Implicit memory within a word recognition task: an event-related potential study in human subjects

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Received 15 March 1999; received in revised form 3 May 1999; accepted 4 May 1999

Abstract

First, we recorded brain potentials from 15 healthy young subjects during the performance of a word/non-word discrimination task. During continuous visual presentation, some of the meaningful words were repeated after 86–94 s. We found a significant decrease of response time associated with the classification of repeated words which is an index for priming, an unconscious brain process. However, event-related potentials (ERPs) did not differ significantly between first and second presentations. Second, we recorded brain potentials during a following recognition test. Some of the meaningful words which were presented only once during the semantic discrimination task were repeated and had to be discriminated from randomly interspersed new words. We compared ERPs produced by incorrectly classified repeated words (misses) with ERPs produced by correctly classified new words (correct rejections). We found early ERP differences between 250 and 400 ms and later differences starting at about 500 ms after the stimulus onset. The early effect occurred over parietal scalp locations and the later effect over frontal, parietal and occipital scalp locations. This is evidence for unconscious brain activity related to the processing of missed repeated words. We suggest that the later frontal effect we found is due to an enhanced effort of the retrieval of item representations during word recognition and that the earlier parietal effect reflects partial recognition.

Keywords: Event-related potentials; Word recognition; Correct and incorrect responses; Implicit memory

Behavioural analysis in normal subjects and in patients with amnestic syndrome showed the existence of unconscious memory processes (implicit memory and priming) [2,5,15]. Physiological evidence for unconscious memory in a patient with amnestic syndrome was reported by Lalouschek et al. [9]. Recently, Rugg et al. [14] conducted an experiment involving a shallow-encoding task which elicited perceptual processing of visually presented words. Their instruction was to decide whether the first and the last letters of presented words were in alphabetical order or not. During a following recognition test, they recorded brain potentials and compared ERPs produced by missed shallowly studied words with ERPs produced by words which were correctly classified as new. ERP differences occurred between 300 and 500 ms after stimulus onset over parietal scalp locations, whereas no such differences were found over frontal scalp locations. Rugg et al. [14] interpreted these parietally distributed ERP differences as a physiological correlate of implicit memory.

The goal of the present study was to directly compare two forms of unconscious memory processes, namely repetition priming in a lexical decision task and implicit memory in a following word recognition task. The subjects were not informed about this recognition task before. Therefore, incidental encoding was provided. During the lexical decision task meaningful words had to be discriminated from randomly interspersed non-words. Some of the meaningful words were repeated after a lag of 86–94 s. In analysis 1 we compared response times associated with and ERPs produced by correctly classified first and second presentations of meaningful words.

During the following recognition task, some of the meaningful words which were presented only once during the lexical decision task were repeated and had to be discriminated from new words. In analysis 2 we compared response times associated with and ERPs produced by missed repetitions and correctly classified new words. In both cases subjects classified the presented words as new.
and any ERP differences would be evidence for unconscious information processing. EEG was recorded with 38 Ag/AgCl electrodes fixed to the scalp according to the procedure described by Bauer et al. [1]. Linked mastoid electrodes served as reference. Some electrodes which are not included in the conventional 10–20-system [8] were placed at more inferior lateral sites. The EOG was measured in order to enable the removal of trials contaminated by eye artefacts. The potentials were amplified by a multi-channel DC amplifier [10], digitized with a sampling rate of 250 Hz and low pass filtered with 100 Hz (linear digital FIR-filter of very high order, realized by a high-speed digital signal processor). So the frequency range of the signal was DC to 100 Hz.

The whole recording epoch was 2.1 s, starting 800 ms before the stimulus onset until 1.3 s after the stimulus onset. Fifteen healthy young people participated in the study (the mean of age was 25.1 years; range from 21–30 years; eight females). All were right handed as assessed with a modified version of the Edinburgh Inventory [12], and all had normal or corrected to normal vision.

Subjects were seated in a comfortable chair in front of a computer screen (distance from eyes to screen was around 1.10 m and the visual angle for words was between 1.5 and 3.6°). First, three blocks of word lists were presented, with each block consisting of 200 meaningful words (three to nine letter nouns of low frequency of occurrence) and 40 orthographically legal non-words (240 stimuli). Forty of the 200 meaningful words were repeated after a lag of 86–94 s. Each word appeared for 300 ms with an inter-stimulus interval of 2.2 s. Subjects were asked to discriminate between words and non-words. Responses were made by moving the index finger of the right hand over either a left or a right light barrier relative to a neutral resting position. The word recognition task followed after a short rest of about 5 min. During this recognition task, 200 meaningful words from the previous presentation blocks, which were presented only once were now presented again together with 200 new words. Subjects were asked to discriminate between repeated words and new words.

The recorded digitized data were averaged over all 15 subjects. 17 time intervals of 100-ms duration were selected covering the period from 100 to 1000 ms after stimulus onset and overlapping each neighbouring interval for 50 ms. Mean amplitudes were corrected to a baseline consisting of the period 300 ms before stimulus onset. All data were normalized according to McCarthy and Wood [11] and analyzed with the software package SPSS. Mean amplitudes were analyzed by within subject ANOVA, examining main effects of word condition and word condition/electrode site interactions. Word conditions for analysis 1 were correctly classified first presentations of meaningful words and their correctly classified second presentations from the semantic discrimination task. Word conditions for analysis 2 were missed repetitions and correct rejections from the recognition task. All resulting probability values were Huynh–Feldt corrected. To illustrate the distributions of resulting effects $t$-tests were calculated in order to compare the mean ERP amplitudes at every single electrode site.

