MEG Studies of Lexical Access

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1 Introduction

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. However, despite numerous behavioral and imaging studies on word recognition, the time course of lexical processing remains a controversy. The challenge faced by both behavioral reaction time (RT) and by neuroimaging studies is to create experimental situations which allow differences in RTs or in brain responses to be interpreted as reflecting differences in some particular cognitive process. In what follows I first lay out various methods for addressing this question both behaviorally and with neuroimaging and then report results of specific experiments from the KIT/MIT MEG laboratory employing some of them.

2 Methods: What neuroimaging can add to the study of lexical access

Reaction time studies use at least three methods for determining what cognitive processes lie behind what behavioral effects. One is to have the experimental task require processing only up to the level of interest. For example, while a word-like stimulus always activates multiple entries in the lexicon, a nonword can be judged as the same or different from a previous stimulus without comparing it to the entries it has activated; all that is needed for task performance is comparing the stimulus to the preceding stimulus (Vitevich and Luce 1997, 1999). In this type of task, competition between lexical representations is not induced and hence differences in RTs can be attributed to some earlier stage of processing. On the other hand, if the task is to decide whether a given stimulus is a real word or not, comparing it to all the active representations in the lexicon is necessary for determining whether or not it matches an entry. If this type of task yields differences in RTs that are not found in the more "low-level" same-different task, they must be due to a later processing level than the effect found in the same-different task. Thus, task manipulations can help us narrow down the cognitive processes behind a behavioral effect, provided that our models of different tasks are specific enough.

The second purely behavioral way to investigate the time course of lexical processing is to vary the interval between a prime and a target (so-called *stimulus onset asynchrony*, SOA). When the processing of one stimulus facilitates the processing of another, the first stimulus (i.e. the prime) is said to *prime* the second (the target). By varying the SOA we can, at least to some extent, vary the amount of processing that takes place on the prime. Thus if we have a hypothesis about the cognitive process on the prime that facilitates the processing of the target, we can study the timing of that process by shortening the SOA until the priming effect disappears. For example, if NURSE primes DOCTOR when the SOA is 250 ms but not when the SOA 150 ms, we know that the process evoked by NURSE that facilitates the processing of DOCTOR takes at least 150 ms occur. The opposite inference, i.e. that the facilitating process must take place within 250 ms, does not, however, follow since the processing of the prime may continue even after the target has been presented.

Finally, we can investigate whether a priming effect is due to automatic lexical processing or to more conscious post-lexical processing by masking the prime. In such a design the prime is made invisible to conscious recognition by, for example, showing it for a very short time sandwiched between nonlinguistic symbols. If such a prime speeds up RTs to the target, we can infer that the priming effect is due to automatic rather than conscious processing.

In sum, reaction time studies allow us to make two types of inferences about the time course of lexical processing. First, we can draw conclusions about the ordering of effects: effect A must take place before effect B if, for example, A is observed in some low-level task in which B isn't, if A is observed at a shorter SOA than B or if A is elicited in masked priming while B isn't. Second, we can estimate how long it must *at least* take for some cognitive process to occur by varying SOA. However, what behavioral methods cannot give us, is specific time windows for specific operations.

Electrophysiological measures such as EEG and MEG allow measuring the latencies of all response components between stimulus onset and RT and hence potentially have the additional dependent variables necessary for addressing the specific timing of different processes. Thus they make it possible to locate the source of a behavioral effect in time as the first response component sensitive to the stimulus manipulation eliciting the RT difference. Furthermore, the additional data allow the simultaneous study of facilitory and inhibitory effects, which is impossible in purely behavioral studies: in brain data one response component can be faster and another slower in the test condition than in the control condition but an RT effect can only go one way for any one comparison.

Below I describe three MEG experiments addressing the time course of lexical activation. These studies show that (i) the first response component sensitive to stimulus properties affecting lexical access peaks between 300 and 400 ms after stimulus presentation and (ii) that this component can be manipulated independently of RTs if we vary stimuli both along a dimension that facilitates lexical access and along a dimension that slows down postlexical processing.

