Psychophysiology, 40 (2003), 115–130. Blackwell Publishing Inc. Printed in the USA.

Event-related potential indices of masked repetition priming

MAYA MISRA AND PHILLIP J. HOLCOMB
Department of Psychology, Tufts University, Medford, Massachusetts 02155, USA

Abstract

Two experiments sought to identify event-related potential (ERP) correlates of masked repetition priming of words in lists and to verify that such effects are not due to brief prime durations. In Experiment 1, prime stimuli were masked and their durations were individually titrated for each participant. Targets that were immediate or delayed repetitions of masked primes resulted in attenuation of the N400, with little or no enhancement of a late positive component (LPC). Delayed, in-the-clear repetitions of unmasked targets led to attenuation of the N400 and enhancement of the LPC. Experiment 2 used similar stimulus timing parameters, but primes were unmasked. More typical unmasked repetition effects were observed for immediate repetitions including a larger attenuation of the N400 and enhancement of the LPC. These findings are discussed within current notions of the functional significance of the N400 and LPC.

Descriptors: ERPs, Repetition, Masked priming, N400, LPC

Psychologists have long known that the context in which information occurs plays an important role in how it is processed. Numerous studies have shown that even a single contextual clue or "prime" can influence the speed and efficiency of subsequent "target" processing, as is the case when prime and target items are semantically related words (e.g., doctor—NURSE) or when the prime and target are repetitions of the same word (e.g., nurse—NURSE). Such priming effects have played an important role in theories that attempt to explain the structure and function of memory and language processing systems (e.g., Forster, 1998; Jacoby, 1991; Neely, 1991; Schacter, 1992; Squire, 1992; Tulving & Schacter, 1990).

Repetition priming, which is the focus of the current study, typically takes the form of more accurate and faster behavioral responses to repeated as opposed to nonrepeated items, even when words repeat after many intervening items (e.g., Ratcliff, Hockley, & McKoon, 1985; Rugg, 1985; Stark & McClelland, 2000). A similar pattern of effects has been observed in semantic priming paradigms (in which the prime and target are semantically related words, such as dog and cat, as opposed to the same word as in repetition priming). However, whereas semantic priming effects are thought to be exclusively due to semantic similarities between primes and targets, additional sources of priming are available in repetition paradigms (e.g., prime/target orthographic and phonological overlap). Observed repetition priming effects may therefore reflect activation at any or all of these various levels.

Over the past 20 years, another form of priming has been widely investigated (e.g., Cheesman & Merikle, 1985; Forster & Davis, 1984; Marcel, 1983). In these studies the prime stimulus is presented very briefly and is then immediately obscured by either a pattern mask (e.g., a series of letters or symbols occupying the same location on the screen as the prime) or the target word itself. Using this procedure, participants are usually unable to report having seen the prime word, let alone identify it (in fact, in many studies participants retrospectively claim to be surprised that words were presented in the prime position). The typical finding is that in-the-clear target words produce faster response times (RTs) and result in fewer errors when they follow primes (both repetition and semantic) that are masked below levels of awareness, although such effects are typically somewhat smaller than comparable effects measured to targets following supraliminal primes (e.g., Forster & Davis, 1984; Marcel, 1983). The original functional explanation proposed by Marcel (1983) still seems to be the most widely accepted interpretation of the underlying processes that account for this phenomenon: Masked priming results from the same set of processes that produce supraliminal priming, with the exception of those that require conscious awareness of the prime (but see Kahan, 2000). In other words, masked priming results from what are thought to be the automatic components of word recognition processes. Forster (1999) has proposed that in the case of masked repetition priming, this includes word recognition processes up to and including lexical access. One inference that can be drawn from this interpretation of masked priming results is that much of what occurs during normal word recognition goes on outside of awareness.

Many studies have shown that repetition priming produces characteristic differences in event-related potentials (ERPs) as well as behavioral responses. Repeated words produce attenuated N400 s compared to nonrepeated words (e.g., Düzel,

This research was supported by NICHD grant # HD25889 to the second author.

Address reprint requests to: Phillip J. Holcomb, Department of Psychology, Tufts University, 490 Boston Ave., Medford, Massachusetts 02155, USA. E-mail: pholcomb@tufts.edu.

Yonelinas, Mangun, Heinze, & Tulving, 1997; Rugg, 1985, 1990; Rugg, Doyle & Wells, 1995; Rugg & Nagy, 1989; Van Petten, Kutas, Kluender, Mitchiner & McIsaac, 1991). Such N400 "effects" are believed to be sensitive to the lexical and/or semantic properties of the stimulus and its context (Van Petten et al., 1991). Words that are easily integrated with their contextual framework produce an attenuated or nonexistent N400, whereas those that are impossible or difficult to integrate with the surrounding context generate larger N400 s (refer to Van Petten, 1993). The N400 repetition priming effect, then, is believed to reflect greater ease in accessing and integrating the word upon its second presentation than at first presentation. In addition to affecting the N400, word repetitions also result in changes in a late positive component (LPC), which occurs slightly after the N400 and is larger to repeated items than items presented for the first time in an experiment (e.g., Rugg, 1990).

