*Psychophysiology, 40* (2003), 146–159. Blackwell Publishing Inc. Printed in the USA.


# ERP correlates of true and false recognition after different retention delays: Stimulus- and response-related processes

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**Abstract**

Performance and electrophysiological correlates of true and false recognition were examined after short (40 s) and long (80 s) delays. True recognition showed no significant decrease after a long delay, whereas false recognition increased. Early frontal and parietal ERP old/new effects, considered as correlates of familiarity and recollection, were observed across delay for true recognition. No frontal effect occurred in the long delay for false recognition. This absence may arise from weakened memory traces preventing familiarity discrimination for LUREs. Response-related analysis revealed an error-related negativity (ERN) for true and false recognition, assuming that the effect reflects at least partly an internal misrepresentation of the correct response. The larger and topographically different ERNs for false recognition suggest an additional contribution of increased task demands and conditions of high response uncertainty.

**Descriptors:** Event-related potentials, False recognition, Retention delay, Familiarity, Recollection, Error-related negativity

Recently the study of false memory has been considered especially useful while investigating the nature of basic memory processes. Accordingly, there has been an increase in the amount of research examining different kinds of memory distortions, by means of electrophysiological and neuroimaging measures in addition to behavioral techniques (for overviews, see Lampinen, Neuschatz, & Payne, 1998; Reyna & Lloyd, 1997; Schacter, Norman, & Koutstaal, 1998). A majority of these studies are concerned with false recognition arising from a semantic overlap between study and test items (e.g., Mather, Henkel, & Johnson, 1997; Robinson & Roediger, 1997). In the typical task of such studies, participants learn lists of semantically associated words of a nonpresented word, the so-called LURE word (cf. Deese, 1959). In a subsequent memory test, participants falsely recognize the LURE words at a much higher rate than words unrelated to the study lists (e.g., McDermott, 1996; Payne, Elie, Blackwell, & Neuschatz, 1996; Read, 1996). (In the following, false alarms to LURE words will be labeled "false recognition" and old responses to previously studied OLD words will be labeled "true recognition.") Rates of false recognition exceeded 70% in some conditions and were nearly as high as rates of true recognition (e.g., Payne et al., 1996; Roediger & McDermott, 1995). Moreover, participants are often as confident in these false recognitions as they are in their true recognitions (e.g., Roediger & McDermott, 1995). In some studies, participants were also asked to indicate whether an old response was based on consciously recollected aspects of prior experience, that is, a memory trace ("remember" response), or merely in the belief that a test word had appeared in the study list without any specific recollection of the encoding episode, that is, familiarity ("know" response, cf. Tulving, 1985). Surprisingly, rates of remember responses did not differentiate between true and false recognition (cf. Payne et al., 1996; Roediger & McDermott, 1995). Participants are also willing to report that a LURE word had been presented in a male or in a female voice even when the word had in fact not been presented (Payne et al., 1996). In sum, such results suggest that true and false recognition might be based on similar cognitive processes.

Event-related potentials (ERPs) can provide direct measures, with a temporal resolution on the level of milliseconds, of the neural activity associated with cognitive processes involved in true and false recognition (e.g., Donchin, Spencer, & Dien, 1997; Johnson, 1993; Rugg & Coles, 1995). Initially, ERP studies

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. All steps of data collection were performed at the Max-Planck-Institute of Cognitive Neuroscience in Leipzig, Germany. We thank Arlett Schueller and Lutz Munka for their assistance in data collection and Markus Ullsperger and Martin Duff for their valuable comments on earlier versions of the manuscript.

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reported similar waveforms for true and false recognition, suggesting similar neural processes (Düzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Johnson et al., 1997). However, more recent studies have reported distinct electrophysiological responses depending upon the particular manipulations used. Fabiani, Stadler, and Wessels (2000) report that retrieval of true memories but not of false memories leads to lateralized brain activity in a recognition test with central presentation, reflecting the lateralized encoding of studied words. The authors argue that true memories may leave a sensory signature that makes each memory trace distinctive, whereas false memories lack such a distinctive feature. If these features are consciously accessible, it may lead to the use of strategies that allow participants to distinguish false from true memories (cf. Schacter, Isreal, & Racine, 1999). In a study in which words from semantic categories were used, investigators also found differences between ERPs to true and false recognition (Nessler, Mecklinger, & Penney, 2001). Specifically, the results of Experiment 1 showed highly similar ERP effects for true and false recognition in a group with a high proportion of false alarms to LURE words, whereas ERP differences occurred in a group with a low proportion of false alarms to LURE words. The authors interpreted these differential effects as a reflection of strategic differences during encoding. This assumption was supported in Experiment 2, where ERP effects for true and false recognition were identical in a group of participants focusing on categorical features during encoding whereas differences were evident in a group of participants focusing on item-specific features.

In the present study, we examined the effects of memory delay on the ERP correlates of true and false recognition. Previous studies have shown that larger retention intervals lead to decreases in true recognition performance, that is, to smaller accuracy and to longer reaction times (Friedman, 1990; Friedman, Berman, & Hamberger, 1993; Nielsen-Bohlman & Knight, 1995; Poon & Fozard, 1980; Swick & Knight, 1997). If it is based on cognitive processes similar to those underlying true recognition, false recognition should also decrease with increased memory delays. Conversely, if different processes contribute to true and false recognition, the two forms of recognition could be differentially affected by a delay manipulation. In support of the former view, Lampinen and Schwartz (2000) report a decrease in true and false recognition after 48 h. A more recent study examined rates of true and false recognition after 0, 2, and 7 days (Thapar & McDermott, 2001). The authors also report a decrease for rates of true and false recognition. However, in both studies, the decline in false recognition was less pronounced than the decline in true recognition. Payne et al. (1996) report decreasing rates of true recognition but stable rates of false recognition after a 24-h retention interval. Moreover, another study showed a decrease in the rate of true recall but an increase in the rate of false recall after a delay of 1 day (McDermott, 1996). In sum, the studies examining true and false recognition under different retention intervals do not provide a clear answer to the question of whether true and false recognition can be dissociated by delay manipulations.

Although there is, to our knowledge, no study examining ERPs to false recognition after different retention delays, some studies have compared ERPs elicited by true recognition. For instance, Rugg and Nagy (1989) presented a series of words in which items were repeated after 6 or 19 intervening words. Participants were required to make old/new discriminations to every word. In line with other ERP studies examining the effects of explicit old/new recognition tests (for reviews, see Johnson, 1995; Rugg, 1995; Rugg & Allan, 2000), ERPs to true recognition were more positive going, from around 250 ms poststimulus, than those to correctly rejected NEW words (new responses to NEW words). These positive differences are called ERP old/new effects and are assumed to be comprised of a frontally focused N400-like component (early frontal ERP old/new effect), which is attenuated with repetition, and a late parietally focused positive component (parietal ERP old/new effect), which is enhanced by repetition (Rugg, 1990; Rugg & Doyle, 1994; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991; for reviews, see Friedman & Johnson, 2000; Mecklinger, 2000).

