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Short communication

A magnetoencephalographic component whose latency reflects lexical frequency

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Abstract

Magnetoencephalography (MEG) measured subjects' brain responses during a lexical decision task. The words employed come from six frequency categories, which were defined in terms of a linear decrease in log-frequency. Although frequency effects in reaction-time are well-documented in studies of lexical access, a neural component whose latency predicts reaction time has not been discovered. This study identifies an MEG component (the M350) whose latency mirrors the frequency-effect.

Theme: Neural basis of behavior

Topic: Cognition

Keywords: MEG, Language; Lexical access; Lexical decision

Frequency-effects in the processing of (open-class) words have been documented in a number of studies since Ref. [17]. The identification of a neural response component that predicts the frequency effect in behavior addresses a number of questions about the nature and timecourse of lexical access. Here, we present results that identify a magnetoencephalographic (MEG) component whose latency reflects the frequency effect, and discuss the implications of this finding. The importance of response component latency as a variable indexing stimulus properties has been amply demonstrated in MEG studies of the auditory cortex stemming from Refs. [16,19].

Earlier attempts to identify a component reflecting lexical frequency are found in the electrophysiological literature. One prior study [6] reports an increase in the latency of a c. 270–315 ms component (their LPN, or N280) from (1) short and frequent closed-class words, to (2) longer and less-frequent closed-class words, to (3) open-class words. However, the study involves a sentence-processing task, in which numerous additional factors could contribute to, or obscure, frequency effects. Because the design involved a comprehension probe (true/false) as a task, there are no behavioral data correlating with the differences in latency reported. In addition, the study classifies all open-class words into the same category. The study thus conflates frequency and category in the comparison of (1) and (2) with (3), and frequency and length in the comparison between (1) and (2). In addition, whether or not frequency effects are expected in this experiment is unclear, given (1) the finding that normals show frequency effects with only open-class words, as opposed to Broca's aphasics, who show them with open- and closed-class words [1], and (2) the finding that frequency-effects in lexical decision are only found with words with a frequency of 400/million or less [4].

Two additional recent studies have also attempted to identify a neural correlate of the frequency effect. A second event-related potentials (ERP) study [2] looked specifically at frequency within open-class words, and

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found no statistically significant effects; the design was once again one in which subjects were presented with sentences. Finally, a prior MEG study [11] sought frequency effects in a picture-naming task. However, no component in the MEG response showed any significant sensitivity to frequency, whether in terms of latency or amplitude.

The present study employs a simple lexical-decision design, which avoids complicating factors that might result from sentential processing, and which also provides a behavioral index of the frequency effect. The design of the experiment employs six separate frequency classes of open-class words in a lexical decision task, and is thus directly suited for the goal of establishing a connection between reaction time and the latency of a component in the neuromagnetic response.

In addition to the six categories of open-class words, the stimuli contained two classes of non-words (pronounceable and non-pronounceable). Words were divided into six categories according to log-frequency (Table 1); frequency decreased linearly from 2.8 to −0.7 log units (frequencies from the Cobuild corpus of 320 million words). The frequency value is based on the frequency for all parts-of-speech for a particular word, e.g., for *number*, the frequency of both nominal and verbal occurrences of this word. Within the word class, we controlled for number of syllables (range, 1–3; mean, 1.37) as well as length (range, 3–7 letters; mean, 4.8); in addition, words with morphological affixes were excluded. The ratio of words to non-words was 1:1; within each frequency bin, there were ten words, each of which was also presented three times. There were 30 pronounceable and 30 non-pronounceable non-words, each of which was repeated three times.

Subjects ($n=9$, five female, four male, native speakers of English, each of whom gave informed written consent) lay prone in a magnetically shielded room. Stimuli were projected onto a horizontal surface located above the subject's head; stimulus presentation was from a Macintosh computer running Psyscope [3]. Intertrial intervals were randomized from a set of 16 values ranging from 100 to 900 ms, with each 50 ms interval represented. Button-presses were used to record the subjects' responses of *word* or *non-word* for each particular stimulus, and accuracy and reaction time were recorded. The recording time per subject lasted approximately 15 min.

MEG recordings were conducted at the KIT/MIT MEG laboratory, in 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. Prior to analysis, data were noise-reduced to remove environmental artifacts. Epochs with large artifacts were removed during averaging; more than 90% of epochs survived this criterion. Presentations were averaged according to stimulus condition; following averaging, data were baseline-adjusted (−100 to 0 ms) and were filtered between 1 and 30 Hz. The root mean square (RMS) was calculated for each sample point from a set of 17 sensors located in the left hemisphere; sensors were chosen on the basis of their showing large responses in the time-regions of interest. RMS analysis employing multiple sensors can detect both positive and negative polarities of the magnetic field, and might therefore yield a more accurate measure of latency than that provided by a single sensor. RMS analysis has been employed in studies of the auditory M100 [16,19]. The same set of sensors was held constant for all subjects and all stimulus categories.

