

A neural response sensitive to repetition and phonotactic probability: MEG investigations of lexical access

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1 Introduction

Despite numerous imaging studies on visual word recognition, the timing of lexical activation remains a controversy. For example, whether the N400 event-related potential reflects automatic lexical activation or a post-lexical process is still an open question. The present study investigated the time course of activation in lexical decision tasks using magnetoencephalography (MEG). We identified an MEG component with a similar time window to the N400, peaking at approximately 350 ms (M350). Our results show that the latency of the M350 reflects reaction times (RTs) when stimuli are varied in a way that affects the speed of lexical activation (as hypothesized by behavioral studies). Interestingly, the component does not track RTs when stimuli are varied along a dimension that affects the speed of the postlexical word/nonword *decision*. Thus our findings indicate that the M350 reflects automatic lexical activation rather than a post-lexical decision process.

2 Experiment 1: Repetition

2.1 Goal

We based our first experiment on the well-known behavioral effect of repetition priming: subjects' response times in word recognition tasks become faster on repeated presentations of stimuli. Within activation-based models of visual word recognition, the repetition priming effect can be explained as resulting from a level of activation that remains in the representation of a word for a certain period after its presentation. When the word is presented for the second time, lexical access is faster since the representation is already active to a degree (e.g., [1]). In this experiment we investigated whether there is an MEG response whose properties are also modulated by word repetition, thus reflecting the behavioral effect.

2.2 Methods

Subjects. Seven right-handed, English-speaking adults with normal or corrected-to-normal vision gave their informed consent to participate in the experiment.

Stimuli. Prime-target pairs were presented in four categories of 100 stimuli: (i) repeated word (DOG – DOG), (ii) nonrepeated word (DOG – WIND), (iii) repeated pronounceable nonword (GULK – GULK) and (iv) nonrepeated pronounceable nonword (DOG – GULK). All stimuli were monosyllabic and the actual words were from a continuous scale of frequency from 20-750 instances per million.

Procedure. Stimulus pairs were presented in a randomized order in two blocks of 200 stimuli with an intervening rest period. The interval between the prime and the target was fixed at 500 ms and the intertrial interval randomly varied between 500 and 1500 ms. Subjects performed lexical decisions on the target stimuli by pressing a button.

During the experiment, neuromagnetic fields were recorded in the KIT/MIT MEG laboratory using a 64-channel axial gradiometer whole-head system (Kanazawa Institute of Technology, Japan). The sampling rate was 500 Hz, with acquisition between 1 and 200 Hz. The recording time per subject lasted approximately 20 minutes. Data were noise-reduced to remove environmental artifacts. Responses to target stimuli were averaged by stimulus condition. Following averaging, data were baseline adjusted using a 100 ms pre-stimulus interval and filtered between 1 and 30 Hz.

Analysis. In the behavioral data, RTs deviating over 3SD from the mean for the particular subject were excluded from the analysis. Only correct trials were analyzed both in the behavioral and in the MEG data. One subject had over 40% incorrect trials and was therefore excluded from the analysis. Following averaging of the MEG signals, the root mean square (RMS) field strength was calculated from a minimum of 17 left hemisphere sensors showing large responses between 150 and 450 ms.

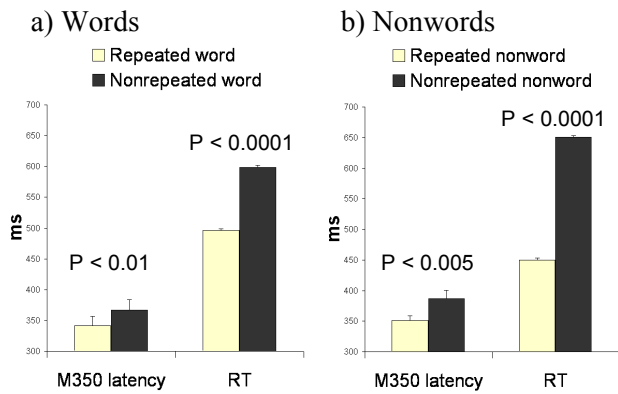


Figure 1: *The effect of repetition on M350 latencies and RTs.*

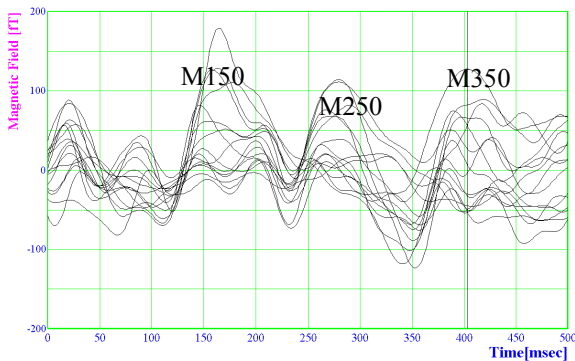


Figure 2: *An averaged waveform for one condition and one subject showing the three major components elicited by all stimuli.*

The latencies and amplitudes of major RMS peaks were recorded using latency and magnetic field distribution as criteria for determining whether a peak belonged to a certain category of responses.

