, a subsequent performance based group comparison showed equivalent old/new ERP effects for true and false recognition for participants with high rates of false recognition. In contrast, false recognition failed to elicit an old/new ERP effect in a group with low false recognition rates. To examine whether this between group difference was driven by the differential use of information that studied words and semantically related non studied test words (LURE) have in common (conceptual similarity), we manipulated encoding strategy in Experiment 2. When encoding focused on conceptual similarity, comparable ERP-effects for true and false recognition were obtained, suggesting that both forms of recognition were equally based on familiarity and recollection processes. Conversely, when encoding was focused on item specific features, differences in brain activity for true and false recognition were obtained. The ERP data indicate that, in addition to the false recognition rate, strategic processes during encoding, such as processing conceptual features, are an important factor in determining electrophysiological differences between true and false recognition.

Theme: Neural basis of behavior

Topic: Learning and memory: systems and functions

Keywords: False memory; Event related potential; Recognition memory; Familiarity; Recollection

1. Introduction

The act of remembering is the outcome of multiple, fundamentally reconstructive, component processes (for an overview see [51,61]). These processes include inferences drawn on the basis of feelings of familiarity elicited by a stimulus, as well as the active recollection of a memory trace [30,66]. Although the majority of memory studies have focused on whether or not studied items are accurately recalled or recognized, more recently the investigation of memory illusions, so-called false memories, has received increased attention. In the typical laboratory study of false memory, participants learn lists of associate words of a non presented word, the so-called LURE word. The critical finding, replicated many times [33,45,50], is that in a subsequent recall or recognition test, participants falsely recall or recognize the LURE words at a much higher rate than words unrelated to the study lists[1].

One explanation of false recognition holds that it is due to a feeling of familiarity and is not due to the active recollection of a memory trace. According to this explanation, LURE words feel familiar and are judged old because

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[1] In the following, false alarms to LURE words are labeled as 'false recognition' and old responses to previously studied, OLD words are labeled as 'true recognition'.

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PII: S0926-6410(00)00049-5

they are broadly consistent with the conceptual features that were studied; they largely match the overall themes of words encountered in the study phase [61,60][2]. Support for this view comes from studies showing that more sensory and distinctive details (item specific memory traces) are retrieved for true than for false recognition ([31,34,40], cf. [60]).

An alternative explanation suggests that the false memory phenomena is based on both inferences drawn on the basis of feelings of familiarity and the active recollection of a memory trace. According to this model, the non studied LURE words are activated, and hence memory traces formed, during study of the associated words via spreading activation through the mental lexicon [5,69]. For example, studying words like *butter* or *sandwich* could lead to the activation of the word *bread*. In the test phase, participants may correctly recognize *butter* as a studied word but may falsely recognize a LURE word like *bread* because it was also activated during study. Consequently, in this model, false recognition results from feelings of familiarity that arise due to conceptual similarities between OLD and LURE words and from prior activation in the study phase with a failure to attribute that activation to its correct source [15,25,23]. Support for this view is provided by Roediger and McDermott [52]. They required participants to indicate whether an old response was based on consciously recollected aspects of prior experience, i.e. a memory trace ('Remember' response), or merely on the belief that a test word had occurred in study without any recollection of the specific study episode, i.e. familiarity ('Know' response). Importantly, 'Remember' response rates following true and false recognition were equal, indicating that participants used similar information for true and false recognition (for similar results see Ref. [45]).

Event-related potentials (ERPs) can provide an additional source of information about whether the cognitive processes involved in true and false recognition are the same or different. This is because the timing and scalp topography of particular ERP-components allows inferences about the timing and nature of cognitive processes underlying recognition memory judgments to be made [10,26,55]. In the case of studies of false recognition the reasoning is that if the same cognitive processes underlie true and false recognition, then the ERP patterns elicited should be the same. Indeed, Johnson et al. [24] and Düzel et al. [12] found equivalent ERPs for true and false recognition when a random word order test presentation was used, suggesting that true and false recognition engage the same neural and cognitive processes. Assuming that both familiarity and active recollection processes underlie true recognition in their experiments, then these results are consistent with the view that both processes also underlie false recognition.

However, both of these ERP studies used word lists from the false memory paradigm introduced by Deese [9]. In this paradigm, the LURE words are theme words (e.g. *sweet*) that are more highly associated with the studied words (e.g. *candy*, *sour*) than the studied words are to each other (for a critical discussion of the Deese paradigm see Refs. [39,53]). Consequently, a difficulty with this paradigm is that it may enhance activation of LURE words via associative mechanisms in the encoding phase, leading to equivalent activation for LURE and studied words. This, in turn, could result in equivalent ERP waveforms for true and false recognition. Given this possibility, the goal of the present study was to determine whether OLD and LURE words elicited equivalent ERPs when the LURE words were equivalently related to a studied theme as were the OLD words. As the ERP data were analysed within a theoretical framework based on ERP studies of true recognition a brief description of the evidence for this framework follows.

True recognition elicits more positive ERP waveforms than correctly rejected NEW words in explicit old/new recognition tests (for reviews see Refs. [27,54]). These ERP old/new effects have a broad temporal and spatial distribution and can be decomposed into at least three spatio-temporally specific effects [13,36] that are associated with distinct cognitive processes underlying true recognition. These effects are an early fronto-medial old/new ERP effect, a somewhat later parietal old/new ERP effect and a late right frontal old/new ERP effect.

The fronto-medial focused positivity starts around 300 ms and lasts approximately 200 ms. This early old/new effect is assumed to arise from the attenuation of a frontally focused N400-like component that occurs because access to conceptual and perceptual information related to the test word is facilitated [6,7,28,35,37,46] and results in a feeling of familiarity [36]. That the effect is not driven by active recollection of item specific information is supported by its insensitivity to depth of processing manipulations [57].

The second positive deflection, maximal at parietal locations, starts around 400 ms and lasts for several hundred milliseconds. This parietal old/new ERP-effect, which is usually left lateralised or bilateral shows larger amplitudes for deeply than for shallowly encoded items [43,68]. Consequently, a relation to consciously controlled recollection of item specific information from the study phase is assumed ([12,42,65,71] and see Refs. [27,54] for reviews).

Third, a late right frontal old/new effect, which onsets around 800 ms, but is sustained longer in time than the ERP-effects described above, has also been reported [2,37,71]. At present there is no consensus on its precise functional significance [13,36]. Although a relation to recognition related processes is assumed, sometimes the

[2]The label 'conceptual similarity' is used to indicate overlapping conceptual information, i.e. information which is common for some items.

effect is present for NEW words [49], suggesting that the late right frontal positivity also reflects general task related processes [11].

In the present study, if false recognition is based on both familiarity and active recollection, then the ERP-waveforms for true and false recognition are expected to be equivalent. More specifically, relative to new responses of NEW items true and false recognition are expected to elicit early fronto-medial old/new ERP effects and parietal old/new ERP effects. If, however, false recognition is based only on familiarity, then it will fail to elicit a parietal old/new effect.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twenty-two volunteers (13 female) between 19 and 28 years of age (mean 23 years) participated. They were students at the University of Leipzig, were right-handed and had normal or corrected-to-normal vision. They reported to be in good health and were paid 12 DM/h for their participation. None of the participants had prior experience with the task.

2.1.2. Experimental materials

Stimuli consisted of 300 German nouns taken from a categorical word pool. This pool was created in a categorical noun generation experiment performed with 139 undergraduate students at the University of Leipzig (107 female), between 18 and 34 years old (mean=22) (for details see Ref. [68]). The present experiment used 30 categories, and the exemplars for each category were selected so that the mean word typicality of the 10 category examples was similar across the categories. The words were used to construct three randomised study-test-lists, which were balanced across participants. Each study list comprised 90 words and contained five members from each of 18 categories. Each test list consisted of these 90 studied words (OLD), the remaining 90 non studied words from studied categories (LURE) and 120 NEW words drawn from the 12 non studied categories. To increase the likelihood of false alarms to LURE items, these words were always drawn from the seven most typical words of each category.

2.1.3. Procedure

The participants were seated comfortably in an acoustically and electrically shielded dimly lit chamber in front of a 17-in. computer monitor. They sat at a distance of about 100 cm from the screen and during the test phase they held a small response box on their lap. Each participant performed one session consisting of a study and a test phase that were separated by a visuo-motor tracking task of 10 min duration. Participants were told that they would hear a tape recorded word list and that later they would be asked to recognize the words. In the study phase, participants heard 90 words in a female voice (five nouns from each of 18 categories). The name of a word category appeared on the screen for 2400 ms and was followed by a delay of 1600 ms. Next, the five nouns from the category were played at a rate of one every 2 s. Prior to the test phase, participants performed the tracking task. In the recognition test, the items were presented visually in a quasi random order with the constraint that no more than three words of the same type (OLD, NEW, LURE) were presented consecutively. Each test trial started with a fixation cross in the middle of the screen. After 100 ms the screen went blank for 500 ms and then the word was presented visually for 200 ms. The next trial started after a delay of 2800 ms (blank screen) during which participants were required to indicate as quickly and as accurately as possible whether the presented word was heard in the study phase (old response) or not (new response). They responded by pressing the left or the right button of the response box with the thumb of the corresponding hand. The response button used for old responses was counterbalanced across participants. After 150 items the participants were given a short break. Including electrode application and removal each session lasted about 1.5 h.

