BRAIN RESEARCH 1180 (2007) 39–58

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Research Report

Exploring the temporal dynamics of visual word recognition in the masked repetition priming paradigm using event-related potentials

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ARTICLE INFO

Article history:
Accepted 1 June 2007
Available online 21 September 2007

Keywords:
Visual word processing
Word recognition
N400
N250
Masked priming

ABSTRACT

The present study used event-related potentials (ERPs) to examine the time-course of visual word recognition in a masked repetition priming paradigm. In two experiments, participants monitored a stream of words for occasional animal names, and ERPs were recorded to non-animal critical target items that were either repetitions or were unrelated to the immediately preceding masked prime word. In Experiment 1, the onset interval between the prime and target (stimulus-onset-asynchrony—SOA) was manipulated across four levels (60, 180, 300 and 420 ms) and the duration of primes was held constant at 40 ms. In Experiment 2, the SOA between the prime and target was held constant at 60 ms and the prime duration was manipulated across four levels (10, 20, 30 and 40 ms). Both manipulations were found to have distinct effects on the N250 and N400 ERP components. The results provide converging evidence that the N250 reflects processing at the level of form representations (orthography and phonology) while the N400 reflects processing at the level of meaning.

1. Introduction

Visual word recognition occurs rapidly and with little apparent mental effort in skilled readers (Rayner, 1998). For over two decades, behavioral researchers have used the masked priming technique to help unravel the temporal dynamics of the mental processes underlying this skill (see Forster et al., 2003; Grainger and Jacobs, 1999; for reviews). Although there are several versions of the masked priming technique, the one typically used to study word processing involves the rapid sequential presentation of a series of visual stimuli: a forward mask (e.g., a series of hash marks #########) followed by a *prime* (usually a word), a backward mask (another row of hash marks) and finally a *target* stimulus, to which participants are asked to make a speeded judgment (e.g., lexical decision). Critical to the typical pattern of effects is that the prime be very briefly displayed (e.g., 50 ms) and that it be sandwiched between the presentation of the preceding forward and subsequent backward masking stimuli which together serve to make the prime imperceptible (i.e., participants are usually unaware of its presence). However, even with such brief exposure, the prime can produce robust effects on subsequent processing as indicated by changes in reaction time and/or error rates to the target. The classic finding is that when the prime and target are the same word, responses to the target are facilitated compared to the baseline condition were the prime and target are different unrelated words. This "repetition priming" effect,

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doi:10.1016/j.brainres.2007.06.110

which has been widely interpreted as indicating that processing of the masked prime interacts with the stream of processes involved in recognizing the target, has proven to be one of the most useful techniques for helping researchers study visual word recognition.

Recently, a number of studies have used the masked repetition priming paradigm in combination with the recording of event-related potentials (ERPs; Schnyer et al., 1997; Misra and Holcomb, 2003; Holcomb et al., 2005; Holcomb and Grainger, 2006; Kiyonaga et al., 2007; Grainger et al., 2006; Petit et al., 2006; Eddy et al., 2006). In one such study, Holcomb and Grainger (2006) found that the N400 component was larger to target words following unrelated primes than primes that were identical to or nearly identical to the target. This pattern is similar to that found in a multitude of unmasked repetition and semantic priming studies (e.g., Bentin et al., 1985; Holcomb et al., 2005) and has been interpreted as reflecting processing of the semantic attributes of the stimuli.