Several lines of evidence suggest that the N400 and LPC are separate components reflecting different underlying cognitive/neural processes. Repetitions of both high- and low-frequency words elicit the earlier (N400) repetition effect, but only repeated low-frequency words elicit the LPC (Rugg, 1990). Also, N400 repetition effects occur at short and intermediate prime-target intervals (lags), but not at longer lags, whereas the LPC occurs at both short and long lags (Rugg & Nagy, 1989). These findings are consistent with the hypothesis that the N400 reflects more automatic lexical/semantic processing, whereas the LPC reflects some aspect of episodic memory retrieval (Van Petten et al., 1991). Moreover, it has been suggested that the LPC depends on conscious recollection of the prime–target relationship (Düzel et al., 1997).

There is some controversy, however, as to whether N400 effects might also require conscious processing. Holcomb (1988) reported that the N400 effect in a semantic priming task was significantly larger when participants were encouraged to use conscious strategic resources to process prime/target relationships than when instructions and the proportion of related items encouraged subjects to ignore the relationship and process it automatically (see also Chwilla, Brown, & Hagoort, 1995). Results of selective attention paradigms have also led some to suggest that N400 effects require conscious processing to occur. In a repetition priming experiment with native Japanese speakers using Kanji, repetitions of unattended primes resulted in negative deflections in the ERPs to the target words between 450 and 700 ms, whereas repetitions of attended words resulted in a typical priming effect on the N400 consisting of a positive deflection of the ERP waveform between 300 and 550 ms (Yamagata, Yamaguchi, & Kobayashi, 2000). Experiments in English have also failed to find N400 priming effects for unattended words (McCarthy & Nobre, 1993; Otten, Rugg, & Doyle, 1993).

Masked priming paradigms have also been used to evaluate automatic effects on the N400. Recall that behavioral priming studies have established that masked primes speed reaction times and increase accuracy in both semantic and repetition priming experiments. This pattern has typically been interpreted to indicate that word recognition processes up to and including lexical access are largely automatic (e.g., Forster & Davis, 1984; Marcel, 1983). Brown and Hagoort (1993) used this logic to determine if there was an unconscious/automatic, and therefore purely lexical, contribution to the N400. Using both masked and unmasked semantic primes they found evidence for modulation of target N400s only when primes were not masked. They concluded that the N400 is sensitive to higher order (conscious) lexical integration and not to automatic lexical access.

More recently, Schnyer, Allen, and Forster (1997) reported a significant N400 effect with masked repetition priming. Words that were flashed for 48 ms and then repeated after a word that served as the masking stimulus showed a positive shift in their ERPs between 400 and 800 ms (i.e., an N400 attenuation). However, if the repeated item was the second word after the masking item, the ERPs to the repeated items were indistinguishable from those for new words. Unmasked repetitions produced a broad attenuation ranging from 200 to 1,000 ms when participants were asked to make recognition judgments, although this effect was not present when they replicated the experiment with a lexical decision task (LDT). By 500 ms, the late positivity associated with recognition judgments of unmasked words was statistically larger than for the masked repetitions. The authors concluded that their results support the view that the early (N400) ERP repetition effect may be automatic and reflect implicit memory processing, whereas the later (LPC) ERP repetition effect relies at least in part on conscious recollection processes.

Schnyer et al.'s (1997) study of masked repetition priming challenges the previous conceptions of the N400 as reflecting an exclusively conscious process (see also Deacon, Hewitt, Yang, & Nagata, 2000) and suggests that the N400 may in fact be sensitive to word recognition processes that are widely thought to be automatic (Forster, 1999). However, their study left a number of issues unresolved. First, their experimental design did not take into account individual variations in priming thresholds. Previous studies have shown that there are significant individual differences in the timing parameters needed to effectively mask words below recognition levels (e.g., Cheesman & Merikle, 1984). Second, no method was used to verify that primes were presented at recognition thresholds other than subjective accounts of prime awareness reported at the end of the experiment, and even by this measure approximately 20% of the subjects reported awareness that at least some of the masked words were later repeated. Both of these problems leave it unclear whether the observed masked N400 priming effects reflect purely automatic implicit processing effects or whether they simply reflect some degree of residual conscious processing (or a combination of the two). Finally, Schnyer et al. compared masked and unmasked repetition priming effects under different circumstances that prevented direct comparisons of the processes involved in each condition: Masked priming was evaluated within one phase of the experiment, whereas unmasked priming effects were observed across two separate phases of the experiment.