2.1.4. ERP recording

The EEG activity was recorded with Ag/AgCl electrodes mounted in an elastic cap (Electro-cap International) from 61 scalp sites of the extended ten-twenty system. Electrode labeling was based on the standard nomenclature [64]. The ground electrode was positioned 2 cm to the right of Cz. The vertical Electro-oculogram (EOG) was recorded from electrodes located above and below the right eye. The horizontal EOG was recorded from electrodes positioned at the outer canthus of each eye. Electrode impedance was kept below 5 kOhms. The right mastoid was recorded as an additional channel. All scalp electrodes were referenced to the left mastoid and were offline rereferenced to both mastoids. EEG and EOG were recorded continuously with a band pass from DC to 30 Hz and were A–D converted with 16 bit resolution at a sampling rate of 250 Hz.

2.1.5. Data analysis

2.1.5.1. Behavioral data. Reaction time was defined as the interval between the appearance of the test item and the participant's keypress. Data were averaged separately for each response condition.

2.1.5.2. ERP data. In the test phase, ERPs were computed for each participant at all recording sites with epochs extending from 200 ms before onset of word presentation until 2000 ms thereafter. ERPs were selectively averaged for the following combinations of item types and responses: old responses of OLD words (true recognition), old responses of LURE words (false recognition), new responses of LURE words and new responses of NEW words. Because there were too few old responses to NEW items and too few new responses to OLD items to form reliable ERPs, these conditions were excluded from further analyses.

The average voltages in the 200 ms preceding stimulus presentation served as a baseline. Prior to averaging, each epoch was scanned for EOG and other artifacts. Whenever the standard deviation in a 200 ms time interval exceeded 30 μV in an EOG channel or 40 μV in the Pz channel the epoch was rejected. In a second step, the EEG epochs were visually scanned for further artifacts. The averages were lowpass filtered below 10 Hz in order to increase the signal-to-noise ratio by eliminating those frequencies that were irrelevant to the measurements of interest [48]. Because some of the ERP components were not clearly visible as peaks at all electrode sites, mean amplitude measures were considered more reliable for component scoring than peak measures [21]. In order to avoid a loss of statistical power that is implicated when repeated-measures ANOVAs are used to quantify multi-channel and multi-time window data [16,17,41], electrode sites were pooled to six topographical regions, so-called regions of interests (ROI). The following regions were defined: left frontal (F9, AF7, F7, F5, FT9, FT7, FC5); medial frontal (AFz, AF3, AF4, Fz, F3, F4, FCz); right frontal (F10, AF8, F8, F6, FT10, FT8, FC6); left parietal (TP9, TP7, CP5, P9, P7, P5, PO7); medial parietal (CPz, Pz, P3, P4, PO3, POz, PO4) and right parietal (TP10, TP8, CP6, P10, P8, P6, PO8). According to Homan, Herman, and Purdy [20], who established a correspondence between electrode site and underlying cerebral structures using radiographic techniques, the medial frontal region is approximately over the middle frontal gyri (Brodmann area BA 46). The left and right frontal regions are approximately over the inferior frontal gyri (BA 45 on the left and BA 46 on the right). The left and right parietal regions cover approximately the posterior part of the middle temporal gyri and the anterior occipital sulcus (BA 19, 37), whereas the medial parietal region is approximately over the occipital gyri and the superior parietal lobe.

For statistical analysis, a hypothesis-driven approach was chosen. Based on prior studies examining ERPs in explicit recognition memory tasks ([6,57], cf. also [36]), three different time windows were used for the quantification of the ERP effects. The early frontal old/new effect was examined in a time window between 300 and 500 ms, the parietal old/new effect was expected to be maximal between 500 and 700 ms, whereas the late right frontal old/new effect was examined between 1200 and 1600 ms. For each time window we first tested whether true recognition elicited old/new effects. ERP measures were subjected to a two-way repeated-measures ANOVA with the factors Condition (two levels: true recognition, new responses of NEW words) and ROI (six levels: left frontal, medial frontal, right frontal, left parietal, medial parietal, right parietal). Using the same ANOVA design, we next tested whether false recognition elicited similar old/new effects. Second, ERP-differences between the old/new effects for true and false recognition were examined in an additional two-way repeated-measures ANOVA (factors: Condition (two levels: true recognition minus new responses of NEW words, false recognition minus new responses of NEW words); ROI (six levels)), separately for the time windows. In order to test whether the old/new effects differed topographically, the same repeated measure two-way ANOVA was conducted on the difference waves after they had been rescaled such that amplitude differences between the two contrasted conditions were removed [32].

In an additional analysis procedure, we directly contrasted brain activity elicited by new and old responses of LURE words using a two-way repeated-measures ANOVA (factors: Condition type (two levels: false recognition, new responses of LURE words); ROI (six levels)) for the early time window (300–500 ms).

In order to avoid reporting large amounts of statistical results not relevant for the issues under investigation, only main effects or interactions including the Condition factor are reported. In the case of significant interactions involving this factor, one-way ANOVAs with the factor Condition were performed to examine the effects of this factor in each of the topographical regions. Measures of treatment magnitude (ω^2, cf. [29]) for the single effects are reported in combination with main effects of Condition. All effects with more than one degree of freedom in the numerator were adjusted for violations of sphericity according to the Greenhouse and Geisser formula [18]. Scalp potential topographic maps were generated using a two-dimensional spherical spline interpolation [47] and a radial projection from Cz, which respects the length of the median arcs.

2.2. Results

2.2.1. Behavioral data

Mean reaction times and proportion of old responses to OLD, LURE and NEW words are presented in Table 1. Participants showed more false alarms to LURE words (false recognition) than to NEW words. Further, correct responses were faster for OLD and NEW words than for LURE words.

This pattern of results was confirmed by statistical analyses. A repeated-measures ANOVA for the proportions of old responses (three levels) revealed reliable differences between the three item types ($F(2, 42)=249.05$, $P<0.001$). Separate tests showed that LURE words elicited more false alarms than NEW words ($F(1, 21)=90.17$, $P<0.001$), and that the rate of old responses of OLD words (true recognition) was higher than the rate of old responses of

Table 1
Performance results in Experiment 1[a]

Item type	Response	Reaction time (ms)	Proportion old-response (%)
OLD	old	914 (35)	77.8 (2.8)
	new	1129 (71)	
LURE	old	1132 (53)	26.4 (2.9)
	new	1064 (54)	
NEW	old	1163 (68)	5.3 (1.4)
	new	930 (43)	

[a] Mean reaction times of the old and new responses, and mean proportion of the old responses for the different item-types in Experiment 1. The standard error of the mean is presented in parentheses.

LURE words (false recognition) ($F(1, 21)=165.88$, $P<0.001$). Reaction times for the four response categories relevant for the ERP analyses (true recognition, false recognition, new responses of LURE words, new responses of NEW words) were significantly different as revealed by a one-way repeated measures ANOVA ($F(3, 63)=27.71$, $P<0.001$). Separate tests showed that participants responded faster to OLD and NEW words than to LURE words.

2.2.2. Event related potentials

2.2.2.1. ERP old/new effects to OLD and LURE words. Fig. 1 displays the ERP waveforms at two midline electrodes and at lateral frontal and parietal recording sites elicited by true recognition, false recognition, and new responses of NEW words.

Starting at around 300 ms the waveform elicited by *true recognition* was more positive than that for NEW words. This old/new ERP effect appeared first at frontal locations and extended to parietal locations somewhat later. From around 800 ms until the end of the recording epoch the old/new effect was maximal at right frontal locations. Similar positive ERP-differences relative to NEW words were also obtained for *false recognition*, but the old/new effect between 400 and 800 ms was less pronounced than for true recognition. Notably, for false recognition only, there was a negative component over bilateral parietal locations. It started around 900 ms and extended until the end of the recording epoch over parietal locations.

The results of the two-way ANOVAs with factor condition and ROI for: (a) true recognition and new responses of NEW words; and (b) false recognition and new responses of NEW words are displayed in Table 2.

In the early time window (300–500 ms), for both true and false recognition, there were significant main effects of Condition. Based on the significant Condition×ROI interaction for true recognition, separate tests were performed for the different ROI's. For true recognition, there were significant old/new effects for all six ROI's, but the medial frontal ROI showed the highest treatment magnitude ($\omega^2=0.65$). In the middle time window (500–700 ms), analyses of true and false recognition revealed significant main effects of Condition as well as a significant Condition×ROI interaction for true recognition and a marginally significant interaction for false recognition. For true recognition, all ROIs showed significant old/new effects, but the treatment magnitude, even though quite large at the medial frontal ROI ($\omega^2=0.71$), was largest at the medial parietal ROI ($\omega^2=0.72$). However, for false recognition separate tests for single ROIs revealed a larger old/new effect at the medial frontal ($\omega^2=0.32$) than at the medial parietal ROI ($\omega^2=0.24$). As is evident from Table