As a result of analysis 1, for every subject, response times were shorter for correctly classified repeated words compared with their correctly classified first presentations, $P < 0.001$, whereas the mean response times associated with the word conditions of the word recognition task (analysis 2) did not ($P = 0.165$).

Table 1

<table>
<thead>
<tr>
<th>Experimental design</th>
<th>Word conditions</th>
<th>Response time (ms)</th>
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<tbody>
<tr>
<td>Word/non-word discrimination task (analysis 1)</td>
<td>Correctly classified first presentations of meaningful words</td>
<td>630 (SD = 63)</td>
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<tr>
<td></td>
<td>Correctly classified second presentations of meaningful words</td>
<td>577 (SD = 47)</td>
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<tr>
<td>Word recognition task after incidental encoding (analysis 2)</td>
<td>Incorrectly classified repeated words (misses)</td>
<td>924 (SD = 97)</td>
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<tr>
<td></td>
<td>Correctly classified new words (correct rejections)</td>
<td>898 (SD = 84)</td>
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a The mean response times associated with the word conditions of the word/non-word discrimination task (analysis 1) differed significantly ($P < 0.001$), whereas the mean response times associated with the word conditions of the word recognition task (analysis 2) did not ($P = 0.165$).

Table 2

<table>
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</thead>
<tbody>
<tr>
<td>Word condition/electrode site</td>
<td>0.157</td>
<td>0.051</td>
<td>0.006</td>
<td>0.016</td>
<td>0.234</td>
<td>0.321</td>
<td>0.209</td>
<td>0.072</td>
<td>0.021</td>
<td>0.027</td>
<td>0.182</td>
</tr>
</tbody>
</table>

a Word condition and electrode site interactions were calculated. All data were Huynh–Feldt corrected.
with differences in response times for the two conditions ranging from (24 ms) to (90 ms) (mean ± standard deviation: 53 ± 24). Consequently, across all subjects, this difference in response times for correctly classified repeated words compared with their correctly classified first presentations was found to be significant, \( t(14) = 7.39, P < 0.001 \) (Table 1) whereas the ERPs elicited by these two conditions did not differ.

During the recognition test, 53.3% of the repetitions were correctly recognized as repeated (hits), whereas 25.2% of the new words were falsely classified as repeated (false alarms). In order to correct the memory performance for guessing false alarms were subtracted from hits [16]. In our case, 53.3% hits minus 25.2% false alarms result in 28.1%. This represents poor memory performance during the recognition task which is due to the incidental encoding of the first presentations during the semantic discrimination task. However, 46.7% of the repeated words were wrongly classified as new (misses) whereas 74.8% of the new words were correctly classified as new (correct rejections).

Analysis 2 revealed no significant difference between the two means of response times associated with misses and correct rejections (\( P = 0.165; \) Table 1). Instead, the within subject ANOVAs revealed significant word condition/ electrode site interactions between 200 and 350 ms and between
500 and 650 ms after stimulus onset indicating topographical differences within these periods between misses and correct rejections (Table 2). During the first period, ERPs produced by misses were less negative than ERPs produced by correct rejections over left inferior parietal scalp locations (Figs. 1 and 2). During the second period ERPs produced by misses were more negative going than ERPs produced by correct rejections over frontal, right superior parietal and right occipital scalp locations (Figs. 1 and 2).

Analysis 1, focusing on first and second presentations of meaningful words in a word/non-word discrimination task, yielded a clear behavioural priming effect related to repeated meaningful words as measured by a decrease of response time. However, this form of unconscious brain processing did not leave a physiological trace detectable in the EEG. Analysis 2, investigating missed repeated words and correct rejections in a word recognition task revealed ERP differences between these two conditions. This indicates that the repeated words were differently processed compared with new words, although subjects classified both conditions as new. According to some authors, in electroencephalography less negativity is interpreted as reflecting less cortical activity. The fact that misses elicited less negativity than correct rejections over parietal scalp locations during the early period (200–350 ms after stimulus onset) is consistent with the results of Rugg et al. [14], who also found less negativity elicited by misses compared with correct rejections. Instead of perceptually encoded misses we investigated semantically encoded misses. Therefore, our findings extend previous results showing the ability of the EEG to detect implicit brain processes also related to deep semantic encoding. This could be seen as evidence supporting previous reports about the independence of implicit memory effects to depth of processing [7].

During the later period (starting at about 500 ms after stimulus onset), misses produced higher negativity than correct rejections over frontal, parietal and occipital scalp locations. The higher frontal activation during the presentation of repeated words, although subjects were not aware of their repeated nature, is suggested to be due to an enhanced effort to retrieve item representations of the prior word exposures. This idea is consistent with previous findings indicating that the prefrontal cortex plays an important role within memory retrieval processes [6,13]. The posterior activity increases during repeated word presentations might reflect activity related to item representations itself [3,4].

We suggest that the early posterior effect we found reflects a kind of partial recognition leading to an enhanced effort to retrieve item representations. This enhanced effort, on the other hand, is reflected by the later frontal effect we found in our study.

This study was supported by the Austrian Science Fund (P10971-MED). We would like to thank Dr. Ross Cunnington for helpful comments.