EXPERIMENT 1

Experiment 1 also sought to determine if there are ERP effects associated with masked repetition priming. Participants were presented with pairs of items consisting of a brief pattern masked prime and a subsequent clearly visible target word. Masked primes could be repeated as unmasked target words either within the same trial (i.e., immediate repetition) or across trials (i.e., delayed repetition). Unmasked target words were also repeated across trials to allow for a comparison between masked and unmasked repetition priming effects within a single paradigm. Participants performed a semantic categorization task in which they were instructed to monitor all stimuli for occasional exemplars from a designated category of probe words (animal names), and to press a button when such items were detected. No response was required to other (nonanimal) stimuli. Use of this task insured that participants attempted to process all words semantically, provided data for the evaluation of behavioral priming effects (i.e., enhanced speed of response to repeated probe items), and allowed the recording of ERPs to nonprobe items that did not require a behavioral response (thus avoiding contamination with motor-related potentials and equating task relevance for trials of interest).

Crucial to the interpretation of masked priming results is the assurance that primes are *effectively* masked. In the current experiment "effective" was operationally defined as participants being near chance levels in detecting a word's semantic category. Several precautions were implemented to assure this level of masking. First, the parameters of masking were carefully selected by titrating prime durations for each participant prior to the beginning of the formal ERP experiment. The criteria used to select prime durations resulted in participants not being able to accurately identify the semantic category of the masked item. Second, to check that primes were effectively masked during the experiment, animal names were presented in both the target and masked prime positions. A significant number of button presses to animal probe words in the prime position or the presence of an ERP difference between animal and nonanimal masked primes (e.g., a larger P3 to animal names) would indicate that primes were not effectively masked and were processed explicitly. Third, in a further test of masking effectiveness, a postexperimental recognition test was used, which compared hit rates for items presented as masked primes and unmasked targets to false alarms for a matched list of foil items. Hit rates for masked primes should be much lower than for targets and approximately the same as the false alarm rate for foils if masking was effective.

The following predictions were made. First, following Schnyer et al. (1997), it was predicted that even under conditions of effective prime masking there would be an attenuation of the N400 to target words immediately preceded by identical masked primes as compared to target words preceded by an unrelated masked prime word. It was hypothesized that this would occur because the N400 is sensitive to lexical processes that are, at least to some degree, automatic or implicit in nature and therefore not entirely reliant on conscious explicit memory representations. Second, it was predicted that there would not be a comparable increase in the amplitude of the subsequent LPC, as this ERP component is primarily sensitive to conscious explicit memory processes that are largely blocked by effective masking. It was also predicted that targets occurring several trials after an identical masked prime would not show the same degree of N400 attenuation seen to targets immediately following a masked prime. This is hypothesized to be because the automatic/implicit process indexed by the masked N400 should be of limited duration. In contrast it was predicted that targets that were primed several trials earlier by the same unmasked targets would show an N400 attenuation (Rugg, 1990). If these last two predictions were upheld, it would suggest that somewhat different factors contribute to masked and unmasked N400 effects. It was also predicted that, due to the influence of explicit recollective processes, targets primed several trials earlier by the same unmasked targets would produce an LPC enhancement. Finally, it was predicted that behavioral masked priming effects, in terms of speeded RTs for primed probe words, may be observed for animal target hits. Although previous behavioral studies of masked repetition have failed to find significant masked repetition effects over a lag (e.g., Humphreys, Besner, & Quinlan, 1988), these studies have used word naming rather than the semantic categorization task adopted here. This task may require deeper semantic processing of items resulting in more robust priming effects (see Dorfmueller & Schumsky, 1978, for evidence of greater priming on reaction time measures with depth of processing manipulations).

Method

Participants

Sixteen right-handed, native-English-speaking undergraduates at Tufts University (10 female, mean age = 19.44 years, *SD* = 2.66 years) received partial course credit for their participation in this experiment.

Stimuli

One hundred animal words and 400 nonanimal words (all four- or five-letter concrete nouns, frequency less than 30 per million; Kučera & Francis, 1967) were used as stimuli. The nonanimal words were divided into eight groups of 50 items (length and frequency balanced across groups) and the animal names were separated into two groups of 50 items. These groups were systematically combined to make eight stimulus lists such that each list included all ten groups of 50 items, and across lists each group occurred at least once in each possible condition (nonanimal in all nonanimal conditions and animal in all animal conditions). Stimuli were arranged and presented as trials, where a trial consisted of a lowercase prime stimulus followed by a pattern mask and then an uppercase target stimulus. There were a total of nine different trial types in which stimulus items could appear as primes, targets, or both (see Table 1). Five trial types had blanks in the prime position, but all target positions were occupied by words.

The trial types allowed for comparisons to be made between unrepeated targets (Type 1) and targets repeated after a delay (Type 2), which is the traditional form of in-the-clear repetition priming. In addition, targets immediately following identical masked primes (Type 3) or following masked primes over a delay (Type 5) were compared with targets following unrepeated masked words (Types 4 and 9) or targets following masked blanks (Type 1), respectively.[1] The primes and targets of Type 9 also served as recognition memory test stimuli in a behavioral posttest (note that each of these words occurred only once during the experiment). Fifty of the nonanimal words were never seen during the experiment and served as foils for the behavioral recognition posttest.