There is increasing evidence that the different spatiotemporal patterns of old/new effects are associated with different subcomponents of recognition memory (cf. Mecklinger, 2000). For example, early midfrontal old/new effects have been shown to be insensitive to depth of processing manipulations (Rugg et al., 1998), an effect suggesting an association with a feeling of familiarity (see also Johnson, Kreiter, Russo, & Zhu, 1998; Ullsperger, Mecklinger, & Müller, 2000). This view is further supported by results showing that the frontal positivity arises not only for studied items but also for erroneously classified plurality reversed LURE words (e.g., "dog" when "dogs" was studied; Curran, 2000) and semantically related but nonstudied LURE words (Nessler et al., 2001). These effects are accounted for by assuming that words that are semantically related to studied words attenuate the search in semantic memory and that this process is reflected by a decrease of a frontally focused N400-like component, that is, the FN400 (Curran, 2000; Mecklinger, 2000; Windmann & Kutas, 2001). Notably, similar modulations of frontally distributed N400-like components are found for concrete nouns (Holcomb & McPherson, 1994) or photographs and line drawings of objects in perception and memory tasks (Ganis, Kutas, & Sereno, 1996; Mecklinger, 1998), suggesting that, depending on task context and stimulus condition, a variety of processes contribute to these frontally focused negativities.

In contrast, the strength of the parietal ERP old/new effect depends on manipulations that enhance recollective experience, that is, remembering specific episodes (e.g., Smith, 1993; Ullsperger et al., 2000; Wilding & Rugg, 1996). The effect correlates with hit rate and decision confidence (Johnson et al., 1998) and is sensitive to depth of processing manipulations (Paller & Kutas, 1992; Paller, Kutas, & McIsaac, 1995), suggesting that the parietal ERP old/new effect is associated with the active recollection of item specific information (for an overview, see Friedman & Johnson, 2000; Mecklinger, 2000).

Rugg and Nagy (1989) report no differences in ERP old/new effects elicited after 6 (about 36 s) and 19 (about 114 s) intervening items. However, a delay of 45 min was sufficient to abolish the early frontal effect whereas the parietally focused old/new effect was still present after this long delay. Friedman and colleagues (1993) repeated words after 2, 8, or 32 intervening items. The early frontal ERP effect was unaffected by these lag manipulations, whereas the late positive component diminished similarly in young and elderly participants. Swick and Knight (1997) investigated the ERPs elicited by words and nonwords in a continuous recognition task, with item repetitions after short (1–3 items) and long delays (9–19 items). In this study the old/new ERP effects decreased for all participants with increasing delay. Interestingly, elderly participants showed smaller ERP effects than young participants in both delays. There was no early

ERP old/new effect (300–500 ms) for elderly participants and a late old/new ERP effect was only elicited in the short delay (for similar results, cf. Rugg, Mark, Gilchrist, & Roberts, 1997; for a review, see Friedman, 2000).

In the present study, we examined whether ERP old/new effects to false recognition show similar changes as ERPs to true recognition after different retention delays. Similar to the delays used in prior continuous recognition studies (e.g., Friedman et al., 1993; Rugg & Nagy, 1989) retention delays of 40 and 80 s were chosen. As revealed by animal and patient studies, tasks with retention delays of this length can be assumed to require access to long-term memory structures (cf. Alvarez-Royo, Zola-Morgan, & Squire, 1992; Mecklinger, von Cramon, & Matthes-von Cramon, 1998).

In addition to the issue of how delay manipulations influence performance and electrophysiological correlates of true and false recognition, we also examined response-related ERPs for true and false recognition. Prior research has reported electrophysiological evidence for a brain mechanism dedicated to monitoring performance and compensating for errors (e.g., Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990; Gehring, Goss, Coles, Meyer, & Donchin, 1993). An ERP-component, the so-called error-related negativity (ERN) is usually elicited when participants commit an error in reaction time tasks. The ERP is characterized by a negative peak about 50 to 100 ms following erroneous responses, and source-localization studies suggest that it is generated in the anterior cingulate cortex (ACC). As the ERN is elicited by incorrect responses in a wide variety of tasks, it is assumed to reflect a highly flexible error processing and response monitoring system (Holroyd & Coles, in press). In the present study, we examined whether the ERN is also elicited by incorrect responses in recognition memory tasks.

## Methods

### Participants

Fifteen right-handed volunteers (6 female) between 20 and 30 years of age (mean 23 years) participated. They were students at the University of Leipzig, had normal or corrected-to-normal vision, and reported to be in good health. All participants provided informed consent and were paid 12 DM/h for their participation. None of the participants had prior experience with the task.

### Experimental Materials

The present experiment used 10 German nouns from each of 30 categories (300 words; see also Nessler et al., 2001). The words were taken from a categorical word pool that was created in a noun-generation experiment performed with 139 undergraduate students at the University of Leipzig, between 18 and 34 years old (mean = 22, cf. Ullsperger et al., 2000). Words length ranged from 3 to 11 letters and only the 10 most typical exemplars (based on the number of generations across participants) were selected. The mean number of generations across the categories ranged from 30.6 to 117.2.

The words were used to construct four different stimulus lists, each comprised of 10 study–test trials. Each trial consisted of a study phase, a delay, and a recognition test phase. One study phase consisted of 12 words, that is, 4 words from three different categories each (e.g., randomized presentation of *Amsel, Star, Papagei, Meise*—category bird, English: blackbird, starling, parrot, titmouse; *Kamm, Deodorant, Rasierer, Schminke*—category beauty care, English: comb, deodorant, shaver, make-up; *Haus, Laube, Hotel, Palast*—category housing/buildings, English: house, arbor, hotel, palace). The delay lasted either 40 or 80 s. The respective test phase included 10 words from the 12 studied words (OLD words), 2 nonstudied words from each of the three studied categories (6 LURE words, e.g., *Fink, Drossel, Creme, Bürste, Zelt, Hütte*—English: finch, thrush, creme, brush, tent, hut), and 1 nonstudied word from each of eight nonstudied categories (8 NEW words, e.g., *Hummel, Moped, Mango, Basilikum, Aal, Erbsen, Fussball, Gitarre*—English: bumble bee, moped, mango, basil, eel, peas, soccer, guitar). Consequently, each list (i.e., 10 study–test trials) consisted of 100 OLD words, 60 LURE words, and 80 NEW words. Study categories were randomly assigned to the 10 study–test trials of each list version. Each category appeared only once as a study category in each list and words also appeared only once in each list, given the repetition of studied words in the test phase of the respective trial. The duration of the delay in each trial was randomized, with five short (40 s) and five long (80 s) delays in each list.

### 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 all four lists. Two lists were performed on a first day and the remaining two on a second day. The sequence of the different lists was counterbalanced across participants. The two sessions were separated by from 3 to 8 days.

In each study phase, participants heard nouns, spoken by a female voice at a rate of one word every 3 s. Prior to the test phase of each study–test trial, participants counted loudly backwards starting from a digit presented on the screen. This delay randomly lasted 40 or 80 s. In the recognition test, the words were presented visually to control for sensory-based priming effects. Words appeared in a quasi-random order with the constraint that no more than two words of the same type (OLD, NEW, LURE) were presented consecutively. Each word presentation in the test phase started with a fixation cross in the middle of the screen. After 200 ms, the screen went blank for 400 ms and then the word was presented visually for 500 ms. The 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. Response hand was counterbalanced across participants. After a 2,500 ms blank screen interval, participants received feedback. A green (+) was presented for correct answers for 200 ms and a red (−) for incorrect answers. A blank screen followed for another 1,000 ms before the next trial started. Participants were given a short break between the two lists that were performed on one day. Including electrode application and removal the sessions on each day lasted about 2.5 h.