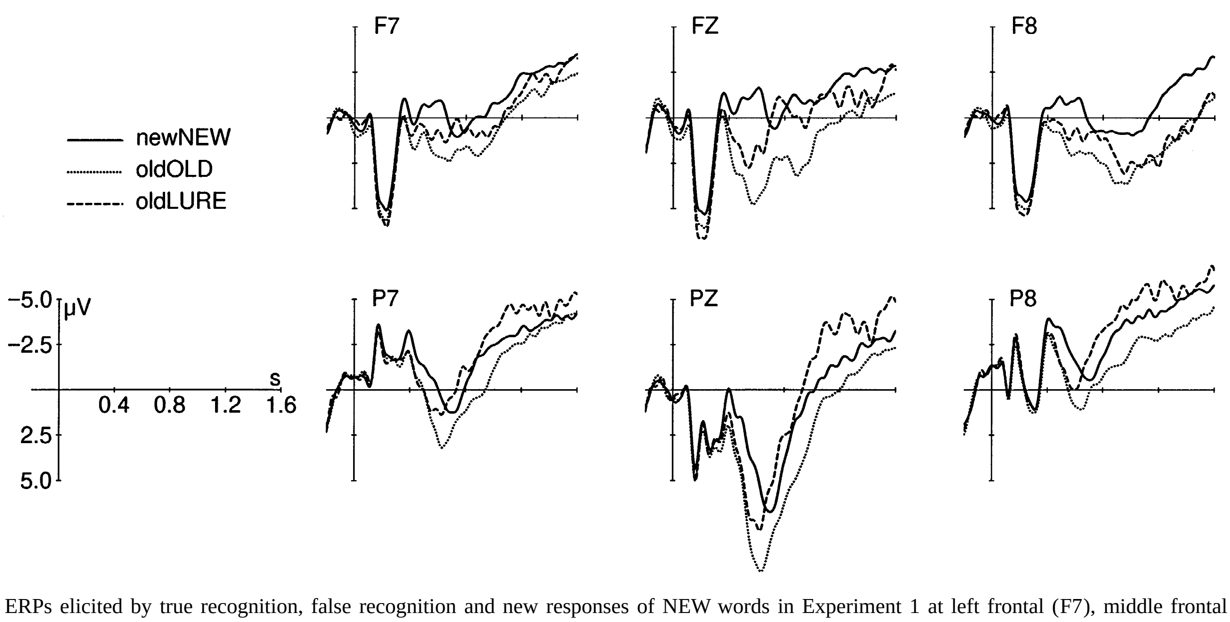

Fig. 1. ERPs elicited by true recognition, false recognition and new responses of NEW words in Experiment 1 at left frontal (F7), middle frontal (FZ), right frontal (F8), left parietal (P7), middle parietal (PZ), and right parietal (P8) electrode sites. In this and the following figures, negative voltages are plotted upwards.

Table 2
ERP old/new effects in Experiment 1[a]

	F-values							
	True recognition				False recognition			
	df	300–500 ms	500–700 ms	1200–1600 ms	df	300–500 ms	500–700 ms	1200–1600 ms
Cond	1.21	40.56***	62.54***	11.49**	1.21	5.61*	8.20**	0.50
Cond×ROI	5.105	3.81*	6.73**	3.85*	5.105	0.58	2.31(*)	7.68***

[a] Note: Cond, Condition; df, degrees of freedom; ROI, region of interest. *** $P<0.001$; ** $P<0.01$; * $P<0.05$; (*) $P<0.1$. ANOVA results for the old/new ERP effects to true and false recognition in the three time windows in Experiment 1.

2, ANOVAs in the late time window (1200–1600 ms) revealed a significant main effect of Condition as well as a significant Condition×ROI interaction for true recognition. There was only a Condition×ROI interaction for false recognition. For true recognition, separate tests for the different ROIs showed more positive ERPs at the medial frontal ($\omega^2=0.38$), the right frontal ($\omega^2=0.38$) and the right parietal ROI ($\omega^2=0.28$). For false recognition, ERPs were more positive at the medial frontal ($\omega^2=0.13$) and the right frontal ($\omega^2=0.29$), but more negative at the medial parietal ROI ($\omega^2=0.14$).

2.2.2.2. Topographic analyses of old/new effects. For the present study it was of major relevance to directly compare the amplitude differences and topographical distributions of the old/new effects elicited by true and false recognition. For this reason, ANOVAs were performed on the difference measures (true recognition minus new responses of NEW words; false recognition minus new responses of NEW words) for raw data and amplitude normalised data [32]. The scalp topographies of the old/new effects elicited by OLD and LURE words are depicted in Fig. 2.

There was no difference between the old/new effects elicited by the two forms of recognition in the early time window (300–500 ms) as the ANOVA showed no significant main effect ($F(1, 21)=1.39$) or interaction (F(5,

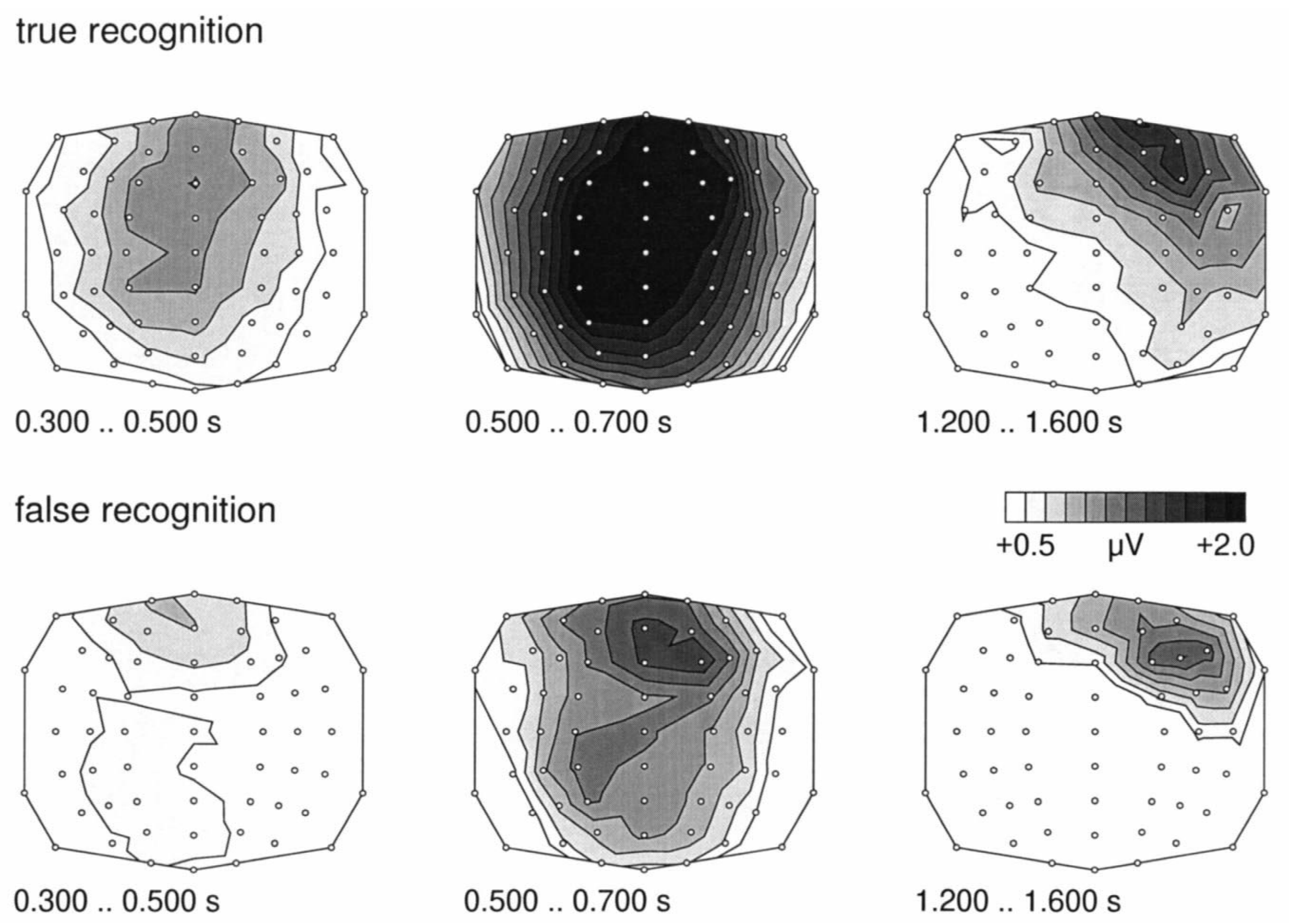

Fig. 2. Topographic distributions of the difference waves for ERPs to true recognition and new responses of NEW words and to false recognition and new responses of NEW words in the early (300–500 ms), middle (500–700 ms), and late (1200–1600 ms) time interval in Experiment 1.

105)=0.34). In the middle interval there was a main effect of Condition ($F(1, 21)=5.47$, $P<0.05$), indicating larger effects for OLD words. The ANOVA performed on amplitude normalised data revealed no significant Condition×ROI interaction ($F(5, 105)=2.25$, $P>0.05$), suggesting that the topographical distributions were the same for true and false recognition. To compare the magnitude of the late frontal effect in both recognition conditions, we restricted the analyses to frontal locations. There was no difference between the effects elicited by both recognition forms, as the ANOVA performed for difference waves showed no significant main effect ($F(1, 21)=0.87$) or interaction ($F(2, 42)=0.06$).

2.2.2.3. ERPs for correctly classified LURE words. As an alternative measure of familiarity, we further contrasted old and new responses to LURE words in the early time window (300–500 ms). LURE words that attract an old response should be more familiar than those that are rejected. Fig. 3 displays the topographical distribution of the effect in the early time window.

There was a significant main effect of Condition ($F(1, 21)=6.79$, $P<0.05$) indicating more positive ERPs for false recognition.

In sum, differential recognition related brain activity for true and false recognition was not obtained before 500 ms. While both forms of recognition elicited similar early old/new ERP effects, a positivity starting around 500 ms was significantly smaller for false recognition than for true recognition. Moreover, in a late time interval both recognition forms elicited a right frontal effect, while only false recognition gave rise to a medial parietal negative slow wave.

2.2.2.4. Effects of different rates of false alarm to LURE words. The present study found dissociable brain activity for true and false recognition using OLD and LURE words from the same semantic categories in a random word order test presentation, whereas prior ERP studies failed to find recognition related dissociations between true and false recognition [24,12]. These studies also reported higher rates of false recognition, 50 and 70% in the studies of Düzel et al. and Johnson et al., respectively, against only 26% false recognition in the present study. It is conceivable that the lower false recognition rate was responsible for the ERP-differences obtained here.