2.3 Results

The behavioral results demonstrated a clear repetition priming effect. A two-factor ANOVA on reaction times (repetition: repeated vs. nonrepeated, lexicality: word vs. nonword) showed a significant effect of repetition ($F = 876.01$, $P < 0.0001$), with RTs being shorter in the repeated than in the nonrepeated conditions. According to post-hoc planned comparisons (Scheffe), this effect was significant both for words and for nonwords ($P < 0.0001$) (Fig. 1).

In the MEG data, three primary peaks with similar magnetic field distributions were identified at 150-200 ms (M150), at 200-300 ms (M250) and at 320-400 ms (M350) (Fig. 2). Of these three responses, the M350 showed a similar priming effect to the one observed in the behavioral data: it peaked approximately 40 ms earlier in the repeated than in the nonrepeated conditions (Fig. 3). An ANOVA on

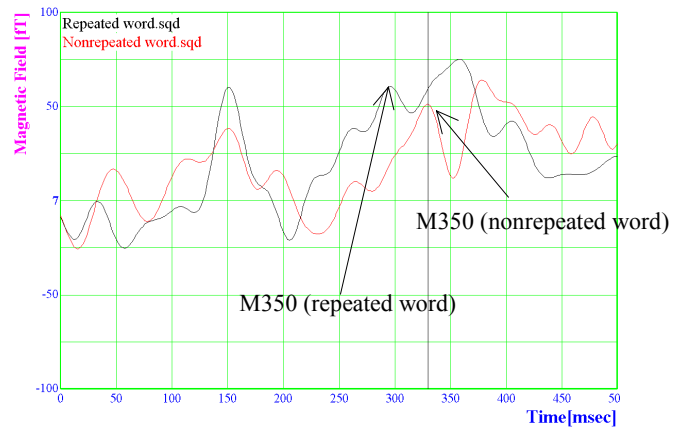


Figure 3: *M350 waveform for sensor 7, the positive signal maximum, showing the repetition priming effect (above) and contour map showing a typical field distribution of the M350 (below).*

the latencies of this response showed a significant effect of repetition ($F=51.9$, $P < 0.001$). According to post-hoc planned comparisons, this effect was significant both for words ($P < 0.01$) and for nonwords ($P < 0.005$) (Fig. 1). However, repetition did not affect the latencies or amplitudes of the M150 or the M250.

Our results indicate that the earliest MEG component whose latency can serve as a predictor of the behavioral repetition priming effect occurs at approximately 350 ms post stimulus presentation. One interpretation of these data is that the M350 reflects automatic activation of the lexicon and shows the repetition priming effect since repeated stimuli activate lexical representations faster than nonrepeated stimuli. On the other hand, if repetition shortens the latency of lexical activation, we would expect it to shorten the latencies of post-lexical processes, such as the word/nonword decision, as well. Thus the repetition priming result does not exclude interpretations in which the M350 reflects some process following lexical activation.

To address the tension between the two interpretations, we conducted a second experiment

where we varied stimuli in a way that affects processing both in the lexical and post-lexical level.

3 Experiment 2: Phonological Probability/Density

3.1 Goal

Most current models of lexical access assume that lexical processing is a combination of activation and competition: a stimulus activates its own entry and a family of related representations (its neighbors) which then compete for selection (e.g. [2]). The hypothesis for our second experiment was based on previous results about the relationship between phonological neighborhood density (i.e., how crowded a word's phonological similarity neighborhood is) and phonotactic probability [3]. The interest of these two variables for the present study comes from the fact that even though the two factors are highly correlated (i.e. words with a high phonotactic probability also have many similar neighbors), they have different effects on processing times. Which effect surfaces depends on the experimental task. In tasks which do not require selecting one lexical entry from those activated by the presentation of a stimulus (such as the shadowing task, [4], or the same-different task, Experiment 1 in [3]), words with a high phonotactic probability are processed faster than low probability words. However, if the task does require selection among related representations, reaction times are *slower* for high probability stimuli. This is because high probability items come from dense phonological neighborhoods, and therefore activate more representations than low probability items. This consequently induces more intense competition, which slows down the selection process.

We hypothesized that if the M350 reflects automatic lexical activation, it should show sensitivity to phonotactic probability but not to phonological density. In other words, we predicted that even though the dense neighborhood of high probability words should slow down lexical decisions, their M350s should be fast. This follows if the M350 indeed represents lexical activation prior to the selection of one particular entry and if phonotactic probability has a facilitatory effect on processing at this pre-competition level.

3.2 Methods

Subjects. Nine right-handed, English-speaking adults with normal or corrected-to-normal vision

gave their informed consent to participate in the experiment.

Stimuli. Our materials were based on the spoken stimuli of [3] which we converted into orthographic stimuli to permit direct comparison of the brain responses to those elicited in Experiment 1. The orthographies of the nonwords were determined by having three native English-speakers spell the spoken nonwords of [3].