### ERP Recording

EEG activity was recorded with Ag/AgCl electrodes mounted in an elastic cap (Electrocap International) from 61 scalp sites of the extended 10–20 system. Electrode labeling was based on the standard nomenclature of the 10-20 system (Sharbrough et al., 1990). The ground electrode was positioned 2 cm to the right of Cz. The vertical electrooculogram (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 kΩ. The right mastoid was recorded as an additional channel. All scalp electrodes were referenced to the left mastoid and were rereferenced offline to both mastoids. EEG and EOG were recorded continuously with a bandpass from DC to 30 Hz and were A-D converted with 16-bit resolution at a sampling rate of 250 Hz.

### *Data Analysis*

*Behavioral data.* Reaction time was defined as the interval between the appearance of the test item and the participant's key press. Data were averaged separately for old and new responses to OLD, LURE, and NEW words.

*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 1,600 ms thereafter. The average voltages in the 200 ms preceding stimulus presentation served as 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. ERPs were selectively averaged for the following combinations of item types and responses: old responses to OLD words (true recognition), old responses to LURE words (false recognition), new responses to LURE words, and new responses to NEW words. The range of trials that entered the individual averages were as follows: true recognition, short delay 81–163, long delay 73–160; false recognition short delay 7–39, long delay 8–41; new responses to LURE items short delay 40–101, long delay 36–92; new response to NEW items short delay 66–145, long delay 63–146. 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.

**Table 1.** *Mean Reaction Times and Mean Proportion Rates of the Old and New Responses for the Different Item Types in the Short and Long Retention Delay Conditions*

| Delay | Item type | Response | Reaction time (ms) | Proportion rates |
|---|---|---|---|---|
| 40 | OLD | old | 743.8 (44.2) | 87.27 (1.50) |
| | | new | 1,019.3 (78.4) | 12.67 (1.47) |
| | LURE | old | 959.0 (67.3) | 17.72 (2.43) |
| | | new | 850.3 (56.2) | 82.17 (2.44) |
| | NEW | old | 823.6 (102.0) | 1.58 (0.60) |
| | | new | 749.3 (45.9) | 98.33 (0.67) |
| 80 | OLD | old | 755.9 (45.6) | 85.87 (1.74) |
| | | new | 1,006.8 (82.0) | 13.97 (1.66) |
| | LURE | old | 979.6 (68.8) | 21.33 (2.52) |
| | | new | 861.3 (56.7) | 78.44 (2.55) |
| | NEW | old | 944.7 (117.5) | 2.00 (1.09) |
| | | new | 764.6 (46.9) | 97.88 (1.18) |

*Note*: The standard error of the mean is presented in parenthesis.

Stimulus-related ERP waveforms were quantified using averaged voltages (Hoormann, Falkenstein, Schwarzenau, & Hohnsbein, 1998). Time windows and electrode positions used for statistical analyses were based on descriptive effects obvious in the measured ERP waveforms and are described in the respective Results sections.

Statistical analyses focused on ERP old/new effects for true and false recognition, that is, ERPs to both kinds of recognition were compared to the ERPs to correct rejections of NEW items. For this, three-way repeated measures ANOVAS with the factors delay (2 levels: short delay, long delay), item type (2 levels: true or false recognition, new responses to NEW words), and electrode location (for used levels and electrodes, see respective Result section) were used. To avoid reporting large numbers of statistical results irrelevant to the issues under investigation, only main effects or interactions, including the factor item type, will be reported. In the event of significant interactions involving the factor item type, two-way and, if appropriate, one-way ANOVAs were performed to examine the effects in each delay condition and at each topographical region. Measures of treatment magnitude ($\Omega^2$, cf. Keppel, 1991) for these 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–Geisser formula (Greenhouse & Geisser, 1959). Scalp potential topographic maps were generated using a two-dimensional spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989) and a radial projection from Cz, which represents the length of the median arcs.

## Results

### *Behavioral Data*

Mean reaction times and proportion of old and new responses to OLD, LURE, and NEW words are presented separately for the two different delays in Table 1. Participants showed more false alarms to LURE words (false recognition) than to NEW words in both delay conditions. Performance decreased, although only slightly, in the long delay condition for all item types. This is especially noticeable in rates of false alarms to LURE words (false recognition). Responses for all item types were slower in the long delay condition compared to short delays.

To examine the decrease in performance between long and short delay conditions, a two-way repeated-measure ANOVA with the factors delay (2 levels; short delay, long delay) and item type (3 levels; OLD, LURE, NEW words) for the proportion of correct responses was conducted. There was a main effect of delay, $F(1,14) = 8.36$, $p < .05$, indicating more correct responses in the short than in the long delay. Analysis also revealed reliable differences between the three item types, $F(2,28) = 47.60$, $p < .001$, as well as a significant interaction between delay and item type, $F(2,28) = 4.93$, $p < .05$. Separate tests for the different item types revealed more correct responses to LURE words in the short compared to the long delay condition, $F(1,14) = 12.78$, $p < .01$, that is, higher false recognition rates in the long than in the short delay condition that was proved additionally, $F(1,14) = 11.69$, $p < .01$. True recognition rates and rates of new responses to NEW words in both delays failed to reveal statistically significant differences, $ps > .1$, reflecting that the delay manipulation mainly influenced response rates to LURE words. This was also supported by an analysis showing a higher relative false recognition rate (false recognition minus false alarms to NEW words) for the long than for the short delay, $F(1,14) = 5.61$, $p < .05$.

To be consistent with the ERP analyses, reaction times were analyzed for those four response conditions that are relevant for the ERP analyses (true recognition, false recognition, new responses to LURE words, and new responses to NEW words). A two-way repeated-measure ANOVA with the factors delay and item type revealed reliable differences between the two delays, $F(1,14) = 7.39$, $p < .05$, reflecting faster responses for the short than for the long delay. There was also a significant main effect of item type, $F(3,42) = 35.65$, $p < .001$, but no significant interaction between delay and item type, $F(3,42) = 0.17$. Old responses to OLD words and new responses to NEW words, which revealed no reaction time differences in the short and in the long delay, $ps > 0.1$, were faster than responses to LURE words in both delays. Further, reaction times for new responses to LURE words were faster than false recognition, in the short as well as in the long delay, $ps < .001$.

***Event-Related Potentials***

*ERP Old/New Effects to OLD and LURE Words.* Figure 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 to NEW words for the short and long retention delay conditions.