To examine whether the lower error rates to LURE words in the present study caused the differential ERP patterns elicited by true and false recognition, we compared two groups of 10 participants each. Participants were assigned to the groups based on their false alarm rates to LURE words, i.e. a group of participants with high false recognition rates (mean rate of false recognition 38.5%) and participants with low false recognition rates (mean rate of false recognition 15.3%). If the similarity between brain activity elicited by true and false recognition memory is determined by false recognition rate, then ERPs elicited by true and false recognition should be more similar in the group with high false recognition rates than in the group with low false recognition rates.

From Fig. 4 it appears that for participants with high false recognition rates the ERPs for true and false recognition were highly similar, whereas for the group with low false recognition rates the ERPs for false recognition resemble those elicited by new responses of NEW words. This was confirmed by statistical analysis, as shown in Table 3. Old/new effects were elicited by true recognition for both groups, although the analysis did not reveal a late right frontal effect in the group with high false recognition rates. Further, there were old/new effects in all three time ranges for false recognition in the group with high false recognition rates, whereas no positive old/new effect

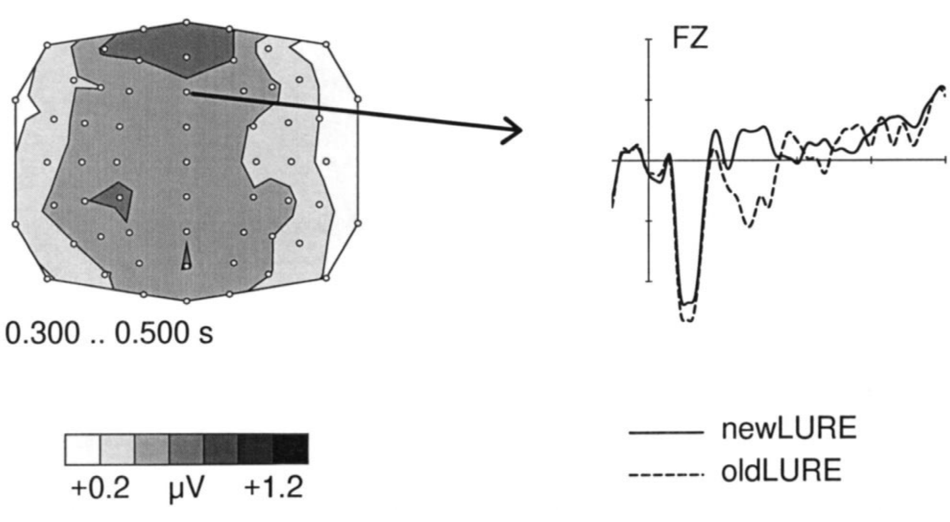

Fig. 3. Topographic distribution of the difference wave for ERPs to false recognition and new responses to LURE words in the early (300–500 ms) time interval (left). The corresponding ERPs are plotted for a middle frontal (Fz) electrode site (right).

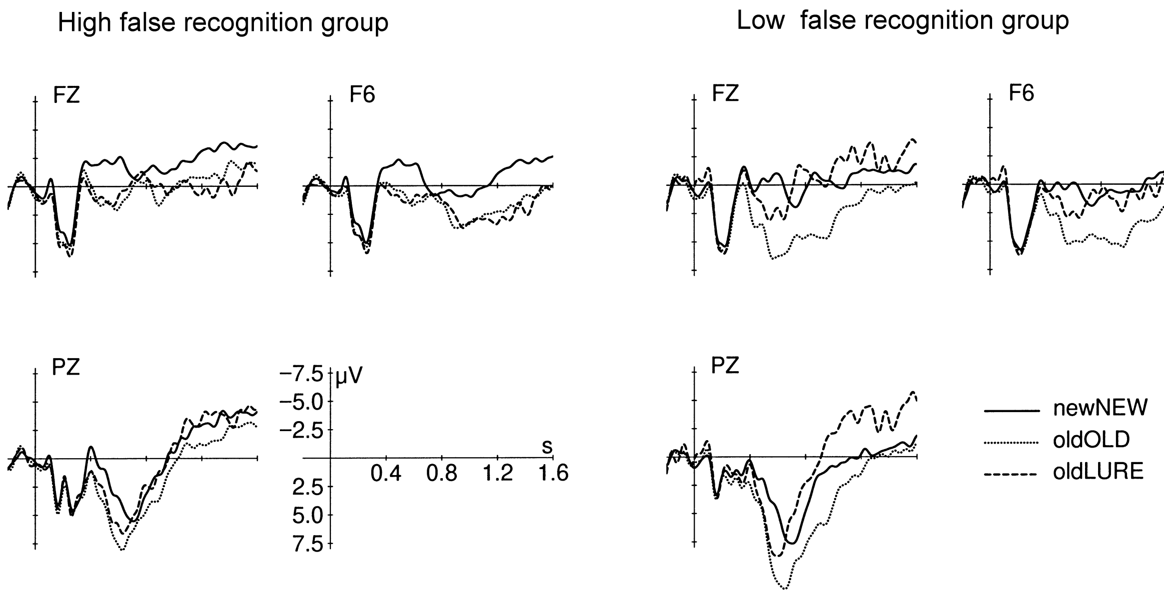

Fig. 4. ERPs elicited by true recognition, false recognition and new responses of NEW words for the group with high false recognition rates (left) and the group with low false recognition rates (right) in Experiment 1. To illustrate the three ERP old/new effects (cf. [36]), middle frontal (FZ), middle parietal (PZ), and right frontal (F6) electrode sites were chosen.

appeared for false recognition in the group with low false recognition rates. Interestingly, there was a late negative deflection for false recognition at medial parietal locations in the group with low rates but not in the group with high false recognition rates.

2.3. Discussion

As expected, we found higher false alarm rates to non studied, but semantically related, LURE words (false recognition) than to non studied NEW words that were not members of studied categories. The proportions of false recognition found in Experiment 1 were lower than in studies performed with the Deese paradigm [15,33,52], but resemble those found in a behavioral study that also used categorical lists [63]. This outcome indicates that the strength of semantic relations between the studied (OLD) and LURE words influences the false recognition rate. The important issue here, however, is whether both familiarity and active recollection processes contributed to false recognition given the weaker semantic relations between studied and LURE words.

In contrast to prior studies [12,24], the initial analyses showed ERP differences between true and false recognition. While both forms of recognition elicited similar early fronto-medial old/new ERP effects, there was a smaller parietal old/new ERP effect for false than for true recognition between 500 and 700 ms.

As described in the Introduction, prior studies of true recognition suggest that the early frontal effect reflects facilitated access to conceptual information associated with a feeling of familiarity [7,36]. This old/new ERP effect was similar for true and false recognition, indicating that both forms of recognition were based on feelings of

Table 3
Group comparison of the ERP old/new effects, Experiment 1[a]

	F-values							
	True recognition				False recognition			
	df	300–500 ms	500–700 ms	1200–1600 ms	df	300–500 ms	500–700 ms	1200–1600 ms
Group with low false recognition rates								
Cond	1.9	34.56***	99.37***	7.12*	1.9	1.39	2.14	0.88
Cond×ROI	5.45	2.03	4.00(*)	1.62	5.45	0.17	0.54	3.33*
Group with high false recognition rates								
Cond	1.9	8.70*	11.91**	2.64	1.9	3.61(*)	11.65**	3.64(*)
Cond×ROI	5.45	1.68	2.27	2.30	5.45	1.97	3.48(*)	4.28*

[a] Note: Cond, Condition; df, degrees of freedom; ROI, region of interest. *** $P<0.001$; ** $P<0.01$; * $P<0.05$; (*) $P<0.1$. ANOVA results for the old/new ERP effects to true and false recognition in the three time windows, separately for the group with low false recognition rates and the group with high false recognition rates in Experiment 1.

familiarity due to conceptual similarity. Further, more positive ERP waveforms for old than for new responses of LURE words in this early time window indicate that semantically related words that attract an old response are more familiar than such words that elicit a new response.

While both explanations of false recognition presented in the Introduction make similar predictions about the involvement of familiarity inducing processes, they differ in their predictions about the involvement of recollection based processes. Whereas the first approach specifies only familiarity based false recognition, the second also includes recollection based processes. Given that the parietal ERP effect indicates active recollection of a memory trace [36,54], there seems to be recollection based false recognition in the present study also. Analyses revealed significant old/new ERP effects at parietal locations for true and for false recognition in the middle time window (500–700 ms). Although this effect was smaller for false than for true recognition, the old/new ERP effects showed similar topographical distributions reflecting that the underlying neural activity had the same source and suggesting that the same cognitive processes were involved. However, the differenting strengths of the ERP-effects suggests that less conscious recollection occurred for false recognition. Therefore, true and false recognition are differentiated under testing conditions that involve similar semantic relations for OLD and LURE words.

Note, that this effect in the middle time interval was also pronounced at frontal locations, such that a contribution from the early frontal effect cannot be excluded. However, in contrast to true recognition the treatment magnitude measures for false recognition indicate larger old/new ERP effects at the medial frontal ROI than at the medial parietal ROI. This pattern further emphasizes that less conscious recollection occurred for false than for true recognition.

Finally, both true and false recognition judgments showed more positive going waveforms than new responses of NEW words at right frontal locations in a late time window. Interestingly, there was a late bilateral parietal negative slow wave to false recognition. The possible functional implications of both late effects are addressed in the General discussion.

Overall then, it appears that false recognition arises from familiarity as well as active recollection processes. However, in contrast to prior ERP studies which reported no differences in brain activity for true and false recognition [12,24], differential ERP patterns were observed in this study. Smaller parietal ERP old/new effects for false than for true recognition indicate that false recognition is based to a lesser extent on recollection processes than is true recognition in a paradigm where LURE and OLD words have symmetric semantic relations. Consequently, the degree of recollection seems to be overestimated for false recognition in prior ERP studies with the Deese paradigm [12,24], due to the higher associative relation between LURE words and studied words than between the studied words [39,53]. However, an alternative explanation is that the ERP differences between true and false recognition in the present study were due to the low rate of false recognition relative to earlier studies [15,45]. Indeed, this interpretation is supported by the finding that a subgroup of participants with high false recognition rates showed equal old/new ERP effects for true and false recognition, whereas the low false recognition group failed to show old/new effects for false recognition.