Animal names (probes) could appear in the prime position of a trial (Type 6) or in the target position (Types 7 and 8). Consequently, behavioral priming effects could be evaluated by examining response times for target position animals repeated from a previous prime position and for those which appeared for the first time. Comparisons of the ERPs for masked animal primes (Type 6) versus nonanimal primes (Types 4 and 9) as well as for unmasked animal targets (Types 7 and 8) versus first presentation nonanimal targets (Type 1) were also evaluated to identify evidence of task-related processing to category exemplars.

[1] Different control conditions were used for these two types of trials so that targets following masked words were only compared to other targets following masked words, and targets following masked blanks were compared to other targets following masked blanks.

Table 1. *Trial Types in the Masked and Unmasked Repetition Priming Experiments with Sample Stimuli*

Trial type		Sample stimuli	
Prime	Target	Prime position	Target position
1. Blank prime	Unrepeated target		POUCH
2. Blank prime	Delayed repeated target		POUCH
3. Word prime	Immediately repeated target	posy	POSY
4. Word prime	Unrepeated target	shank	TONG
5. Blank prime	Delayed repeated prime		SHANK
6. Animal prime	Unrepeated target	moose	TWIN
7. Blank prime	Delayed repeated animal prime		MOOSE
8. Blank prime	Unrepeated animal target		LEECH
9. Word prime (recognition test stimuli)	Unrepeated target	trunk	GAUZE

For each of the delayed repetition conditions (i.e., Type 1 primes Type 2; Type 4 primes Type 5; Type 6 primes Type 7), between-item prime–target lag was pseudorandomly varied so that the second presentation of each word occurred between one and eight trials after the first presentation of the word (average = 4 trials).

Procedure

During a typical trial, a prime stimulus was presented briefly and was then obscured by a pattern mask (XXXXX) located in the same position on the computer screen (see Figure 1). This prime/mask complex could consist of a word and mask or a blank screen and mask (i.e., the mask alone). After 200 ms, the mask was replaced by a blank screen, which in turn was replaced by a 300-ms target word. After a 900-ms posttarget blank screen, the final event on each trial was an asterisk presented for 1,500 ms. This indicated the end of the trial and signaled that the participant could blink. Participants were not given any explicit instructions about the prime–target nature of the trials, nor were they told that the masks followed rapidly presented words in some cases (although the prime duration titration procedure—see below—certainly suggested the presence of words prior to the mask). Their only instructions were to press a button resting in their lap to all animal probes (hand counterbalanced across participants) and to refrain from blinking until the asterisk appeared on the screen (to minimize ocular artifact during recording of ERPs).

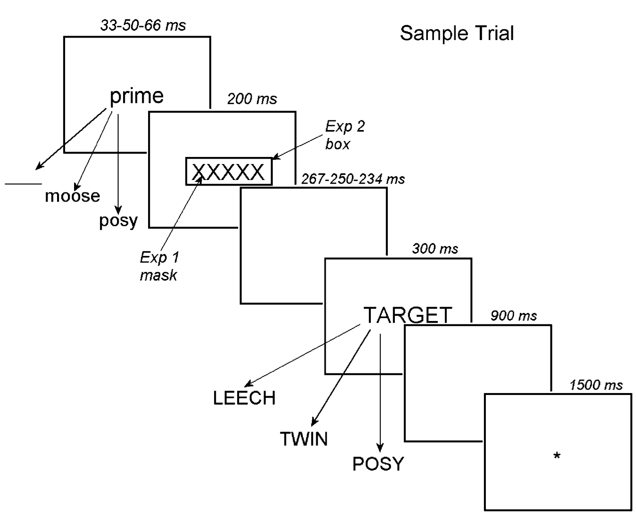

Figure 1. Schematic depiction of a sample trial.

The prime duration was titrated for each individual subject during preexperiment practice trials. Possible prime durations of 33, 50, or 66 ms were tested. To determine which prime duration would be used for a given participant, masked primes and unmasked targets were presented with a 2,000-ms interstimulus interval (ISI). Separate practice runs were conducted at each of the three possible prime presentation rates until one was found where the subject reached 33 to 66% accuracy at indicating the presence of an animal name in the prime position of a trial (chance = 50%).[2] A final block of practice trials with experimental mask–target ISIs was run to ensure that conscious identification of the words (or blanks) in the prime position could not reliably be made. The experimental trials were then all run using the prime duration set for each subject (mean prime duration = 43.44 ms, *SD* = 13.37).