Starting at around 300 ms and extending until 650 ms, the waveforms elicited by true recognition in both delays were more positive than for NEW words. This ERP old/new effect appeared at frontal and parietal locations (cf. Figure 2, top). From around 750 ms until the end of the recording epoch, ERPs for true recognition were more positive at frontal, but more negative at

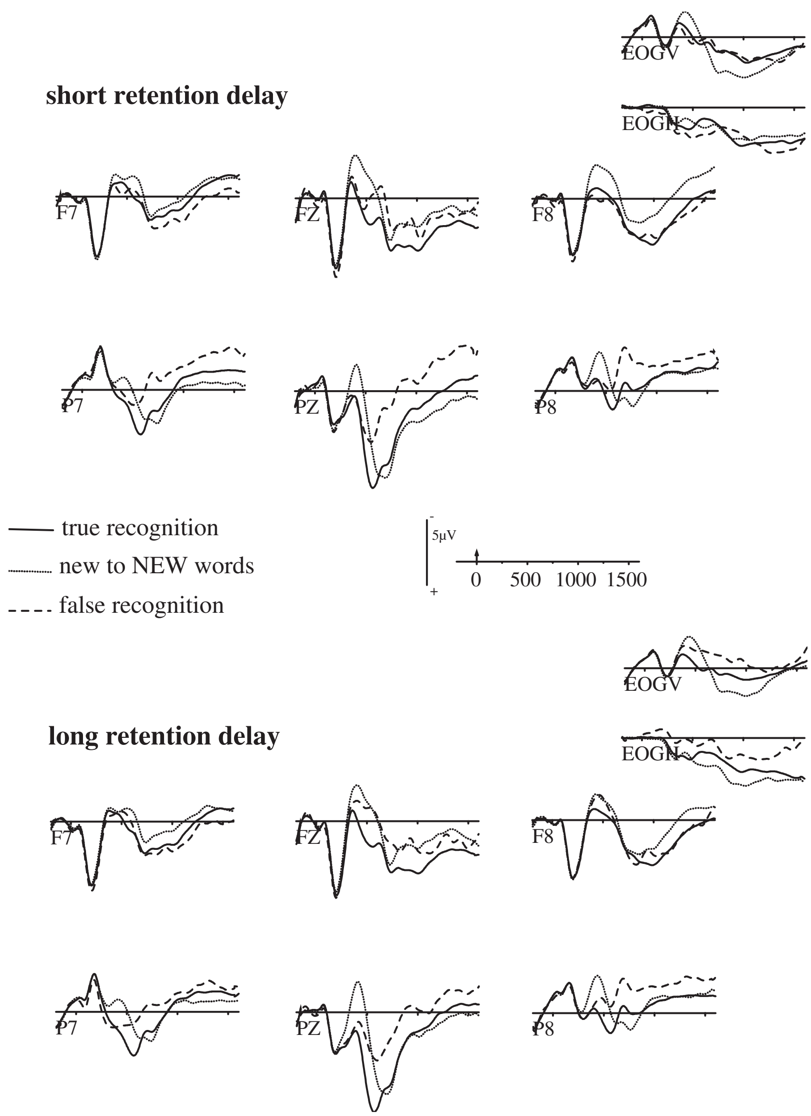


**Figure 1.** ERPs elicited by true recognition, false recognition, and correct rejections to NEW words at left frontal (F7), midline frontal (Fz), right frontal (F8), left parietal (P7), midline parietal (Pz), and right parietal (P8) electrode sites for the short (top) and long retention delay conditions (bottom). In this and the following figures, negative voltages are plotted upwards. All averages were low-pass filtered at 10 Hz for the purpose of presentation.

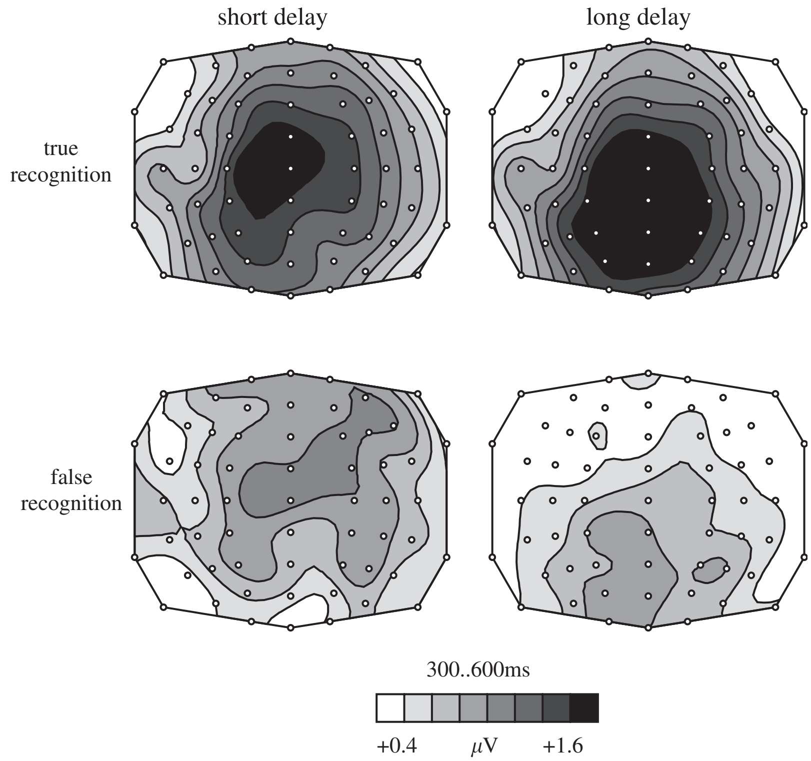


**Figure 2.** Topographic distributions of early (300–600 ms) ERP old/new effects for true recognition (true recognition minus new responses to NEW words; top) and false recognition (false recognition minus new responses to NEW words; bottom) for the short (left) and long retention delay conditions (right).

parietal locations than ERPs for NEW words in both delays. Positive ERP differences relative to NEW words were also obtained for false recognition in both delay conditions between 300 ms and 600 ms. However, whereas the ERP old/new effect was broadly distributed over the scalp in the short delay, the positivity between 300 and 600 ms was mainly restricted to parietal recording sites in the long delay (cf. Figure 2, bottom). Starting at around 800 ms, the ERPs to false recognition were more negative going than to new responses to NEW words at parietal recording sites in both delay conditions. The late parietal negativity to false recognition was larger than the negativity obtained for true recognition in both delays.

These observations are supported by statistical analyses. Based on descriptive results, ERP old/new effects to true and to false recognition were statistically examined in an early (300–600 ms) and a late (1,000–1,600 ms) time window. To capture any anterior/posterior and/or left/right asymmetries, analyses were performed on the data recorded from 18 scalp sites, which were representative for electrophysiological effects obtained in this study. To avoid a loss of statistical power that is implicated when repeated-measures ANOVAs are used to quantify multichannel and multitime window data (Gevins, Cutillo, & Smith, 1995; Gevins et al., 1996; Oken & Chiappa, 1986), electrode sites were pooled to six topographic regions. The following regions were defined: left frontal (F7, F5, FT7), midline frontal (AFz, Fz, FCz), right frontal (F8, F6, FT8), left parietal (TP7, P7, P5), midline parietal (CPz, Pz, POz), and right parietal (TP8, P8, P6). (Note that levels of statistical significance did not change when six single electrodes (F7, Fz, F8, P7, Pz, P8) were used.)

*Statistical analyses in the early time window*. ERP measures were subjected to three-way repeated-measures ANOVAs with the factors delay (2 levels), item type (2 levels: true or false recognition, new responses to NEW words), and topographic region (6 levels: left frontal, midline frontal, right frontal, left parietal, midline parietal, right parietal). Based on the significant three-way interaction for true recognition and based on a trend towards a significant interaction for false recognition (Table 2), separate analyses were performed in each delay.