Because the ERP results for the group with high false recognition rates resemble the ERP-results reported for the Deese paradigm, the semantic relations of LURE words are not sufficient to explain the similarity in brain activity. The group with high false recognition rates showed similar fronto-medial as well as similar parietal ERP effects for true and false recognition indicating that both forms of recognition are based on familiarity and recollection processes to the same extent, and could not be differentiated. This was not true for participants with low false recognition rates, where ERPs for false recognition showed no old/new ERP effect at all. A possible explanation is that individual differences in encoding strategy are responsible for the obtained ERP results. In the Deese paradigm, all OLD words in one list are related to a LURE word and, consequently, support activation of this LURE word via spreading activation during encoding. When OLD and LURE words are equivalently related OLD words should provide less semantic activation of LURE words and activation via associative mechanisms during encoding should be smaller. However, activation could be forced if participants focused attention on categorical features, i.e. the information that OLD words have in common (conceptual similarity). Perhaps such an encoding strategy was used by participants in the high false recognition group, whereas participants in the low false recognition group did not focus on conceptual similarity but memorized item specific features.

A second experiment was performed in order to examine this issue. We directly manipulated encoding strategy by requiring participants to focus either on conceptual similarity, i.e. categorical information, or item specific features. In the Category Group participants were required to assign words to a specific category (e.g. *teacher* to *profession*), whereas participants in the Item Group judged whether study words were animate or inanimate. The rationale behind this manipulation was that the Category Group would use conceptual similarity to a higher degree than the Item Group, whereas recognition judgments would be based more on item specific memory traces in the Item Group than in the Category Group. Focusing on categorical information (Category Group) was expected to heighten activation via associative mechanisms in study and consequently recollection based false recognition in the test phase. Further, focusing on categorical information was expected to support also familiarity based false recognition. Consequently similar old/new ERP-effects for true and false recognition were expected in this group. The animacy judgement to each study word in the Item Group was expected to lead participants to think more about the concepts themselves and consequently activate item specific information to a higher extent than participants from the Category Group. An attentional focus on item specific features was not expected to support familiarity or recollection based false recognition. Consequently, neither an early fronto-medial nor a parietal ERP old/new effect for false recognition was predicted for this group.

3. Experiment 2

3.1. Methods

3.1.1. Participants

Thirty-six volunteers (25 female) participated in the experiment. They were students at the University of Leipzig and were between 20 and 32 years of age (mean: 23 years), were right handed and had normal or corrected-to-normal vision. They reported to be in good health and were paid 12 DM/h. None of the participants had any prior experience with the task.

3.1.2. Stimuli and procedure

We used the same word list as in Experiment 1. In the study phase, Category Group participants assigned words to a specific category, while participants in the Item Group judged whether words represented animate or inanimate objects. The nouns were presented in random order at a rate of one word every 5000 ms. At the beginning of each study trial, a fixation cross appeared in the middle of the screen and 500 ms later there was an auditory word presentation. After another 2000 ms two names of categories were presented on the screen (left and right sides) for the Category Group. In the Item Group the words *belebt* (Engl. living) and *unbelebt* (Engl. non-living) appeared on the screen (also left and right sides and changing locations for each study trial). After the participant responded with a left or right button press, the screen went blank. Participants had 2500 ms to make this decision before the next trial started. The recognition test was the same for both groups and was the same as Experiment 1 with one exception. Participants additionally indicated their confidence for each old/new response. After the response delay (2800 ms) *sicher* (Engl. certain) and *unsicher* (Engl. uncertain) appeared on the screen (left and right side but in the same location for all test trials and counterbalanced across participants) and participants pressed the appropriate button. After the response, the screen went blank and 2200 ms after the confidence decision prompt the next test trial started. Each trial lasted 5800 ms.

3.1.3. ERP recording and data analysis

The procedure for EEG recording and data analysis was the same as in Experiment 1. Additionally, behavioral data were also examined for effects of confidence. This was not possible for the ERPs as, depending on condition, there were too few high or low confidence judgments to form reliable ERPs.

3.2. Results

3.2.1. Behavioral data

The proportion of old responses, mean reaction times, and the proportion of high confidence ratings for the Category Group (a) and the Item Group (b) are displayed in Table 4.

An ANOVA treating Group as a between subjects factor and Condition (three levels: OLD words, LURE words,

Table 4
Performance results in Experiment 2[a]

Item-type	Response	Reaction time (ms)	Proportion old response (%)	Proportion high confidence (%)
(a) Category Group				
OLD	old	1051 (45)	70.4 (3.9)	72.2
	new	1171 (70)		36.9
LURE	old	1177 (60)	34.6 (3.6)	34.0
	new	1108 (64)		57.3
NEW	old	1245 (84)	8.0 (2.5)	24.8
	new	983 (57)		82.9
(b) Item Group				
OLD	old	1128 (63)	75.4 (2.7)	80.8
	new	1300 (70)		40.8
LURE	old	1278 (81)	33.8 (2.3)	42.0
	new	1236 (73)		61.0
NEW	old	1312 (84)	16.9 (2.2)	26.2
	new	1179 (70)		67.0

[a] Mean reaction times of the old and new responses, mean proportion of the old responses, mean proportion of the high confidence responses for: (a) the Category Group; and (b) the Item Group in Experiment 2. The standard error of the mean is presented in parentheses.

NEW words) as a within subjects factor was conducted on the proportions of old responses. There was a significant main effect of Condition ($F(2, 68)=340.80$, $P<0.001$). Post hoc tests revealed that there were more old responses to OLD (true recognition) than to LURE words (false recognition) ($F(1, 35)=283.87$, $P<0.001$) and more old responses to LURE (false recognition) than to NEW words ($F(1, 35)=107.06$, $P<0.001$) in both groups. Although there was no interaction of Condition with Group, a separate analysis revealed fewer false alarms to NEW words in the Category than in the Item Group ($F(1, 34)=7.29$, $P<0.05$). The reaction time analysis revealed a significant main effect of Condition ($F(3, 102)=16.95$, $P<0.001$). Correct responses to OLD and NEW words were faster than responses to LURE words and correct reactions to LURE words were faster than incorrect reactions to LURE words. The analysis of confidence ratings revealed more high confidence judgments to correctly rejected NEW words in the Category than in the Item Group ($F(1, 35)=7.08$, $P<0.05$), but there was no group difference in confidence for true or false recognition. Analyses comparing rates of high confidence judgments for true and false recognition in both Groups revealed a significant main effect of Condition ($F(1, 34)=237.07$, $P<0.001$), reflecting higher confidence for true recognition in both groups.

3.2.2. Event related potentials

3.2.2.1. ERP old/new effects to OLD and LURE words. Fig. 5 displays the ERP waveforms elicited by true recognition, false recognition, and new responses to NEW words for (a) the Category Group, and (b) the Item Group at a middle frontal, a middle parietal and a right frontal recording site.

Starting around 300 ms, ERPs for true recognition were more positive than those to new responses of NEW words in both groups. There were old/new ERP effects early in time as well as a late right frontal old/new effect. False recognition also showed more positive ERPs than did ERPs for new responses of NEW words starting around 300 ms. The ERPs indicated smaller early frontal and parietal old/new ERP effects (300–700 ms) to false than true recognition in the Item Group, whereas the early old/new effects elicited by true and false recognition were highly similar in the Category Group. In both groups, starting around 800 ms and maximal at right frontal locations, there were more positive ERPs for false recognition than for new responses of NEW words. Further, in the Item Group there were more negative ERPs for false recognition than for new responses of NEW words at parietal sites between 700 and 1200 ms. Statistical analyses were performed for the same time windows as in Experiment 1. The results of the two-way ANOVAs for true recognition and new responses of NEW words as well as for false recognition and new responses of NEW words for the Category Group and the Item Group are shown in Table 5.

As can be seen from Table 5, the *Category Group* analyses revealed a main effect of Condition for true and false recognition in the early time window (300–500 ms). Separate tests for the different ROIs based on a significant Condition×ROI interaction for true recognition revealed significant old/new ERP effects at all locations, with the highest treatment magnitude at the medial frontal ROI ($\omega^2=0.38$). In the middle time window (500–700 ms), a