Participants were seated in a sound-attenuated room for the duration of the experiment. All prime and target stimuli were presented on a computer monitor in white text on a black background. Stimulus presentation was controlled by an IBM-compatible PC using a DOS-based in-house stimulus presentation program. Presentation of the stimuli was tied to the vertical retrace interval of the monitor (i.e., 16.667 ms to "draw" each screen). The computer signaled when this interval occurred, and all timing was synchronized using that interval and the system's PC timer. The stimulus computer signaled the digitizing computer each time an event occurred (i.e., prime, target, button press), and these events were recorded in the raw files and corresponding log files that were generated for each participant.

[2]This response range was used because only three possible prime durations were used (due to limitations of the computer monitor). Because we wished to test participants as close to threshold as possible, we allowed some to perform the task slightly above the 50% accuracy level rather than testing them at a faster prime duration that lowered their accuracy to below 33%. However, every effort was made to choose a prime duration for each subject that resulted in a prime accuracy of as close to 50% as possible.

Analysis of logs from test data confirmed that primes and targets were presented with the desired timing parameters.

After the experimental task was complete, subjects were given 5 min to recall any words from the experiment that they could and then were given a self-paced old/new recognition memory test that consisted of a list of 50 unrepeated primes, 50 unrepeated targets, and 50 new foils presented in random order on a piece of paper. Participants indicated whether each of the 150 words was an old item or a new item by circling items recognized from the experiment.

EEG Procedure

Thirteen channels of EEG were recorded from scalp electrodes in an elastic electrode-cap (Electro-Cap International). Seven of the electrodes measured from standard International 10-20 system locations at right and left hemisphere frontal (F7 and F8) and occipital (O1 and O2) sites as well as frontal (Fz), central (Cz), and parietal (Pz) midline sites. Additionally, there were six electrodes at nonstandard locations previously shown to be sensitive to language processing (e.g., Holcomb, Coffey, & Neville, 1992). These sites are left and right temporal-parietal, which correspond roughly to Wernicke's region and its right hemisphere homologue (WL and WR: 30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz), left and right temporal (TL and TR: 33% of the interaural distance lateral to Cz), and left and right anterior-temporal (ATL and ATR: 50% of the distance between F7/F8 and T3/T4). Two electrodes measured the electrooculogram (EOG) to monitor for eyeblinks and horizontal eye movements, one below the left eye and one lateral to the right eye. All electrodes were referenced to the left mastoid, and the right mastoid was also recorded to verify that there was no differential mastoid activity.

Impedances for scalp and mastoid electrodes were reduced to less than 5 kΩ when possible, with the criteria for eye electrodes being less than 20 kΩ. The EEG was amplified by a Grass Model 12 amplifier system with a bandpass of 0.01 to 30 Hz and sampled continuously during the experiment at 200 Hz.

Data Analysis

Both behavioral and electrophysiological measures were used to evaluate the subjects' performances. The number of animal name hits was recorded as well as reaction times for responses to animal targets. Recognition test performance for both primes and targets was also evaluated. Paired-samples t tests were used to compare performance on each of these measures. For animal name hits and recognition test performance, frequency data were transformed before the t test was run using the following transformation: $2 \times \arcsin[\mathrm{sqrt}(\mathrm{score/total})]$ (Winer, 1971).

For the electrophysiological analyses, separate ERPs were averaged for each subject at each electrode site to provide waveforms using a baseline of 100 ms prior to presentation of either the prime or target stimulus and continuing throughout the trial. Only those trials that did not contain eye and muscle artifact were included in the averages. Mean amplitudes for latency windows of interest were compared using separate repeated measures ANOVAs (SPSS, version 10.0) for the lateral and midline sites. Variables of interest were target or prime conditions analyzed by electrode site (midline: Fz, Cz, Pz; lateral: F7/F8, ATL/ATR, TL/TR, WL/WR, O1/O2) and hemisphere (for lateral sites only). The Geisser–Greenhouse correction for nonsphericity was applied to variables with more than two levels. When interactions involving condition differences were statistically significant, simple effects analyses were performed by running separate repeated measures ANOVAs comparing the conditions across each level of the factor with which they interacted. Results with a p value of less than .05 were reported as significant. Note that only main effects and interactions involving condition differences are reported; significant channel or hemisphere effects independent of condition effects are not reported, as they do not relate to the key questions of how the various conditions differ from each other.

Results

Behavioral Results

Several behavioral measures were evaluated to determine if primes were adequately masked and to determine if this task resulted in behavioral masked priming effects.

Probe detection. When asked, most subjects reported an awareness of "something" in the prime position of the pairs, but most were not sure whether it was a word or some other stimulus. Animal name hits support these anecdotal reports. Few responses were made to animals in the prime position of trials, whereas most animal names in the target position were correctly responded to (see Table 2). Two-tailed, paired t tests confirm that prime hit accuracy was significantly lower than that for targets (primes vs. primed targets: $t(15) = -20.521$, $p = .000$; primes vs. unprimed targets: $t(15) = -20.098$, $p = .000$) but that the primed and unprimed animal targets did not differ statistically from each other.

