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Active suppression in the mediotemporal lobe during directed forgetting

Eva Ludowig [a,b,*], Jürn Möller [c], Christian G. Bien [a], Thomas F. Münte [c], Christian E. Elger [a], Timm Rosburg [a,d]

[a] Department of Epileptology, University of Bonn, Sigmund-Freud Str. 25, D-53105 Bonn, Germany
[b] Institute of Experimental Psychology II, Heinrich-Heine University, Universitaetsstr. 1, D-40225 Duesseldorf, Germany
[c] Department of Psychology, University of Magdeburg, Universitätsplatz, D-39106 Magdeburg, Germany
[d] Department of Psychology, Experimental Neuropsychology Unit, Saarland University, P.O. Box 151150, D-66041 Saarbrücken, Germany

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ABSTRACT

The aim of the present study was to investigate whether forgetting is merely a passive process or whether it can also be caused by active suppression of memory contents.

We investigated effects of directed forgetting by intracranial event-related potentials (ERPs) in 12 patients with mesial temporal lobe epilepsy. In a single-item directed forgetting paradigm, the patients were presented with words either followed by the instruction that this word has to-be-remembered (TBR) or to-be-forgotten (TBF). All patients were implanted with multicontact depth electrodes along the rhinal cortex and hippocampus as part of their presurgical evaluation.

Patients recognized significantly less TBF than TBR words in a subsequent recognition test. In the hippocampus, TBF cues that caused subsequent forgetting were associated with decreased negative ERPs. In the rhinal cortex, TBF cues elicited a generally prolonged positivity, as compared to TBR cues.

We interpret the decreased hippocampal ERPs following the TBF cues as an indication for an active suppression of hippocampal functions. The increased rhinal activity in response to the TBF cue might indicate an active involvement of this structure in the suppression of hippocampal memory formation.

1. Introduction

Forgetting usually occurs unintentionally and is perceived as a negative consequence of the limited capacity of the memory system. However, forgetting irrelevant information is important for effective information processing, as it avoids interference from irrelevant information (Bjork, 2008). The executive control of forgetting has been examined in experiments on "directed forgetting", where an individual item ("single-item-cueing") or a list of items ("list-cueing") is followed by an instruction to forget or to remember these items. It has been shown that recognition performance for to-be-forgotten (TBF) items is decreased as compared with to-be-remembered (TBR) items (Johnson, 1994). This phenomenon is called the directed-forgetting effect. For list-cueing, directed forgetting is usually attributed to retrieval inhibition that hinders overall access to the list of items associated with the TBF cue (Geiselman & Bagheri, 1985).

For single-item-cueing, more intense rehearsal of TBR than TBF cued words is the predominant explanation for the directed-forgetting effect. Accordingly, the "selective rehearsal model" (Bjork, LaBerge, & LeGrande, 1968) assumes that the presentation of a TBR cue triggers elaborated rehearsal processes, whereas active rehearsal of an item is aborted after the presentation of a TBF cue. This leads to only shallow encoding of the TBF cued words and consequently to a worse recognition performance. The intention to encode the TBR cued word has been assumed to be mediated by the inferior prefrontal cortex, while the mediotemporal lobe (MTL) has been regarded as crucial for successful long-term memory encoding (Davachi, Mitchell, & Wagner, 2003; Reber et al., 2002).

If the directed-forgetting effect is solely based on a less elaborated rehearsal following the TBF cue, forgetting would be a passive process, caused by fading of memory traces. In addition, forgetting might be attained by active inhibition processes. In the directed forgetting condition, rehearsal might be actively aborted or even memory formation actively suppressed. Consistent with the "active-suppression model" (Zacks, Radvansky, & Hasher, 1996), a recent fMRI study indicated that inhibition during directed forgetting is mediated by medial and superior frontal areas (Wylie, Foxe, & Taylor, 2008). The view of frontal inhibition has also been supported by an event-related potential (ERP) study, where TBF cues elicited enhanced positive activity at frontal and prefrontal areas (Paz-Caballero, Menor, & Jimenez, 2004).

If the frontal cortex directly inhibits memory encoding in the MTL, activation in the MTL should be decreased. This assumption is supported by an fMRI study using the think/no think paradigm,

* Corresponding author. Address: Institute of Experimental Psychology II, Heinrich-Heine University, Universitaetsstr. 25, D-40225 Duesseldorf, Germany. Fax: +49 211 811 4522.

E-mail addresses: Eva.Ludowig@uni-duesseldorf.de, ludeva@gmx.de (E. Ludowig).

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where the control of unwanted memories was associated with increased dorsolateral prefrontal activation and reduced hippocampal activation (Anderson et al., 2004).

In addition to the frontal cortex, substructures of the MTL themselves might be part of the active suppression system. For instance, it has been proposed that the rhinal cortex actively inhibits information transmission between the neocortex and the hippocampus (de Curtis & Pare, 2004).