In the analysis of the behavioral data, responses above a threshold of 1500 ms were excluded from the analysis, as were incorrect responses. Reaction times (RTs) increased as frequency decreased, ranging from 593 ms for the most frequent category to 732 ms for the least frequent (see Fig. 1). The differences in RTs showed a significant correlation in a regression against the log-frequency categories of the stimuli ($P<0.0001$, linear regression).

In the MEG data, three primary peaks were found, at approximately 150, 250 and 350 ms (Fig. 2) after stimulus presentation. The distribution of the magnetic fields for each of these peaks is given in Fig. 3, which shows distribution in a single stimulus category for a representative subject. The latencies of these peaks were determined as the RMS peaks in the periods of 100–200, 200–300, and 300–400 ms. Peaks in these ranges have been reported in prior MEG studies of visual word or character presentation [7–10,14,18]. The latencies of the M150 and M250

Table 1
Word-frequency categories

Category	n/Million	Log frequency	Example
1	700	2.8	Number
2	140	2.1	Ask
3	30	1.4	Wheel
4	6	0.7	Candle
5	1	0	Clam
6	0.2	−0.7	Snarl

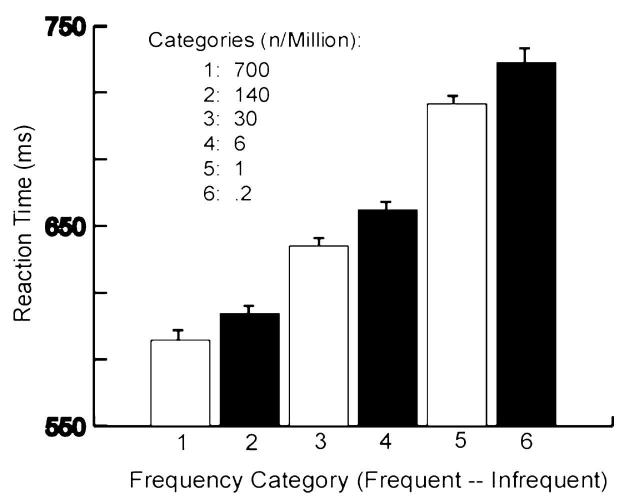

Fig. 1. Reaction time by frequency category (Mean and S.E.).

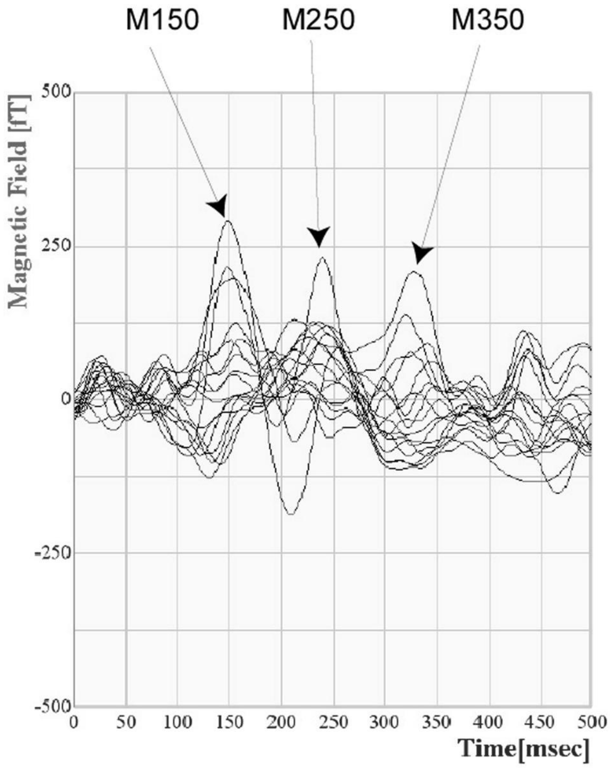

Fig. 2. Waveform illustrating M150, M250, and M350 components.