Recognition test. Recognition test results also support the claim that primes were not consciously encoded during this experiment (see Table 2). Participants identified similar low numbers of primes and foils as recognized, and these two conditions did not differ statistically. Recognition test targets were chosen significantly more frequently than either of these (targets vs. primes: $t(15) = 7.175$, $p = .000$; targets vs. foils: $t(15) = 8.669$, $p = .000$).

Reaction time effects. Behavioral RT priming effects were evaluated for all target probe response trials (see Table 2). Due to the low numbers of responses to animal primes, RTs for these items were not computed. Although accuracy data did not differ for primed and unprimed animal targets, RTs showed that masked repetitions did lead to a priming effect, with speeded

Table 2. *Behavioral Results for Experiment 1*

	Mean percent accuracy (*SD*)	Mean reaction time in ms (*SD*)
A. Animal hits		
Primes	9.88 (13.18)	NA
Delayed repeated targets	85.00 (11.00)	679.66 (117.59)
Unrepeated targets	86.13 (10.52)	704.38 (123.62)
B. Recognition test		
Foils	10.13 (7.06)	—
Primes	11.75 (8.97)	—
Targets	32.50 (13.96)	—

responses to target animal names that had been preceded by a masked prime occurring one to eight trials earlier, $t(15) = 3.487$, $p = .003$.

Electrophysiological Results

Analysis epochs for the ERP results were identified based on previous ERP studies of word processing (e.g., Holcomb & Neville, 1990) and were confirmed by visual inspection of the grand average waveforms. For probe trials (i.e., animal names), P300 effects were evaluated for the interval of 400 to 1,000 ms post stimulus onset. The P300, a positivity enhanced to task-relevant events, would be expected to be observed for all animal words that were detected by the subjects; thus this component should provide an additional check on the success of the masks in blocking processing of the primes. For nonanimal target items, comparisons were made for the mean amplitudes of the N400 (between 300 and 500 ms) and the LPC (between 500 and 750 ms), components that are known to be sensitive to differential aspects of repetition and that were theoretically relevant to our hypotheses. In addition, a third epoch was analyzed for the nonanimal target items, because visual inspection suggested there might be an early effect of repetition on the P2 component (between 150 and 300 ms) that has been shown to be sensitive to word identification (e.g., Barnea & Breznitz, 1998). Mean amplitudes and standard deviation values for the critical conditions in each epoch (by electrode site) are provided in Table 3.

P300 effects on probe items. The pattern of effects on the P300 component provides further evidence that masked primes were unavailable for conscious processing. There was no evidence of a P300 to the masked animal primes as compared to nonanimal masked primes (see Figure 2a). Target animal names, on the other hand, demonstrated a large posteriorally distributed P300 when compared to nonanimal targets[3] (see Figure 2b). This effect began at about 200 ms at Pz and extended until near the end of the epoch (midline: $F(1,15) = 10.686$, $p = .005$; lateral: $F(1,15) = 10.504$, $p = .005$). In addition, a significant interaction was observed at midline sites of Condition $\times$ Channel, $F(2,30) = 24.933$, $p = .000$, as well as significant interactions at lateral sites of Condition $\times$ Channel, $F(4,60) = 10.783$, $p = .001$, and Condition $\times$ Channel $\times$ Hemi- $\times$ Hemisphere, $F(4,60) = 3.858$, $p = .027$. Simple effects analyses revealed that this large P3 for animal targets was significant at all but the frontal and anterior temporal sites (Cz: $F(1,15) = 8.040$, $p = .013$; Pz: $F(1,15) = 23.300$, $p = .000$; O1/O2: $F(1,15) = 13.082$, $p = .003$; WL/WR: $F(1,15) = 15.933$, $p = .001$; TL/TR: $F(1,15) = 9.659$, $p = .007$), consistent with the typically observed posterior distribution of P300 effects. A further Condition $\times$ Hemisphere interaction for O1/O2 was observed in the analysis of the three-way interaction; subsequent simple effects analyses revealed that the P300 effect was present at both sites (O1: $F(1,15) = 13.847$, $p = .002$; O2: $F(1,15) = 11.267$, $p = .004$), although the difference between the conditions was larger on average at the left hemisphere occipital site.

Immediate masked repetitions. As shown in Figure 3, immediately repeated targets (Type 3) following masked primes were compared to unrepeated targets following a different masked prime word (Types 4 and 9). During the P2 epoch, repetitions showed a greater positivity that was significant at midline sites, $F(1,15) = 7.947$, $p = .013$, and lateral sites, $F(1,15) = 6.421$, $p = .023$. There was also a significant N400 attenuation for the immediately repeated targets as compared to targets following unrepeated masked words (midline: $F(1,15) = 12.137$, $p = .003$; lateral: $F(1,15) = 6.772$, $p = .020$). Differences between these two conditions did not reach significance in the LPC epoch at either midline or lateral sites.