As can be seen from Table 3, analysis for the short and the long delay also revealed a main effect of item type and an Item Type × Region interaction for true recognition. Separate tests revealed significant ERP old/new effects at all locations in both delays. However, the largest treatment magnitude was found at the midline frontal region ($\Omega^2 = .79$) for the short delay condition, and it was largest at midline parietal locations ($\Omega^2 = .89$) in the long delay. For false recognition, there was a main effect of item type in the short delay condition and there was a main effect of item type and an interaction of Item Type × Topographic Region in the long delay condition (Table 3). Separate tests performed for the long delay condition showed more positive going ERP waveforms for false recognition at parietal regions, $p$s $< .05$, but no significant effect at frontal regions, $p$s $> .1$.

As indicated by these results, ERPs for false recognition were more positive at frontal locations in the short retention delay only. In the long retention delay, there was no difference between ERPs for false recognition and new responses to NEW items at frontal locations.

**Table 2.** *Results for the ANOVA (Delay × Item Type × Region) for Old/New Effects to True and False Recognition in Both Time Windows*

| | $df$[a] | 300–600 ms | 1,000–1,600 ms |
|---|---|---|---|
| True recognition | | | |
| Item type | 1.14 | 107.58*** | 1.21 |
| Item Type × Delay | 1.14 | 0.30 | 0.31 |
| Item Type × Region | 5.70 | 16.27*** | 9.41*** |
| Item Type × Delay × Region | 5.70 | 5.95** | 0.82 |
| False recognition | | | |
| Item type | 1.14 | 13.84** | 0.56 |
| Item Type × Delay | 1.14 | 0.50 | 0.45 |
| Item Type × Region | 5.70 | 1.11 | 8.84*** |
| Item Type × Delay × Region | 5.70 | 2.43(*) | 1.89 |

[a]df: degrees of freedom.
***$p \leq .001$; **$p \leq .01$; *$p \leq .05$; (*)$p \leq 0.1$.

**Table 3.** *Results for the ANOVA (Item Type × Region) for Old/New Effects to True and False Recognition in the Early Time Window for the Short and Long Retention Delay Conditions*

| | $df$[a] | Short delay | Long delay |
|---|---|---|---|
| True recognition | | | |
| Item type | 1.14 | 73.47*** | 82.48*** |
| Item Type × Region | 5.70 | 7.22** | 21.79*** |
| False recognition | | | |
| Item type | 1.14 | 7.49* | 5.50* |
| Item Type × Region | 5.70 | 0.93 | 4.00* |

[a]df: degrees of freedom.
***$p \leq .001$; **$p \leq .01$; *$p \leq .05$.

To further evaluate this differential effect for false recognition at frontal recording sites, another measurement was conducted. ERPs for old and new responses to LURE words were contrasted at frontal locations for both delay conditions. If this differential effect at frontal locations indicates a change in the processes that underlie false recognition, the effect should also be visible when comparing ERPs to false recognition and to new responses to LURE words. Figure 3 displays the topographical distribution of the effect in the early time window for both delays. Statistical analysis revealed a main effect of item type, $F(1,14) = 10.83$, $p < .01$, in the short delay, reflecting more positive-going waveforms to false recognition than to new responses to LURE words. Separate tests that were performed based on a marginal significant interaction of Item Type × Topographic Region, $F(2,28) = 2.87$, $p < 0.1$, indicated significant differences at all frontal topographic regions, $p$s < .05. Statistical analyses for the long delay condition showed no difference between the waveforms for old and new responses to LURE words at frontal locations. There was no main effect of item type and no interaction of Item Type × Topographic Region, $p$s > 0.1.

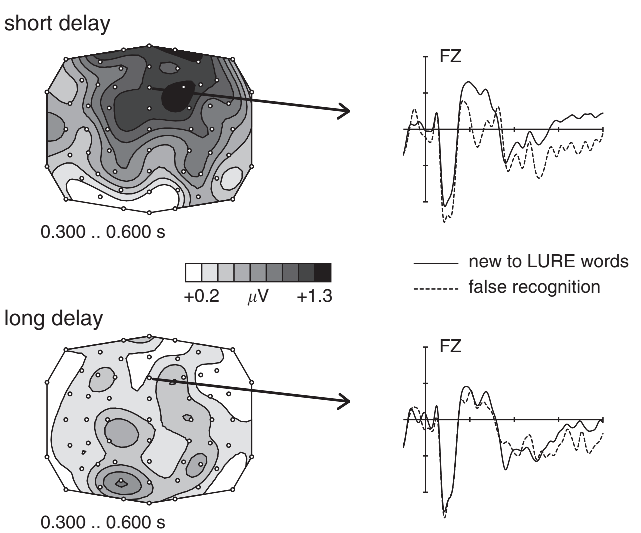


**Figure 3.** Topographic distribution of difference waves for ERPs to false alarms and correct rejections of LURE words in the early (300–600 ms) time interval (left) for the short (top) and long retention delay conditions (bottom). The corresponding ERPs are plotted for a midline frontal (Fz) electrode site (right).

*Statistical analyses in the late time window.* In the late time window (1,000–1,600 ms), ERP measures were subjected to three-way repeated-measures ANOVAs with the factors delay, item type, and topographic region. There was neither a significant three-way interaction of Delay × Item Type × Topographic Region for true recognition nor for false recognition (Table 2). To examine the significant interaction of Item Type × Topographic Region for true and false recognition separate analyses for the different topographic regions were conducted for waveforms averaged over both delay conditions.

Analyses revealed more positive going waveforms for true recognition than for correct rejections of NEW words at midline frontal and right frontal locations, $p$s < .05. At midline parietal and left parietal locations, there were marginally significant effects, $p$s < 0.1, reflecting more negative-going waveforms for true recognition than for correct rejections to NEW words. ERPs for false recognition showed no effect at frontal locations, $p$s > 0.1. However, waveforms for false recognition were more negative than waveforms for new responses to NEW words at left parietal and midline parietal locations, $p$s < .05.

*Response-related activity.* The present study found parietal negative slow waves that started around 800 ms irrespective of delay condition. They were largest for false recognition for which longest reaction times were obtained, but the negative slow waves were also present for true recognition. Similar late parietal negativities were found in previous ERP studies (e.g., Düzel et al., 1997; Johansson, Stenberg, Lindgren, & Rosen, 2002; Wilding & Rugg, 1997), although so far there is no clear explanation of these effects. A fMRI-constrained dipole analysis suggests that the anterior cingulate cortex (ACC) contributes to this late parietal slow wave in the case of prolonged and erroneous responses to LURE words (Mecklinger, Nessler, Penney, & von Cramon, 1999; cf. Mecklinger, 2000; Nessler et al., 2001). Because the ACC is considered to be involved in error detection (Dehaene, Posner, & Tucker, 1994), and because late parietal negativities in the present study were more pronounced for erroneous responses, it is conceivable that response-related processes such as the error-related negativity (ERN; Gehring et al., 1993) contribute to this effect. To examine this issue, response-related averages were created, starting 200 ms before the response was given until 700 ms after. The EEG analysis procedure was the same as for the stimulus-related averages, with the exception that the average voltages in the 200 ms preceding the response served as baseline.

Figure 4 displays the response-related ERP waveforms at six midline electrodes elicited by true recognition, false recognition, and new responses to NEW words. A pronounced negativity was revealed for false recognition peaking around 70 ms after the response at midline central scalp locations. True recognition elicits a negativity relative to new responses to NEW words also, but this effect was smaller than the effect obtained for false recognition in both delays, especially at central and parietal locations.