3 **Manipulating lexical access** (Embick et al. 2000, Pylkkänen et al. 2000)

Two experiments varied stimulus properties known to affect lexical access and examined what response component was the first one to show sensitivity to these stimulus properties. Embick et al. (2000) based their study on the well-known behavioral effect of word frequency. Words were divided into six categories with a (log) linear decrease in frequency across categories. As predicted, RTs increased with the decrease in frequency. Among the MEG response components to visually presented words in the left hemisphere, the earliest component whose latency co-varied with RTs peaked at about 350 ms post-stimulus onset (the M350). Pylkkänen et al. (2000) showed that the M350 is also the first component showing a repetition priming effect. Primes and targets were presented 1000 ms apart (prime duration 500 ms + 500 ms SOA). Repetition decreased both RTs and M350 latencies but not the latencies of any earlier components.

These studies located the frequency and repetition priming effects at 350 ms post stimulus onset. If the M350 reflects automatic lexical activation, it is also predicted to vary independently of RTs if lexical activation and postlexical processing are simultaneously manipulated but in opposite ways.

To test this prediction we conducted a third experiment which we based on the behavioral results of Vitevich and Luce (1999). Vitevich and Luce varied tasks to show that phonotactic probability (i.e. how common the sounds and sequences of the word are) and phonological neighborhood density (i.e. how crowded a word's phonological similarity neighborhood is) affect different levels of processing. In a same-different task, nonwords with a high phonotactic probability are responded to faster than nonwords with a low phonotactic probability. This can be interpreted as a sublexical frequency effect: the processing of high probability items is facilitated because they involve feature combinations that are common in the language and that are, therefore, activated often. However, if the task is lexical decision, high probability items elicit *longer* RTs. This is because high probability items come from dense similarity neighborhoods and therefore activate many related lexical entries. This means that they induce intense competition, which slows down reaction times.

We predicted that high probability words and nonwords should show shortened lexical access times, while the dense neighborhoods of such items should make their RTs longer. We found that under these conditions, the M350 latency and RTs do move in opposite directions: high phonotactic probability shortens M350 latencies while high neighborhood density simultaneously lengthens RTs. This result eliminates all postlexical interpretations of the M350: if the M350 indexed a post-access processing stage, its latency should reflect RTs also in the probability/density experiment.

4 Further predictions and relationship to the N400

The studies summarized above show that the first MEG component that is sensitive to stimulus properties affecting lexical access occurs between 300 and 400 ms and that this component is independent of processes following lexical access. These results are compatible with other studies of visual word recognition where activity in the 300-400 time range has been manipulated (e.g. Sekiguchi et al. 2000, Helenius et al. 1999). Our hypothesis that the M350 indexes lexical access makes the further predictions that (i) in addition to being sensitive to phonological factors, it should show semantic priming (as lexical entries are the connections between sound and meaning) and (ii) it should be the earliest shared component between auditory and visual word processing. These predictions are currently being tested in our laboratory.

The M350 results reported here are also important for determining what cognitive process underlies the N400 event-related potential. The M350 and the N400 have similar latencies and are sensitive to the same stimulus properties. Furthermore, the M350 source, which we have localized into the temporal lobe approximately 4 cm below the auditory cortex, shows the same field distribution as the auditory M100 source, corresponding to the ERP N1, i.e. a negative-going wave in ERP measured over midline electrodes. Thus the M350 generator could plausibly contribute to the N400, a negative-going ERP wave measured over midline electrodes. If the M350 and the N400 indeed have the same generator, our results provide further evidence that the N400 reflects automatic lexical access rather than a post-lexical processing. This is in line with recent results by Deacon et al. (2000) who show that the N400 shows a semantic priming effect even in masked priming.

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