Delayed unmasked repetitions. In the P2 epoch, targets repeated after a delay of one to eight trials (Type 2) showed no significant difference when compared to unrepeated targets (Type 1), but these conditions did differ in the N400 epoch (see Figure 4). The N400 was significantly attenuated for delayed target repetitions as compared to unrepeated targets at both lateral, $F(1,15) = 13.306$, $p = .002$, and midline, $F(1,15) = 33.379$, $p = .000$, sites. There was also an enhanced LPC for these in-the-clear repetitions (lateral: $F(1,15) = 41.075$, $p = .000$, midline: $F(1,15) = 61.243$, $p = .000$). In the LPC epoch, the interaction between condition and channel also reached significance for lateral sites, $F(4,60) = 7.577$, $p = .003$. Simple effects analyses broken down by channel found that the conditions significantly differed at each channel (O1/O2: $F(1,15) = 12.904$, $p = .033$; WL/WR: $F(1,15) = 80.221$, $p = .000$; TL/TR: $F(1,15) = 45.053$, $p = .000$; ATL/ATR: $F(1,15) = 23.078$, $p = .000$; F7/F8: $F(1,15) = 18.252$, $p = .001$), with the delayed repeated targets consistently showing a greater LPC than the unrepeated targets.

Delayed masked repetitions. Small but consistent differences were observed between delayed repeated targets following a masked prime (Type 5) and unrepeated targets (Type 1; see Figure 4). These differences took the form of a slightly more positive waveform for repeated items, especially at midline and right hemisphere sites in the N400 epoch (lateral: $F(1,15) = 4.693$, $p = .047$; midline: $F(1,15) = 8.446$, $p = .011$). A significant interaction between condition and hemisphere for the lateral sites in this epoch, $F(1,15) = 5.525$, $p = .033$, reflected the fact that differences between these conditions were greater in the right hemisphere than the left. No significant differences between the first presentations and delayed repetitions of masked primes were observed in the earlier, P2 epoch or the later, LPC epoch.

A further comparison of delayed masked repetitions (Type 5) with delayed unmasked repetitions (Type 2) was conducted to determine how these two conditions differed from one another. These target conditions could be directly compared, because each had a blank in the prime position and was a repetition of an item occurring one to eight trials earlier. Masked and unmasked delayed repetitions did not differ significantly in the P2 epoch. However, in the N400 epoch, the ERP for the delayed masked repetitions was significantly more negative than the ERP for the delayed unmasked repetitions at midline sites, $F(1,15) = 5.092$, $p = .039$. In the LPC epoch these two conditions also differed (midline: $F(1,15) = 19.132$, $p = .001$; lateral: $F(1,15) = 17.351$, $p = .001$), with delayed unmasked repeated targets producing a larger LPC than delayed masked repeated targets. In addition, a significant Condition $\times$ Channel interaction in the LPC epoch highlighted the fact that these two conditions were most different from each other at temporal-parietal sites, $F(4,60) = 7.960$, $p = .002$.

[3]ERP plots and statistical results for these items were computed including all animal targets, both hits and misses, to equate them with animal prime ERPs that were necessarily analyzed using both hits and misses.

Table 3. *Summary of Mean Amplitude Results for ERP Epochs of Interest in Experiment 1*