As in prior analyses, ERPs to true recognition and ERPs to false recognition were each compared to ERPs to correctly rejected NEW words. Statistical analysis was performed for the mean voltage amplitudes between 20 and 120 ms after the response. As the negativities to true and false recognition showed a broad anterior to posterior distribution, six midline electrodes spanning anterior and posterior brain regions (AFz, Fz, Fcz, Cz, Cpz, Pz) were chosen for statistical analysis. Even though prior ERN studies, using easy reaction time tasks, reported fronto-central distributed ERNs (cf. Gehring et al., 1993), we will refer to the present component as an ERN-like component.

The results of the two three-way repeated-measures ANOVAs with the factors delay (2 levels), item type (2 levels: true or false recognition, new responses to NEW words), and electrode (6 levels: Afz, Fz, Fcz, Cz, Cpz, Pz) are shown in Table 4. Based on the significant three-way interaction for true recognition, separate analyses were performed for each delay. In both delays, analyses revealed a main effect of item type, *p*s $< .01$, but no Item Type × Electrode interaction, $p > .1$, indicating similar negative

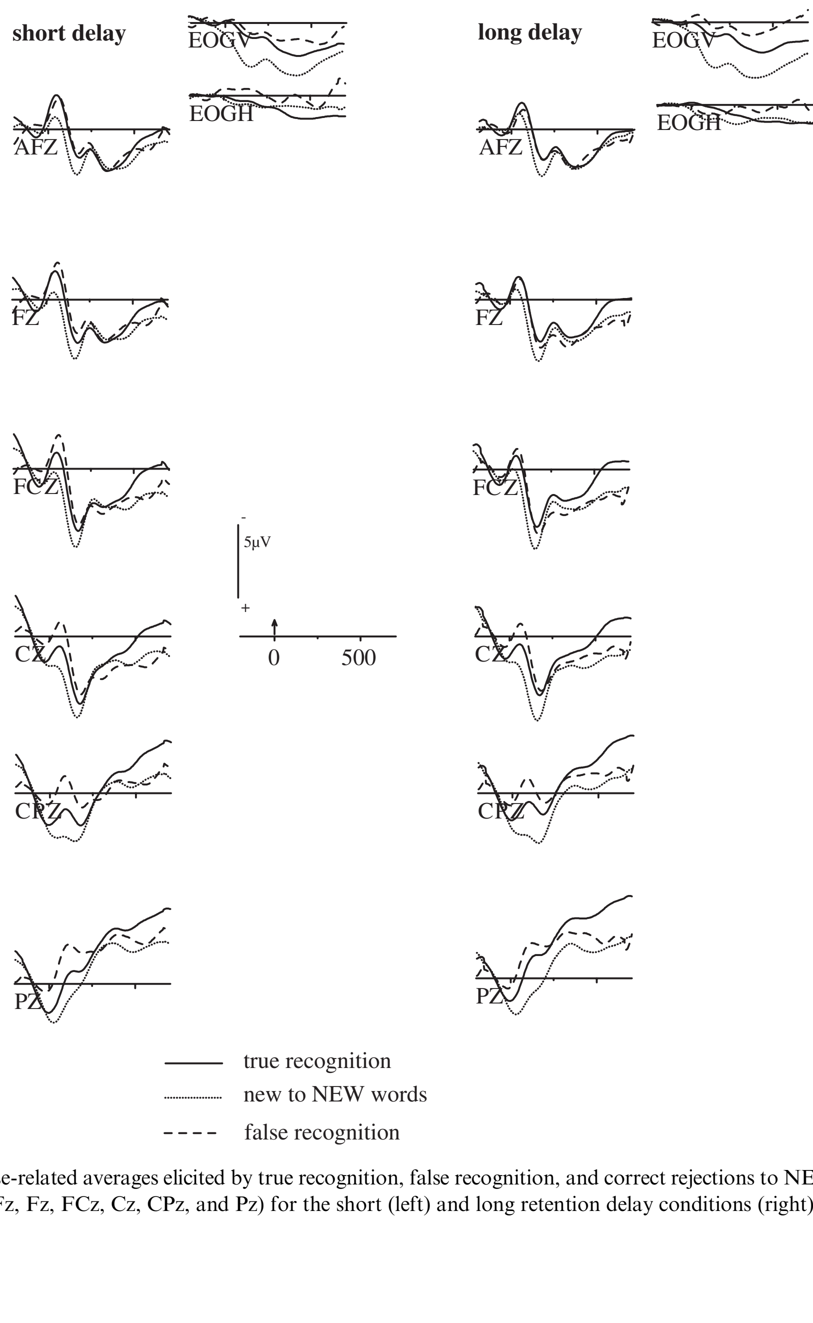


**Figure 4.** Response-related averages elicited by true recognition, false recognition, and correct rejections to NEW words at midline electrode sites (AFz, Fz, FCz, Cz, CPz, and Pz) for the short (left) and long retention delay conditions (right).

amplitude differences at anterior and posterior locations. Negative ERP effects for false recognition were similar in both delays as indicated by the nonsignificant three-way interaction (Table 4). Based on a significant Item Type × Electrode interaction, ERPs were averaged over both delays and separate analyses were performed for each electrode site. ERPs for false recognition were more negative than ERPs for correct rejections to NEW words at all locations. However, treatment magnitude was weakest at AFZ ($\Omega^2 = .30$). and largest at PZ ($\Omega^2 = .42$).

*Comparison of the negative components for true and false recognition*. To directly examine whether the response-related negativity varied in scalp topography for true and false recognition, amplitude differences for true and false recognition (true recognition minus new responses of NEW words, false recognition minus new responses of NEW words, respectively) were compared. The scalp topographies of the difference waves for true and false recognition in both delay conditions are depicted in Figure 5.

A three-way repeated-measures ANOVA with the factors delay (2 levels), difference type (2 levels: waveform to true recognition minus waveform to new responses to NEW words, waveform to false recognition minus waveform to new responses to NEW words), and electrode (6 levels) revealed no significant three-way interaction, $F(5,70) = 0.40$, but a significant Difference Type × Electrode interaction, $F(5,70) = 7.45$, $p < .01$. Based on this interaction, separate analyses for the different electrode sites were performed for the ERP difference waveforms averaged over both delay conditions. Although ERP differences waveforms for true and false recognition showed no effect at Afz, Fz, and FCz, $ps > 0.1$, elicited negativity was larger for false recognition at Cz, CPz, and Pz, $ps < .05$. To examine whether the negativities for true and false responses were generated by different brain structures, a two-way ANOVA with the factors difference type (2 levels) and electrode (6 levels) was performed for the amplitude normalized difference waves (cf. McCarthy & Wood, 1985). There was a significant interaction between Difference Type and Electrode, $F(5,70) = 5.03$, $p < .05$, suggesting that different neuronal sources contribute to the ERN-like negativities for true and false recognition.

To summarize, rates of false recognition increased for the long retention delay whereas there was no significant effect of retention delay for true recognition. Consistent with previous studies, ERPs to true recognition revealed early frontal and parietal ERP effects

**Table 4.** *Results for the ANOVA (Delay × Item Type × Electrode) for Response-Related Negativities Elicited for True and False Recognition Relative to Correct Rejections of NEW Words*

| | *df* [a] | True recognition | False recognition |
|---|---|---|---|
| Item type | 1.14 | 12.74** | 12.42** |
| Item Type × Delay | 1.14 | 0.01 | 1.35 |
| Item Type × Electrode | 5.70 | 0.49 | 5.34* |
| Item Type × Delay × Electrode | 5.70 | 4.28* | 1.35 |

[a]df: degrees of freedom.
***$p \leq .001$; **$p \leq .01$; *$p \leq .05$; (*)$p \leq 0.1$.