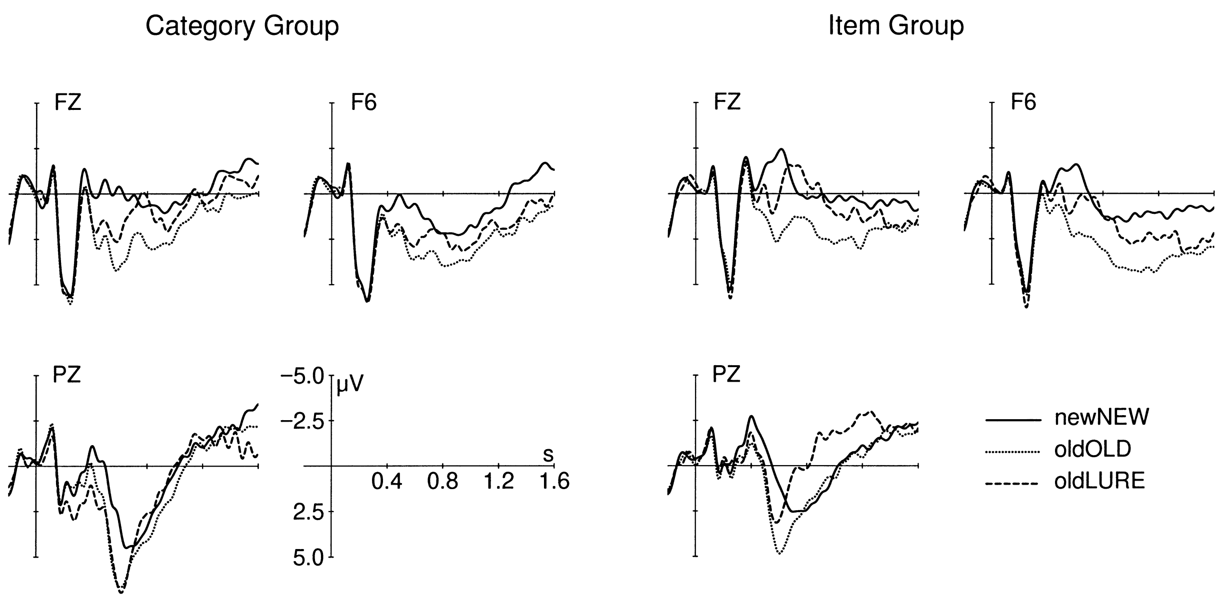

Fig. 5. ERPs elicited by true recognition, false recognition and new responses to NEW words for the Category Group (left) and the Item Group (right) in Experiment 2 at middle frontal (FZ), middle parietal (PZ), and right frontal (F6) electrode sites.

Table 5
ERP old/new effects in Experiment 2[a]

	F-values							
	True recognition				False recognition			
	df	300–500 ms	500–700 ms	1200–1600 ms	df	300–500 ms	500–700 ms	1200–1600 ms
(a) Category Group								
Cond	1.17	7.67*	16.57***	2.71	1.17	22.36***	21.05***	4.28(*)
Cond×ROI	5.85	3.39*	4.79**	5.07**	5.85	2.18	1.95	0.47
(b) Item Group								
Cond	1.17	18.41***	53.14***	5.66*	1.17	2.69	4.83*	2.00
Cond×ROI	5.85	1.02	4.46*	1.51	5.85	1.25	0.43	2.42(*)

[a] Note: Cond, Condition; df, degrees of freedom; ROI, region of interest. *** $P<0.001$; ** $P<0.01$; * $P<0.05$; (*) $P<0.1$. ANOVA results for the old/new effects to true and false recognition in Experiment 2 for: (a) the Category Group; and (b) the Item Group.

significant main effect of Condition and a significant Condition×ROI interaction were obtained for true recognition. Separate analyses revealed significant old/new effects at all six ROIs, but treatment magnitudes were highest at the medial frontal ($\omega^2=0.52$) and the medial parietal ROIs ($\omega^2=0.43$). For false recognition there was only a main effect of Condition. ANOVAs for the late time window (1200–1600 ms) revealed a significant Condition×ROI interaction for true recognition, but only a marginally significant main effect of Condition for false recognition. Separate tests for the different ROIs indicated more positive waveforms to true recognition at the medial frontal ($\omega^2=0.24$) and the right frontal ROI ($\omega^2=0.28$) in this time interval.

The *Item Group* analyses revealed a significant main effect of Condition for true but not for false recognition in the early time window (300–500 ms). As can be seen in Table 5, in the middle time window (500–700 ms) there was a significant main effect of Condition for true and false recognition, but only true recognition gave rise to a significant Condition×ROI interaction. Separate tests for different ROIs revealed significant old/new ERP effects at all locations for true recognition, but treatment magnitude was highest at the medial frontal ROI ($\omega^2=0.70$). In the late time window (1200–1600 ms), there was a significant main effect of Condition for true recognition with the highest treatment magnitudes at the medial frontal ($\omega^2=0.24$) and the right frontal ROI ($\omega^2=0.21$), and a marginally significant Condition×ROI interaction for false recognition. Separate tests performed for false recognition revealed marginally significant effects at the medial frontal ($\omega^2=0.13$) and at the right frontal ROI ($\omega^2=0.14$).

3.2.2.2. Topographic analyses of old/new effects. ANOVAs were performed on the difference measures (true recognition minus new responses of NEW words; false recognition minus new responses of NEW words) to compare the amplitude differences and topographical distributions. Because for the Item Group no old/new effects for false recognition were found in the early time interval, the analyses were restricted to the middle and late time window in this group. The scalp topographies of the old/new effects elicited by true and false recognition for both groups are presented in Figs. 6 and 7.

Neither analysis performed for the different time windows in the Category Group revealed a significant main effect or interaction. In the Item Group, there was a significant main effect of Condition ($F(1, 17)=4.88$, $P<0.05$) in the middle time window only, indicating larger old/new effects to true than to false recognition. The ANOVA performed for the amplitude normalised old/new differences revealed a significant Condition×ROI interaction ($F(5, 85)=3.58$, $P<0.05$), suggesting that there was a different topographical distribution of the old/new effects for true and false recognition.

In sum, while both groups showed old/new effects to true recognition there was an early frontal effect for false recognition in the Category but not in the Item Group. Further, the old/new ERP effect for false recognition in the middle time window was smaller than for true recognition in the Item Group, whereas similar parietal effects were obtained in the Category Group.

3.2.2.3. ERPs for correctly rejected LURE words. Fig. 8 displays the topographical distribution of the ERP differences between old responses of LURE words (false recognition) and new responses of LURE words in the early time window (300–500 ms) for each group separately.

A two-way ANOVA with the factors Condition (two levels: false recognition, new responses of LURE words) and ROI (six levels) was performed for both groups. ERPs for false recognition were more positive than for new responses of LURE words in the Category Group (main effect of Condition: $F(1, 17)=29.54$, $P<0.001$), but not in the Item Group ($F(1, 17)=1.83$, $P>0.1$).

3.2.2.4. Late parietal negativity. In Experiment 1, the analyses revealed a parietal negativity for false recognition in the late time window. In Experiment 2, we failed to find significant negative deflection in the late time window (1200–1600 ms), but there was a bilateral parietal

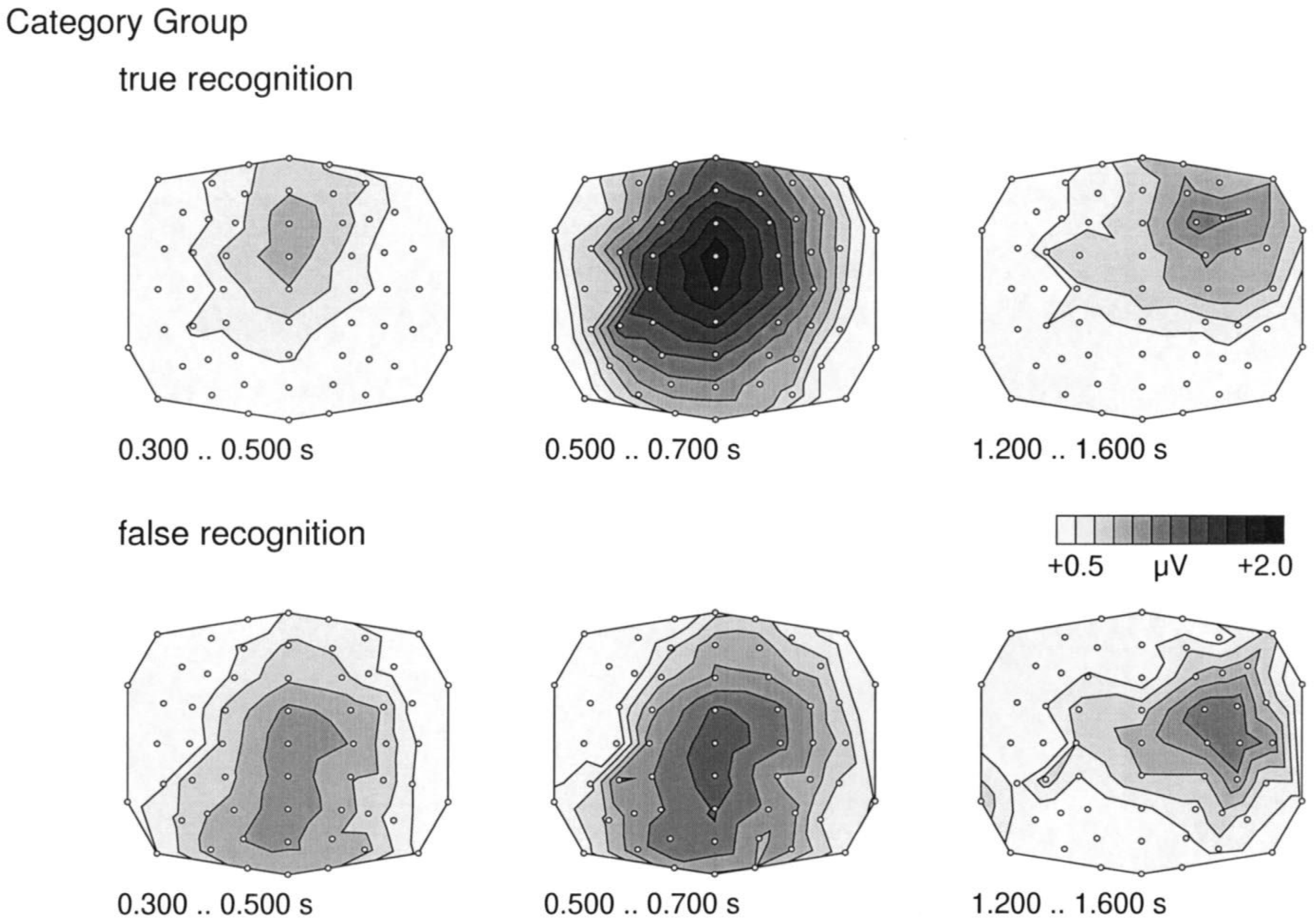

Fig. 6. Topographic distributions of the difference waves for ERPs to true recognition and new responses of NEW words and to false recognition and new responses of NEW words in the early (300–500 ms), middle (500–700 ms), and late (1200–1600 ms) time interval for the Category Group in Experiment 2.

negativity for false recognition between 700 and 1200 ms in the Item Group (Fig. 5). Separate two-way ANOVAs, with the factors Condition (two levels: true recognition or false recognition, new responses of NEW words) and ROI (six levels) were conducted for each group in this time interval. The analyses revealed a parietal negativity to false recognition in the Item Group only. Separate tests for different ROIs, based on a significant Condition×ROI interaction ($F(5, 85)=7.38$, $P<0.001$), indicated more negative going waveforms at right, left and medial parietal ROIs.