Stimuli were presented in four categories of 70 stimuli: (i) high probability/density words (BELL, LINE), (ii) low probability/density words (PAGE, DISH), (iii) high probability/density nonwords (MIDE, PAKE) and (iv) low probability/density nonwords (JIZE, YUSH). All stimuli were monosyllabic, and high and low density words were matched for visual word frequency [5]. The measures for phonotactic probability were positional segment frequency and biphone frequency and phonological neighbors were defined as any item that could be converted to the stimulus by one phoneme substitution, deletion, or addition in any position, as in [3].

Procedure. Stimuli were presented in a randomized order in two blocks of 140 stimuli with an intervening pause allowing subjects to rest. The intertrial interval randomly varied between 500 and 1500 ms. The task was continuous lexical decision. The rest of the procedure was as in Experiment 1.

Analysis. This time the analysis of the MEG signals concentrated on the M350. A response was categorized as an M350 if it peaked between 280 and 420 ms and showed the field distribution illustrated in Figure 3: a dipolar field on the left hemisphere oriented along the anterior-posterior axis with a positive field on the right (including either sensor 7 or 32) and a negative field on the left (including either sensor 41 or 44). One subject showed no responses that filled these criteria and was therefore excluded from the analysis.

The RMS was calculated from a minimum of 12 sensors around the M350 maxima. From the RMS, the peak latencies of each M350 was recorded. If there were more than one peak that filled the M350 criteria, the properties of the first one were recorded.

3.3 Results

The behavioral results of [3] were replicated: RTs to high probability/density stimuli were slower than RTs to stimuli with low probability/density both in the word and nonword conditions. An ANOVA on reaction times showed a significant effect of probability/density ($F = 44.519$, $P < 0.001$) which according to post-hoc planned comparisons

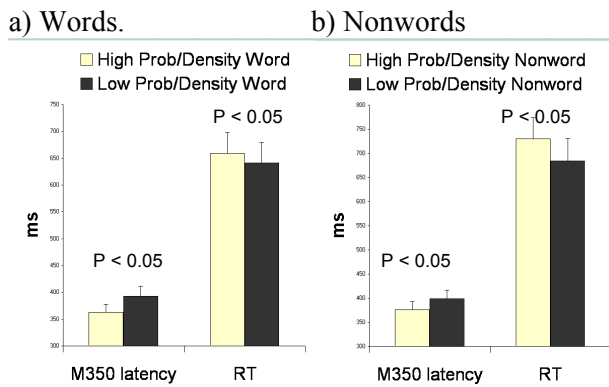


Figure 4: Effect of phonological probability/density on RTs and M350 latencies.

(Scheffe) was significant both for words and for nonwords ($P < 0.05$). As predicted, probability/density had the opposite effect on M350 latencies: the M350 peaked approximately 20 ms earlier in the high probability/density conditions (Fig. 5). According to an ANOVA on the M350 latencies there was a main effect of probability/density ($F = 11.958$, $P < 0.05$) and post hoc t tests showed this effect to be significant both for words and for nonwords ($P < 0.05$) (Fig. 4).

4 Discussion

The present study indicates that the earliest MEG component sensitive to stimulus properties affecting lexical activation occurs at approximately 350 ms (M350). The timing of this component is compatible with responses identified in previous MEG studies of visual word recognition [6, 7, 8]. Our results show that the latency of the M350 is affected both by repetition and by phonotactic probability. In the former case, the component latencies show the same pattern as RTs in a lexical decision task. But remarkably, in the latter case the pattern is reversed, as the dense phonological neighborhoods of high probability stimuli slow down lexical selection. Thus it is unlikely that the M350 reflects a post-lexical decision process. A question for further research is whether the M350 has the same generator as the N400 ERP component. If so, the present results would also shed light on the discussion about the cognitive processes underlying the N400.

Acknowledgements

This work was supported by the JST/MIT [Mind Articulation] Project.

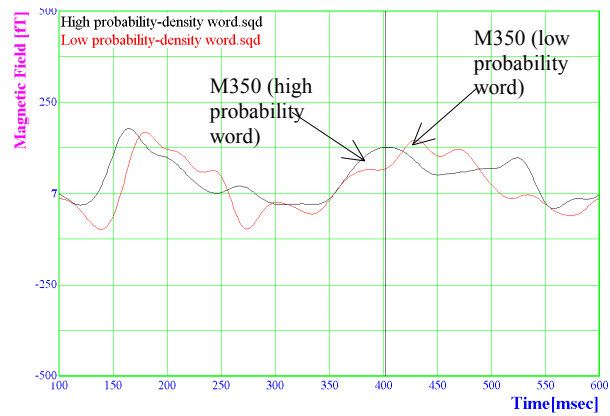


Figure 5: Sensor 7 (see contour map in Fig. 3) showing the effect of phonotactic probability on the M350 latency (one subject).

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