Of most interest for the present study were the findings on two earlier components not previously reported in ERP priming studies (but see Grossi and Coch, 2005). The first of these components, called the N/P150, peaked in the time frame of the exogenous N1. It was a relatively focal effect being most notable over right occipital sites and took the form of a larger positivity to target words preceded by orthographically and lexically unrelated masked prime words compared to targets there were repetitions of their primes. Holcomb and Grainger attributed this earliest of repetition effects to the greater overlap of visual features in the repeated compared to the unrelated targets. The second effect was a more widely but somewhat frontally distributed ERP negativity that started around 170 ms and peaked near 250 ms. Holcomb and Grainger referred to this as the N250 component, and argued that it was sensitive to the degree of orthographic overlap between the prime and target stimuli, as it proved sensitive to the number of letters that the prime and target had in common, being largest when primes and targets shared no letters, intermediate when prime and target shared several letters (partial repetition) and smallest when they shared all letters (full repetition). Collectively, these findings demonstrate that ERPs are highly sensitive to the time-course of early processing in the visual word recognition system and suggest that the combination of the masked priming technique with the recording of ERPs may be very useful for examining a host of issues that are difficult to address with reaction time alone. The general picture that arises from this work so far (see Grainger and Holcomb, in press, for review) is that a series of ERP components, the N/P150, N250 and N400, reflect a cascade of processes triggered on presentation of a printed word and primarily involve feature representations (N/P150), form representations (N250) and meaning (N400). Although Holcomb and Grainger (2006) and Grainger and Holcomb (in press) provided a more detailed analysis of the mapping of ERP components onto the process of visual word recognition, the above description summarizes the essential ingredients of that analysis for the purposes of the present study.

Interestingly, however, several studies prior to Holcomb and Grainger that also used ERPs in the masked repetition priming paradigm did not find evidence for repetition effects earlier than the N400 (Misra and Holcomb, 2003; Holcomb et al., 2005). The biggest difference between these earlier studies and the Holcomb and Grainger experiment was the duration of the interval between the prime and target events. In Holcomb and Grainger (2006), and most of the work done by behavioral researchers interested in word recognition, the prime–target interval (stimulus-onset-asynchrony-SOA) has been relatively short. In Holcomb and Grainger (2006), it was 70 ms (50 ms duration of the prime and a 20 ms backward mask with the target immediately replacing the backward mask). In earlier ERP masking studies, typical prime–target SOAs have been between 500 and 1000 ms. These longer SOAs have been used to avoid problems with the overlap of ERPs that occurs when multiple events are presented in a short period of time. Holcomb and Grainger suggested that many of the early ERP effects that proved sensitive to visual word processing in their study might have been refractory at the longer SOA used in the Misra and Holcomb (2003) and Holcomb et al. (2005) studies. This seems reasonable given that at least one behavioral study has also found that RT is sensitive to word processing manipulations in the masked priming paradigm, but only when the SOA is shorter than 500 ms (Ferrand, 1996).

Experiment 1 of the current study is a follow-up to the Holcomb and Grainger experiment and the earlier long interval masked priming studies (Misra and Holcomb, 2003; Holcomb et al., 2005). Here we explicitly manipulated the interval between primes and targets in the masked priming paradigm between the values used in these previous studies (60, 180, 300 and 420 ms). If prior studies failed to find early onset ERP masked repetition priming effects due to the relatively long SOAs employed, then it seems reasonable to predict that earlier effects should emerge at some point along the interval of SOAs used in the earlier studies (e.g., 500 ms in Holcomb et al., 2005) and the more recent Holcomb and Grainger study (70 ms).

In Experiment 2, the SOA was held constant at 60 ms and the duration of the masked primes was varied between 10 and 40 ms. Prior work has shown that the amplitude of the N400 repetition priming effect is sensitive to prime durations in the range of 40 to 80 ms (Holcomb et al., 2005). What is not known is what happens when the prime duration is reduced below 40 ms. Furthermore, the prime duration manipulation of Experiment 2 allows a within-condition analysis of priming effects as proposed by Jacobs, Grainger, and Ferrand (1995). The main effect of prime duration (or prime intensity if prime duration is held constant) is analyzed for each prime condition separately, in order to examine how increased availability of information from the prime stimulus is modulating the influence of each type of prime on processing of target stimuli. Jacobs et al. (1995) demonstrated that the overall size of masked repetition priming effects found with word stimuli in the lexical decision task was due to a combination of slowing down of response times (RTs) in the different prime condition and faster RTs in the repetition prime condition. The same logic can be applied to the amplitude of ERP components. Although it is not yet possible to unambiguously interpret the direction of ERP effects in terms of underlying processes, concerning the N400 component, it is generally assumed that increased negativity reflects more processing effort (e.g., Holcomb, 1993). Therefore, the incremental priming technique