3.3. Discussion 2

Experiment 2 was performed to determine if differences in encoding focus lead to differential ERP patterns for true and false recognition.

Participants in the Category Group made fewer false alarms to NEW words and higher confidence ratings to correct rejections of NEW words than participants in the Item Group, indicating that categorical information, i.e. conceptual similarity, was used to a larger extent by participants in the first group. This pattern of results suggests our encoding manipulation was successful.

Even though false recognition rates were similar for the Category Group and the Item Group, there were differences in the ERP patterns elicited in the two groups. In support of our hypotheses, true and false recognition elicited similar old/new ERP effects in the Category Group, and different old/new ERP effects in the Item Group.

When participants focused attention mainly on the categorical relations of the studied items (Category Group), brain activity and, consequently, the underlying cognitive processes, were equivalent for true and false recognition. Both forms of recognition were based on familiarity, as indicated by similar early fronto-medial ERP effects, as well as on recollection of item specific memory traces, as indicated by similar parietal ERP-effects.

However, when participants focused attention on item specific information, i.e. distinctive features of concepts activated by the animacy judgments (Item Group), true and false recognition could be separated on the basis of their

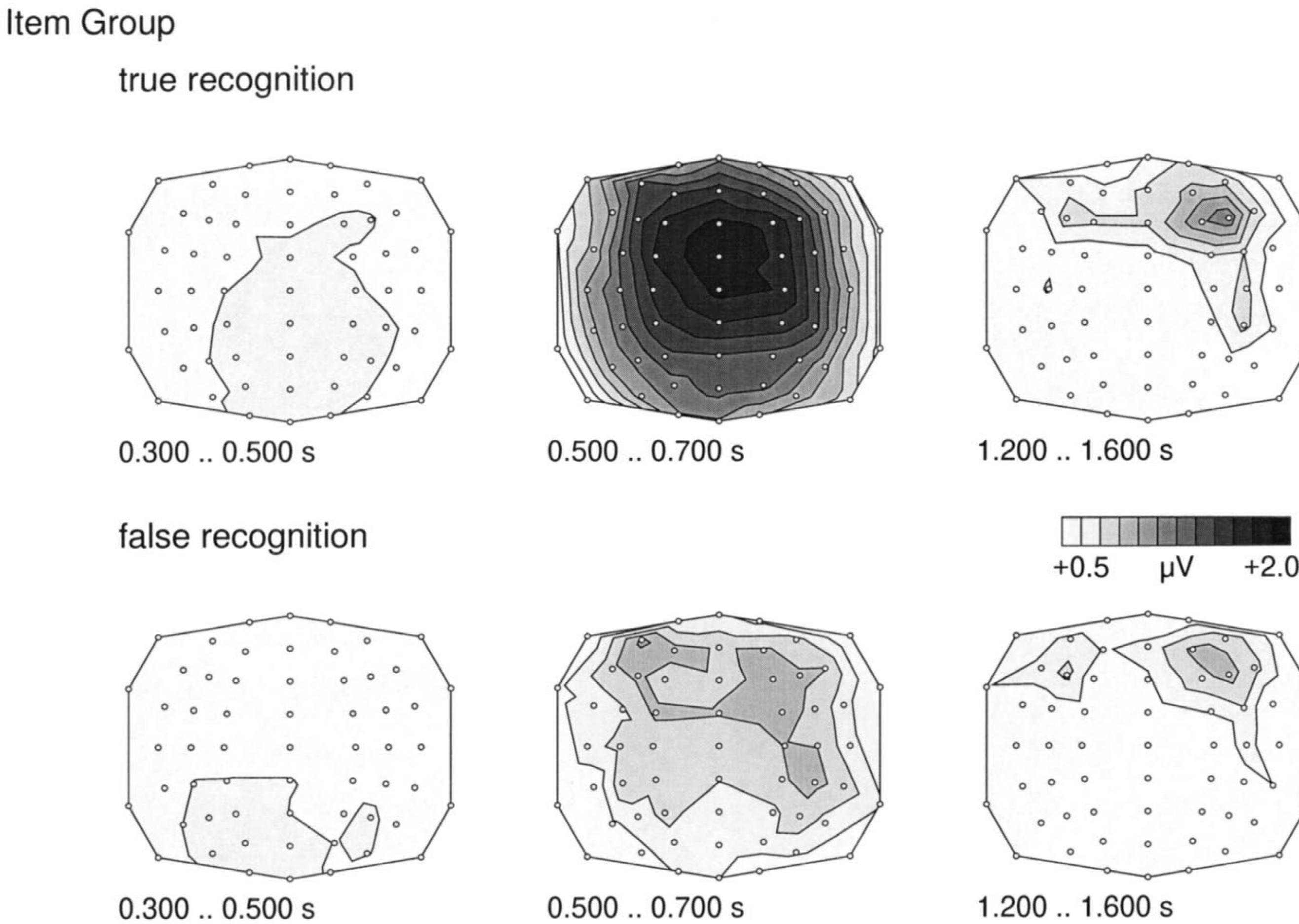

Fig. 7. Topographic distributions of the difference waves for ERPs to true recognition and new responses of NEW words and to false recognition and new responses of NEW words in the early (300–500 ms), middle (500–700 ms), and late (1200–1600 ms) time interval for the Item Group in Experiment 2.

brain activity. In the Item Group, there was an early fronto-medial ERP effect for true but not for false recognition. LURE words might not appear to be familiar, because participants were not focused on categorical relations in encoding. Accordingly, the similar early ERP waveforms for new and old responses of LURE words indicated that it was not familiarity that drove false recognition in this condition. There was a parietal old/new ERP effect for true, and, interestingly, also a smaller one for false recognition. The small parietal positivity in the absence of a frontal effect obtained for false recognition in the Item Group may indicate that automatic spreading activation, that is activation elicited by the exposure of a related word without the need to focus on categorical relations, can lead to recollection based false recognition and that this form of recollection can occur without an accompanying familiarity process. There is some evidence for the occurrence of conscious recollection in the absence of familiarity ([22,30], cf. [1]).

Compared to new responses of NEW words, both forms of recognition showed at least trends for more positive going waveforms at right frontal locations in a late time window (1200–1600 ms), but did not differ from each other in either group. Finally, the Item Group showed a late parietal negativity (700–1200 ms) for ERPs for false recognition compared to ERPs for new responses of NEW words. Possible functional implications of both the late frontal and late parietal ERP effects are addressed in the General discussion.

In sum, the results of Experiment 2 suggest that differences in ERP patterns for true and false recognition depended on strategic aspects during encoding. If participants focused attention on categorical relations of the studied items (Category Group), then true and false recognition were based on both familiarity and recollection processes. However, brain activity for false recognition in a group focusing more on item specific information (Item Group) indicated recollection but not familiarity based false recognition.

4. General discussion

Taken together, the results from the group analysis of Experiment 1 and the results from Experiment 2 support the view that participants differentially encoded categorical relations of the studied words. When participants had high

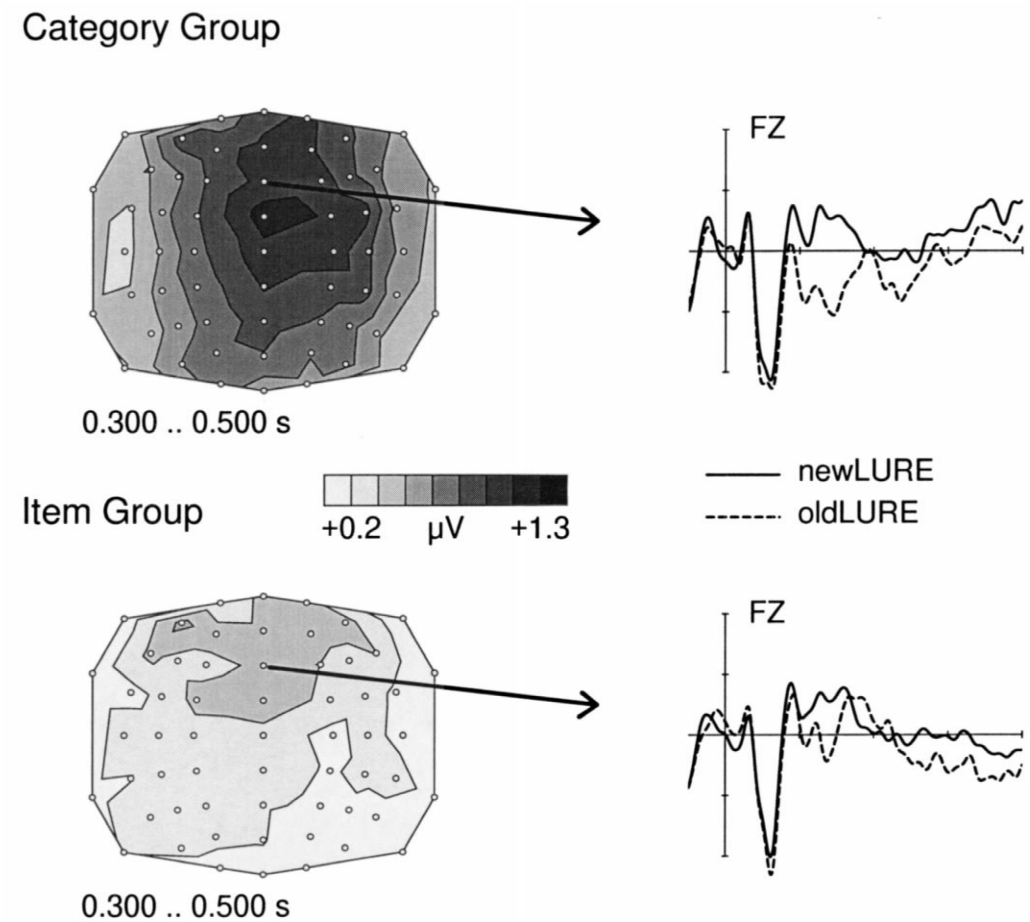

Fig. 8. Topographic distribution of the difference waves for ERPs to false recognition and new responses of LURE words for the Category Group and for the Item Group in the early (300–500 ms) time interval (left). The corresponding ERPs are plotted for a middle frontal (Fz) electrode site (right).