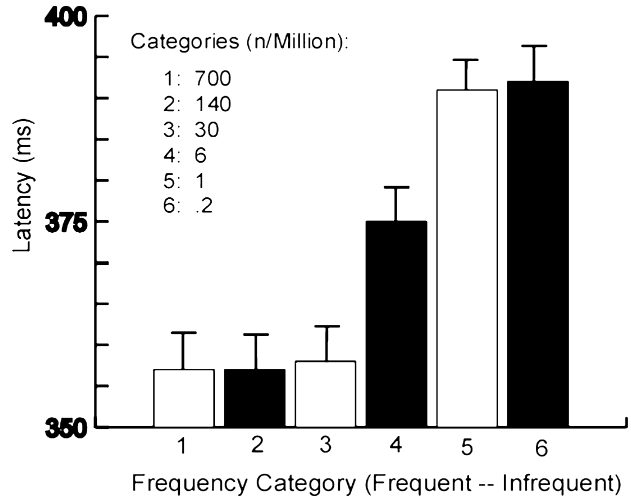

Fig. 4. Latency of M350 by frequency category (Mean and S.E.).

peaks did not vary systematically with stimulus category ($P=0.65$ and 0.8, respectively, linear regression against log-frequency). The third component, M350, had an average latency ranging from 357 ms for the most frequent to 392 ms for the least frequent. The latency of this component increased as stimulus frequency decreased (Fig. 4), and was significantly correlated with the log-frequency category of the stimuli ($P<0.0001$; linear regression). However, it is not clear if a linear model is the best fit for the trend observed in Fig. 4.

The primary objective of this study was the identification of a neural component whose latency reflects lexical frequency. The results show that such a component can be identified, with a latency of approximately 350 ms (M350). The latency of this component is also affected by repetition priming in MEG [15] (its amplitude is affected by frequency as well [18]). The interpretation of these results must be framed against a background of theories that make specific claims about the time-course of lexical access. Our findings show that the earliest component whose latency can serve as a predictor for frequency-effects occurs at 350 ms. Earlier studies of the time-course of lexical access have proposed specific estimates for the time-course of lexical access. One model places the identification of words at around 200 ms (cf. summary in [13]). However, it is unclear whether or not this model makes any predictions about the latency of a component that correlates with the frequency-effect.

The model for picture-naming summarized in [12] has a time-course of 0–150 ms for visual processing/concept

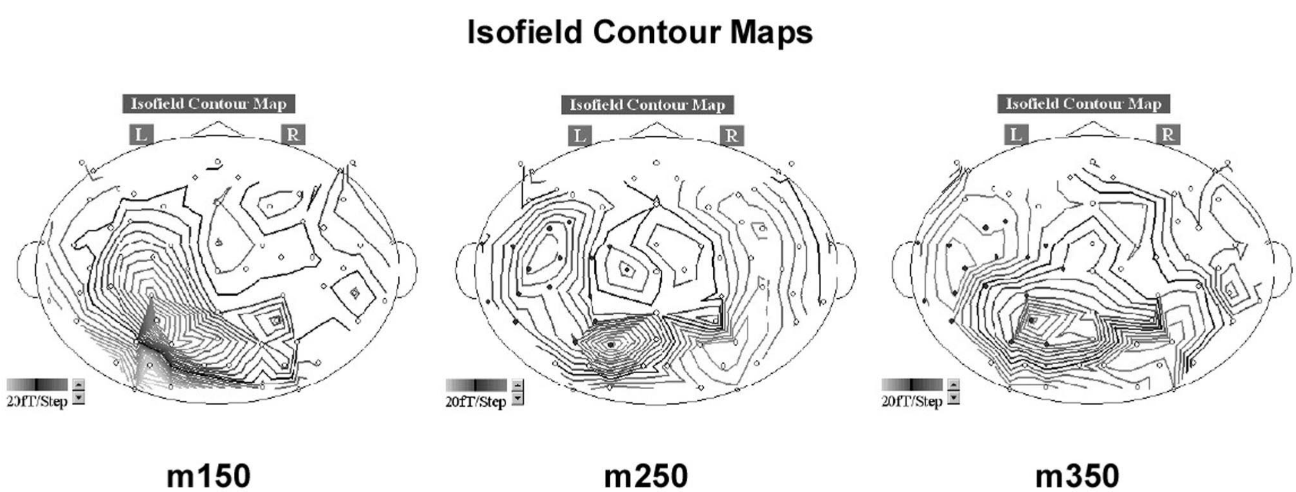

Fig. 3. Contour maps showing sensor distribution of MEG components.

access, 150–275 ms for lemma selection, and 275–400 ms for phonological encoding. Frequency effects have been found in picture-naming tasks, and have been attributed to a level at which word-forms are accessed [5]: between 270 and 400 ms in this model. The finding presented here is thus compatible with the time-window predicted by this model (although [12] found no component reflecting this effect). Interpreting this connection further, however, would require clarification of the differences between picture-naming and lexical decision tasks.

A question for further research is whether the M350 has the same generator as the N400, or measures the same response that of the N400 indexes.

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