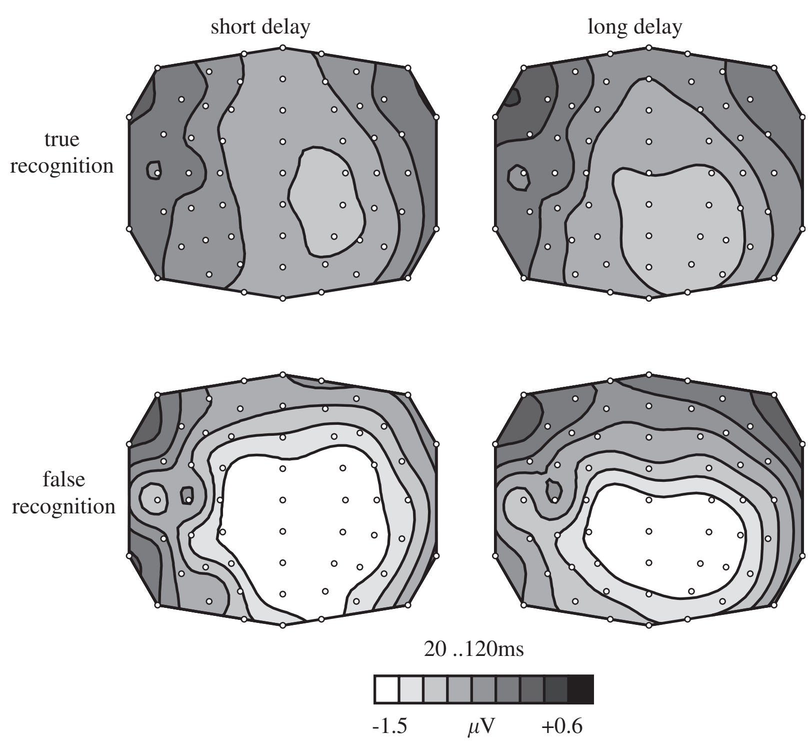


**Figure 5.** Topographic distributions of the error-related negativity (20–120 ms) for true recognition (true recognition minus new responses to NEW words; top) and false recognition (false recognition minus new responses to NEW words; bottom) for the short (left) and long retention delay conditions (right).

in both retention delays. In contrast, false recognition elicited an early frontal positivity relative to new responses to NEW words and relative to new responses to LURE words only in the short delay condition. Late parietal negativities for true and false recognition relative to new responses showed up as ERN-like negativities in the response-related averages. This negativity, though present for true and false recognitions, was larger for false recognitions, especially at posterior recording sites.

## Discussion

### *Behavioral Data*

The present study was conducted to examine the influence of different retention delays on behavioral and electrophysiological correlates of true and false recognition.

Using words from different categorical lists, reliable rates of false recognition were obtained in the present study. In both delays, false alarms were higher to nonstudied but semantically related LURE words (false recognition) than to nonstudied NEW words that were not members of studied categories. The proportion of false recognition found in the present experiment was lower than in studies performed with the Deese paradigm (e.g., Curran, Schacter, Johnson, & Spinks, 2001; Düzel et al., 1997; Fabiani et al., 2000) but resembled those found in other studies that also used categorical lists (Nessler et al., 2001; Seamon, Luo, Schlegel, Green, & Goldenberg, 2000). Consequently, the present results are in line with the assumption that strength of semantic relationship between studied (OLD) and LURE words influences the false recognition rate.

Consistent with prior studies, there was a general decline in performance from the short to the long retention delay (cf. Friedman, 1990; Friedman et al., 1993; Nielsen-Bohlman & Knight, 1995; Rugg et al., 1997). However, although the rate of false recognitions showed a statistically reliable increase from the short to the long retention delay, the rate of true recognitions and the rate of correct rejections of NEW words did not differ significantly between the short and the long retention delay. This dissociation between true and false recognition argues against the view that true and false recognition are based on similar cognitive processes. With the differential effect of the delay manipulation on performance measures for true and false recognition in mind, we now turn to the discussion of the ERP data.

### *ERP Data*

ERPs for true recognition were more positive at frontal and parietal locations than new responses to NEW items, starting around 300 ms in both delay conditions, whereas there were differential ERP effects for false recognition. Similar to true recognition, in the short retention delay, ERPs elicited by false recognition were more positive than the ERPs to correct rejections of NEW words at frontal and parietal locations. However, in the long delay, there was no frontal effect relative to new responses to NEW words and to new responses to LURE words. This differential effect of retention delay on the ERP correlates of true and false recognition will be considered in more detail below.

The ERP effects elicited by true recognition in both delay conditions resemble the traditional ERP old/new effects found in studies using standard old/new recognition tests. Using different manipulations of encoding and retrieval, these studies reported frontally and parietally distributed old/new effects (for an overview, cf. Johnson, 1995; Mecklinger, 2000; Rugg, 1995). In terms of dual-process models of recognition memory (cf. Yonelinas, 2002) these two effects have been considered electrophysiological correlates of the familiarity and recollection subcomponents of recognition memory. Familiarity is assumed to reflect the assessment of the global similarity between studied and test items and is correlated with a frontal old/new effect, that is, an attenuation of a frontally focused negativity component, around 400 ms by familiar items. Recollection is associated with the retrieval of item-specific information and is correlated with the parietal old/new effect, that is, an enhancement of a parietal positivity evoked by old items (cf. Curran, 2000; Friedman & Johnson, 2000; Mecklinger, 2000). As both, the midfrontal and the late parietal effects were present for true recognition, irrespective of retention delay, we assume that both subcomponents of recognition memory contributed to the true recognition judgments.

In contrast to ERP studies using longer retention intervals (Rugg & Nagy, 1989) the delay manipulation in the present study had no effect on the ERP old/new effects for true recognition. There only appeared to be a topographical shift in the strength of the effect, in that effect sizes were largest at frontal locations in the short delay and at parietal locations in the long delay. It should be noted however, that these topographical effects were weak. The absence of any significant ERP differences for true recognition in both delay conditions is paralleled by the highly similar true recognition rates obtained in both conditions, and suggests that similar processes contributed to true recognition in both delay conditions.

Of more interest with respect to the objective of the current study are the ERP effects found for false recognition. False recognition elicited frontal and parietal ERP old/new effects in the short delay. In the long retention delay condition, there was only a parietal positivity for ERPs to false recognition compared to ERPs to correctly rejected NEW words as well as to correctly rejected LURE words. At first glance, the absence of a frontal old/new effect in the long delay condition suggests, in terms of the above mentioned functional dissociation between the frontal and the parietal effect, that LURE words may attract lower feelings of familiarity after long retention delays. As a consequence, the ERPs elicited by incorrect responses to LURE words do not differ from those elicited by NEW words at frontal locations. This interpretation, however, is challenged by the fact that the false recognition rates increased from the short to the long delay. In fact, some of the theoretical accounts of false memory assume that false memory judgments result from more categorical representations of LURE words that may lead to illusory impressions of familiarity.