Summing up, directed-forgetting effects in single-item-cueing are usually explained by two models: selective rehearsal of TBR cued words or encoding suppression of TBF cued words. While selective rehearsal is without much controversy, it is still an open issue whether an active suppression of MTL structures takes place. The aim of the present study was to clarify the role of the MTL (hippocampus and rhinal cortex) in directed forgetting and to search for evidence for or against the active-suppression model. Therefore, we recorded ERPs from intracranial electrodes implanted in the MTL of epilepsy patients in the course of their presurgical evaluation, since in addition to an excellent temporal resolution, intracranial recordings offer the rare opportunity to measure neural activity directly within MTL structures.

We presented single words that were either followed by a TBR or a TBF cue. The recognition performance in a subsequent recognition test was taken into account as an indicator for the success of the instruction during this procedure. Thus, we differentiated TBR and TBF cues of words which were subsequently remembered or subsequently forgotten.

For the two models of directed forgetting, we predicted different ERP patterns in response to TBF and TBR cues (see Table 1): The selective rehearsal model explains the better encoding of TBR cued words with a more elaborated rehearsal of these words, as compared to TBF words. As consequence of a more elaborated rehearsal, we expected larger mediotemporal ERP amplitudes in response to TBR than to TBF cues. Since a more elaborated rehearsal of words usually leads to a more successful encoding, we further predicted on basis of this model that TBR cues of subsequently recognized words would result in larger ERP amplitudes than TBR cues of subsequently forgotten words (Table 1, 1st line).

In contrast to this model, the active-suppression model assumes that TBR cued words are better remembered because the encoding of TBF words is actively inhibited. This active suppression would be triggered by TBF cues but not by TBR cues. In case that the memory encoding in the MTL structures is suppressed by second brain structures, we predicted to observe decreased mediotemporal ERP amplitudes to TBF cues. Furthermore, ERP amplitudes were expected to be smallest in response to TBF cues of subsequently forgotten words, i.e. for successful suppression (Table 1, 2nd line).

In case that MTL structures themselves actively suppress memory formation, a converse pattern was predicted: The mediotemporal ERP amplitudes to TBF cues were expected to be larger than in response to TBR cues and largest to TBF cues of subsequently forgotten words (Table 1, 3rd line).

However, the two models do not exclude each other. Active rehearsal and memory suppression might take place simultaneously. In that case, the effects shown in Table 1 would both be present. But still, differences in the subsequent memory effects (cues belonging to words later recognized vs. not recognized) would give evidence for the underlying process.

The effects of learning are usually studied by comparison of ERPs elicited by items presented before (old items) and ERPs elicited by newly presented items. The difference between both is called old–new effect. Recently, it has been shown that in the hippocampus the old–new effect is sensitive to depth of encoding (Grunwald et al., 2003). Since both a more intense rehearsal of TBR cued words and an active suppression of the encoding of TBF cued words should lead to a deeper encoding of TBR than of TBF cued words, we expected to see larger hippocampal ERP components in response to TBR words as compared to new words and also as compared to TBF words.

2. Materials and methods

2.1. Subjects

We investigated 24 patients with pharmacoresistant temporal lobe epilepsy. Twelve patients (nine females; nine with left, three with right TLE) were included in the study. The other 12 patients were excluded because of the following reasons: seven due to their generally poor memory performance (no words freely recalled or less than 30 of a total of 200 words recognized). Three patients declared after the testing that they had paid no attention to the cue and one patient erroneously assumed that the cue would forego the memory item. Finally, data of one patient had to be excluded due to a technical failure during the recordings.

The age of included patients ranged from 28 to 56 years (mean age = 43 years) and the duration of their epilepsy from 2 to 28 years (mean epilepsy duration = 13 years). At the time of the recordings, all patients received anticonvulsive medication with plasma levels within the therapeutic range. Participants had normal or corrected-to-normal vision and were right-handed. MRI scans or post-operative histological examinations demonstrated hippocampal sclerosis in eight patients (three with additional temporopolar blurring of the gray–white matter junction; one with bilateral hippocampal sclerosis), temporopolar blurring of the gray–white matter junction without hippocampal sclerosis in one

Table 1
Overview of ERP effects in the mediotemporal lobe (MTL) predicted by the selective rehearsal and active-suppression model.

Models	TBR-R	TBR-F	TBF-R	TBF-F
Selective rehearsal model	↑↑	↑	∅	∅
Active-suppression model				
Encoding related MTL parts are suppressed by other structures	∅	∅	↓	↓↓
Other MTL parts are themselves active suppressors	∅	∅	↑	↑↑

TBR-R, to-be-remembered cue, word subsequently remembered.
TBR-F, to-be-remembered cue, word subsequently forgotten.
TBF-R, to-be-forgotten cue, word subsequently remembered.
TBF-F, to-be-forgotten cue, word subsequently forgotten.
∅, ERP amplitudes in the rhinal cortex/hippocampus should not be affected.
↑, ERP amplitudes in the rhinal cortex/hippocampus should be increased.
↑↑, ERP amplitudes in the rhinal cortex/hippocampus should be increased strongly.
↓, ERP amplitudes in the rhinal cortex/hippocampus should be decreased.
↓↓, ERP amplitudes in the rhinal cortex/hippocampus should be decreased strongly.