false recognition rates (Experiment 1), suggesting the use of categorical relations, or when participants directly focused on categorical relations (Experiment 2; Category Group) ERP effects for true and false recognition were similar (see results summary in Table 6).

This outcome resembles ERP results obtained in prior studies with the Deese paradigm [12,24]. Therefore, true and false recognition seem to be based on both familiarity and recollection processes in experiments in which participants might focus their attention on information that items have in common, i.e. their categorical relationship.

When participants used more item specific information, as is probably the case for the low false recognition group in Experiment 1 and the Item Group in Experiment 2, differential ERP patterns arose for true and false recognition. The absence of an early fronto-medial ERP effect for false recognition in both groups indicates that these words did not elicit feelings of familiarity. The absence of a

Table 6
Across experiment comparison[a]

	Experiment 1							Experiment 2				
	All participants (*N*=22)			High false recognition (*N*=10)		Low false recognition (*N*=10)		Category group (*N*=18)		Item group (*N*=18)		
Recognition	True		False	True	False	True	False	True	False	True		False
Early frontal	+		+	+	(+)	+	−	+	+	+		−
Middle parietal	+	>	+	+	+	+	−	+	+	+	>	+
Late right frontal	+		+	−	+	+	−	+	(+)	+		(+)
Late parietal	−		+	−	−	−	+	−	−	−		+

[a] Note: +, significant old/new effect; (+), marginally significant old/new effect; −, no old/new effect; <,>, statistical differences in old/new effects. Patterns of mean differences of the old/new ERP effects elicited by true and false recognition for all participants in Experiment 1, for the group with high false recognition rates in Experiment 1, for the group with low false recognition rates in Experiment 1, and the Category Group and the Item Group in Experiment 2.

parietal ERP-effect in the low false recognition group in Experiment 1 suggests recollection based false recognition also failed to occur. However, the small effect for the Item Group suggests that recollection based false recognition in the absence of familiarity ([30], cf. [1]) did occur in this case. The view that there might be some differences between the two groups is also reflected by the higher false recognition rate in the Item Group than in the low false recognition group in Experiment 1. Although it was shown that encoding strategy influences neuronal activity for false recognition, the different assignment to the groups in both Experiments might be responsible for mentioned differences between the low false recognition group and the Item Group.

In sum, the results indicate that strategic differences in the encoding of categorical information can influence brain activity for false recognition. This view confirms and extends a proposal, made by Johnson et al. [24], that was based on a manipulation of testing conditions rather than encoding strategy. They compared brain activity for true and false recognition in a blocked test presentation (LURE words and OLD words appeared in different test blocks) with brain activity in a random word order test presentation using word lists from the Deese paradigm. Although there were no ERP-differences for true and false recognition in the random design, ERP waveforms were more positive for true than for false recognition between 50 and 775 ms and 775–1500 ms in the blocked design. The authors suggested that judgments in the random design were based mainly on an overall feeling of familiarity that arose due to focusing attention on conceptual similarity. Our interpretation for the group with high false recognition rates (Experiment 1) and for the Category Group (Experiment 2) is consistent with this view.

In addition to the aforementioned medial-frontal and parietal old/new ERP effects there were pronounced positive differences at right frontal recordings sites in the late time window (1200–1600 ms). However, the pattern of right frontal effects for true and false recognition differed across Experiments and groups (cf. Table 6). In Experiment 1, participants with high false recognition rates showed a right frontal old/new ERP effect for false but not for true recognition, suggesting that searching for and accessing weaker representations in memory requires more retrieval effort. This result supports the retrieval effort account of the frontal slow wave [19,58,62]. In contrast, the ERP waveforms for participants with low false recognition rates were more in line with the retrieval success account [3,56,71]. In this group, there was a right frontal old/new effect for true but not for false recognition. In Experiment 2, both true and false recognition showed more positive ERP waveforms relative to NEW words in a late time window (1200–1600 ms) irrespective of encoding instruction, challenging both the retrieval effort and the retrieval success account. Although ERP measures do not allow a precise localization of the neural regions that contribute to scalp-recorded ERPs, the effect found at right frontal electrodes is assumed to reflect the involvement of the right prefrontal cortex in episodic retrieval tasks [36,56]. A similar view has been proposed based on neuropsychological findings with patient B.G., who had an infarction in right frontal lobe [8,59]. While B.G.'s true recognition was not impaired, he showed large false recognition rates to semantically related items. The authors assumed an over-reliance on familiarity resulting from deficits in monitoring memory contents. Therefore, the late right frontal ERP effect for true and false recognition found in the present study may reflect monitoring or evaluation processes required for old responses to studied and non studied words that share semantic features. However, the differential pattern of effects found in both experiments indicate that the involvement of right frontal cortex may additionally depend upon cognitive operations set by a specific retrieval context [36,70].

Interestingly, there was a late parietal negativity elicited by false recognition only for participants with low false recognition rates in Experiment 1 and in the Item Group in Experiment 2. Wilding and Rugg [72] reported a similar parietal negativity for false alarms in a memory exclusion task. Because reaction times were longer for false alarms relative to correctly recognized target words, the authors suggested that the negativity reflected response related processes rather than mnemonic processes. However, although reaction times for false recognition were longer than for true recognition or new responses to NEW words, the view of a response related process does not explain the absence of a negative slow wave for participants with high false recognition rates in Experiment 1 and in the Category Group in Experiment 2. Düzel et al. [12] found a similar negativity between 600 and 1000 ms for true and false recognition that attracted a 'Know' response (cf. [67]). Further, Rubin et al. [53], using conjunction LURE words, found that ERPs for false recognition were more negative than for true recognition between 600 and 900 ms. Unfortunately, neither study offered an clear explanation of the effect.

Interestingly, a prior fMRI study from our lab, contrasting BOLD responses for false recognition with new responses of NEW words, revealed significant activation in the anterior cingulate cortex (ACC) [38]. To examine whether ACC activity accounts for the bilateral negative slow wave in the present experiments dipole analyses were performed. A single dipole was placed at the Talairach coordinates of the ACC activation for false recognition relative to new responses of NEW words reported by Mecklinger et al. [38][3]. Dipole orientation and strength were fitted in the ERP difference waveforms (false recog-

[3]Dipol analyses were performed with the Programm CURRY 4 (NeuroScanLabs). A realistically shaped head model with three volumes was developed using the Boundary Element Method [14]. The Talairach coordinates used for the dipole analyses were x: −9 mm, y: 8 mm, z: 40, and the dipole was allowed to vary in location within a sphere with 5 mm radius.

nition minus new responses of NEW words) for the low false recognition rate group (Experiment 1) and the Item Group (Experiment 2). The single dipole model accounted for 87.5% of the variance in the difference wave between 900 and 1200 ms for the low false recognition group. The dipole analysis for the negative slow wave of the Item Group in the 700–1200 ms time range revealed 88.35% explained variance. The ACC is considered as a part of an attention network ([4] cf. [36]) and is active under conditions of high task demands and remote memory requirements [44]. In the present experiments the ACC activation for the two mentioned groups, which were assumed to focus mainly on the recollection of item specific features from the study phase to evaluate their recognition responses, may reflect the attentional modulation of an enhanced response conflict. This conflict may have been caused by old responses to categorically familiar words (LURE) in the presence of little or no conscious recollection of item specific information.

4.1. Conclusions

The present studies were performed to examine the contribution of familiarity and conscious recollection to false recognition judgments. The results indicated that focusing on categorical relations of the study words lead to true and false recognition that were driven by both familiarity and recollection. True and false recognition could not be differentiated on the basis of ERP waveforms, supporting prior ERP studies performed with the Deese paradigm [12,24]. Conversely, ERP effects for false recognition that were different from those elicited by true recognition were obtained when participants focused on item specific information activated by animacy judgments during encoding rather than on categorical relations. ERP waveforms in this condition revealed some recollection based false recognition, but there was no evidence for familiarity based false recognition. In sum, it is the strength of the use of conceptual similarity that drives the neuronal differences between true and false recognition.

Acknowledgements

This work was supported by the Leibniz-Prize of the German Research Foundation awarded to Angela D. Friederici, Director at the Max-Planck-Institute of Cognitive Neuroscience. We wish to thank Ina Koch, Arlett Schueller, and Kerstin Weber for their valuable assistance in data collection.

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