LURE words are judged old because they are broadly consistent with the conceptual features that were studied or because they match the overall themes of words encountered in the study phase (cf. Schacter et al., 1998). If familiarity-based recognition judgments for LURE words decrease after a long retention delay, as suggested by the absence of a frontally focused old/new effect for false recognition, which processes lead to an enhancement of false recognition responses in the long delay condition? One account could be that familiarity discrimination is used for LURE words in the short delay and that this strategy is not reliable any more after a long retention delay. That is, participants may have focused more on recollective correspondence for false recognition in the long delay condition. If this was indeed the case, we would expect the parietal old/new effect (i.e., as a correlate of item-specific remembering) to be larger for false recognition in the long when compared to the short retention delay. However, inspection of Figure 1 and statistical analyses indicate that this was not the case. Therefore a change in retrieval strategy, that is, familiarity discrimination in the short delay and recollective correspondence in the long delay, seems rather unlikely.

An alternative account for the attenuation of the frontal old/new effect that is paralleled by an increase of false recognition in the long delay condition, may possibly be derived from spreading activation accounts of semantic memory (e.g., Collins & Loftus, 1975). In this framework it can be assumed that prolonged retention intervals lead to degraded memory traces for studied items. Despite the condition of the encoded stimuli, activation of residual traces still allows familiarity discrimination of the OLD items. In contrast, LURE words can only be elicited by spreading activation triggered by studied items. Consequently, their activation in memory may not be robust enough to allow for familiarity discrimination. This point of view would account for the differential frontal old/new effect for true and false recognition in the long delay condition. It would also predict a general decay in memory performance as a function of retention delay. Consistent with this prediction, the statistical analyses revealed main effects of delay condition for reaction times and performance accuracy. The only result of the behavioral analyses not consistent with this position is the lack of a significant effect of retention delay when tested separately for true recognition (i.e., true recognition rates were 1.4% lower in the long than in the short delay, but this effect did not reach the significance level). Given the overall effect of retention delay, it is assumed that the design may have lacked the statistical power to resolve this small effect.

Taken together, we favor the degraded memory traces account and propose that the increase in false recognition in the long delay condition that was paralleled (a) by a general decrease in recognition speed and accuracy and (b) by an absence of frontally focused old/new effects most likely result from a deterioration of memory traces for studied items after a long retention delay.

### *Late ERP Effects and Response-Related Activity*

In addition to early frontal and parietal ERP old/new effects, right frontal ERP old/new effects for true recognition starting around 1,000 ms were obtained. At present, there is no consensus on the precise functional significance of these late and long-lasting right frontal old/new effects. Consistent with prior studies, we assume that an ensemble of post-retrieval processes mediated by the prefrontal cortex contribute to these late ERP effects (e.g., Ullsperger et al., 2000; Wilding, 1999; for overviews, see Mecklinger, 2000; Rugg & Allan, 2000).

In the present study, late right frontal ERP old/new effects were found for true recognition in both delay conditions, but no effects were obtained for false recognition. The absence of significant late frontally focused effects for false recognition presumably results from a component overlap with a pronounced parietally focused negative slow wave being present in about the same time interval. A similar but smaller effect was obtained for true recognition. Similar late and posterior focused negative slow waves have been reported in a variety of prior recognition memory studies. A consistent feature of these studies is that in addition to a recognition judgment a second memory based judgment, like a source discrimination (Cycowicz, Friedman, & Snodgrass, 2001; Johansson et al., 2002; Wilding & Rugg, 1997) or a remember/know judgment (Düzel et al., 1997) was required. Based on the observation that the amplitude of this negative component was related to reaction times, it has been taken to reflect response-related effects (Wilding & Rugg, 1996). A prior fMRI-constraint dipole analysis identified the ACC as a generator for late parietal negativities during false recognition responses (Mecklinger et al., 1999; cf. Mecklinger, 2000; Nessler et al., 2001). It was argued that the ACC modulates response competition in task that require "new" response for lure words that are highly associated with studied words (Mecklinger, 2000).

Consistent with this view, the response-related averages for true and false recognition revealed a negative ERP component relative to new responses to NEW words between 20 and 120 ms after the response. This component was identified as an error-related negativity. Prior studies using perceptual tasks to examine the ERN usually report a fronto-central scalp distribution of this component (for an overview, see Holroyd & Coles, in press). In the present memory task, the ERN had a broad anterior-to-posterior scalp distribution. At anterior scalp locations, true and false recognition responses generated highly simliar ERNs, whereas at posterior scalp locations, the ERN was more pronounced for false recognitions.

An interesting issue that needs some further consideration is whether the error-monitoring processes are similar or different in perceptual and recognition memory task. In a large number of ERN studies, participants consciously experience an error at the moment of the response (cf. Elton, Band, & Falkenstein, 2000; Reason, 1990). Given the low task demands in the present study (PR values: .85 and .84 in the long and short delay conditions, respectively) it is conceivable that our participants were also well aware of making erroneous responses to a proportion of the LURE words. Second, prior ERP studies on error processing, similar to our study, occasionally report ERNs to correct responses. This ERN to correct trials has been accounted for by an inaccurate representation of the appropriate response (Coles, Scheffers, & Holroyd, 2001). This view, which considers the ERN to correct responses as a reflection of error processing, could also explain the present ERN to true recognitions. These similarities between our results and those of prior ERN studies support the view that similar error monitoring processes are engaged in perceptual and in memory tasks.

In contrast to prior studies on error monitoring, the ERN in the present study was also observable at posterior recording sites. At these sites, it was considerably larger for erroneous than for correct responses. As false recognitions were also associated with longer response times, it is conceivable that the posterior portion of the response-related negativity is more related to response competition or response uncertainty. Given this, it is tempting to speculate that the more anterior portions of the ERN are associated with error detection, whereas the posterior portion may reflect evaluative response-monitoring processes, more likely to occur under conditions of response conflict. This view is tentatively supported by the observation that the ACC, besides error detection, mediates an ensemble of processing functions in the service of adaptive behavior. (cf. Bush, Luu, & Posner, 2000; Carter et al., 1998; Luu, Collins, & Tucker, 2000; Paus, Koski, Caramanos, & Westbury, 1998; Tucker, Hartry-Speiser, McDougal, Luu, & deGrandpre, 1999; Tucker & Luu, 2000). However, further studies are needed to elucidate the factors that contribute to the anterior and posterior portions of the observed negative components.

## Conclusions

The motivation for the present study was to examine the effects of retention delay on electrophysiological correlates of true and false recognition. False recognition rates increased from short to long retention delay. This behavioral effect was accompanied by electrophysiological differences in false recognition. An early midfrontal ERP old/new effect, assumed to be associated with familiarity discrimination during recognition judgments, was evident in the short delay but disappeared for false recognition judgments in the long retention delay condition. As speed and accuracy performance decreases as a function of retention delay, it is assumed that the weakening of memory traces for studied items does not permit familiarity-based recognition judgments following long retention delays, and that this accounts for the absence of a midfrontal ERP effect in this condition. An additional analysis of response-related ERP activity revealed an ERN to true and false recognition relative to correct new responses to NEW words. As an ERN-like component was also present at posterior recording sites for false recognitions that were associated with prolonged reaction times, it is assumed that in addition to error detection, the detection of response conflicts may also modulate response-related negative components.

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(Received August 29, 2001; Accepted July 29, 2002)