		Fz	Cz	Pz	F7	F8	ATL	ATR	TL	TR	WL	WR	O1	O2
P300 (400–1,000 ms)														
Animal primes	Mean	−0.28	2.41	3.09	0.66	1.63	1.30	1.67	1.38	1.76	1.04	1.45	−0.46	−1.22
(Type 6)	*SD*	3.56	3.27	4.32	3.20	3.00	2.46	2.77	2.38	2.36	2.80	2.70	3.35	3.22
Nonanimal word primes	Mean	−0.44	2.81	3.13	−0.13	1.32	0.65	1.72	1.04	1.64	0.96	1.29	−0.31	−0.96
(Types 4 & 9)	*SD*	3.74	3.92	4.48	3.42	2.76	2.49	2.23	2.43	2.26	2.64	2.52	2.73	1.97
All animal targets	Mean	−0.03	5.14	7.76	−0.62	1.00	0.21	1.18	2.12	2.84	4.16	4.35	4.09	4.04
(Types 7 & 8)	*SD*	5.13	5.28	5.23	3.15	3.48	2.54	3.37	3.21	4.16	4.26	4.54	3.99	3.53
Unrepeated target	Mean	−0.62	2.26	2.30	−0.56	0.72	−0.07	0.39	0.35	0.62	0.45	0.77	0.76	1.51
(Type 1) blank prime	*SD*	4.06	4.02	3.70	2.37	2.76	2.08	2.53	2.23	2.97	2.84	3.10	2.48	2.51
P2 (150–300 ms)														
Immediately repeated target	Mean	4.38	5.45	5.13	4.18	4.19	3.25	3.25	2.56	2.66	2.00	2.50	0.43	1.35
(Type 3)	*SD*	3.42	3.82	2.87	2.14	2.36	1.77	2.10	1.74	2.15	2.07	2.30	4.38	4.21
Unrepeated target	Mean	3.11	4.12	4.09	3.59	3.16	2.79	2.32	2.25	1.72	1.73	1.65	−0.06	0.81
(Types 4 & 9) word prime	*SD*	3.43	3.56	2.15	1.88	2.25	1.53	2.06	1.81	1.97	2.23	2.00	4.03	3.90
Unrepeated target	Mean	3.81	4.61	4.90	3.22	3.44	2.55	2.65	2.13	2.25	2.00	2.33	0.97	1.17
(Type 1) blank prime	*SD*	2.96	3.59	3.79	2.76	2.92	2.00	2.63	1.81	2.61	2.03	3.04	4.63	4.51
Delayed repeated target	Mean	4.70	5.54	5.45	3.68	3.84	3.11	3.05	2.69	3.09	2.40	2.99	1.06	1.43
(Type 2)	*SD*	4.31	4.07	3.50	3.11	3.08	2.39	2.55	2.18	2.44	2.44	2.70	4.48	4.02
Delayed repeated prime	Mean	3.65	4.46	4.81	3.18	4.14	2.60	3.37	1.99	2.76	1.71	2.54	0.86	1.25
(Type 5)	*SD*	3.74	3.60	3.58	2.73	3.22	2.22	2.84	2.03	2.53	2.35	2.68	4.23	4.33
N400 (300–500 ms)														
Immediately repeated target	Mean	0.65	2.10	3.22	0.27	1.42	−0.05	0.78	−0.27	0.83	0.00	1.48	1.43	2.22
(Type 3)	*SD*	2.67	2.91	3.14	1.94	1.71	1.54	1.74	1.36	2.23	1.82	3.01	4.27	4.44
Unrepeated target	Mean	−0.76	0.53	1.97	−0.01	0.81	−0.55	0.21	−0.81	−0.03	−0.57	0.62	0.70	1.53
(Types 4 & 9) word prime	*SD*	2.33	2.42	2.81	1.90	1.64	1.29	1.57	1.22	1.52	1.85	2.11	3.61	3.71
Unrepeated target	Mean	−1.91	0.06	2.31	−1.52	−0.34	−1.40	−0.70	−1.46	−0.63	−0.94	0.15	0.96	1.11
(Type 1) blank prime	*SD*	3.35	3.16	4.16	3.04	2.23	2.38	2.05	2.05	2.51	2.34	3.19	4.02	4.18
Delayed repeated target	Mean	0.29	2.69	4.13	−0.46	0.58	−0.27	0.29	−0.01	1.17	0.46	1.96	1.55	1.83
(Type 2)	*SD*	3.66	3.25	4.33	2.61	2.86	2.06	2.44	2.09	2.97	2.80	3.58	4.34	4.23
Delayed repeated prime	Mean	−1.01	1.44	3.42	−1.46	0.40	−1.26	0.24	−1.11	0.49	−0.38	1.46	1.60	1.94
(Type 5)	*SD*	3.49	2.92	3.96	3.01	2.42	2.48	2.20	2.28	2.52	2.58	3.19	3.80	4.33
LPC (500–750 ms)														
Immediately repeated target	Mean	0.52	3.18	3.00	0.18	1.39	0.64	1.06	0.85	1.24	0.74	1.45	1.01	2.24
(Type 3)	*SD*	3.44	3.38	3.22	1.74	2.71	1.58	2.35	1.97	2.51	2.25	2.54	2.51	2.26
Unrepeated targets	Mean	−0.03	1.99	1.67	0.29	0.93	0.34	0.49	0.48	0.33	0.30	0.39	0.32	1.51
(Types 4 & 9) word prime	*SD*	3.59	4.01	3.54	2.09	2.60	1.76	2.71	2.24	2.89	2.64	2.88	2.14	2.15
Unrepeated target	Mean	−1.71	1.40	1.78	−1.34	−0.22	−0.65	−0.39	−0.18	−0.13	−0.23	0.03	0.34	1.12
(Type 1) blank prime	*SD*	4.19	4.43	4.07	2.03	2.56	1.82	2.44	2.30	3.12	3.03	3.17	2.74	2.10
Delayed repeated target	Mean	1.77	5.34	5.04	0.80	1.82	1.44	1.75	2.11	2.94	2.27	3.58	1.45	2.62
(Type 2)	*SD*	4.35	4.16	3.72	2.64	3.40	2.25	3.04	2.81	3.53	3.24	3.29	2.86	2.07
Delayed repeated prime	Mean	−0.92	2.61	2.76	−1.46	0.38	−0.53	0.60	−0.09	0.77	0.09	1.23	0.84	1.85
(Type 5)	*SD*	3.20	3.12	3.33	2.92	2.97	2.46	2.72	2.38	2.47	2.48	2.30	1.97	2.36

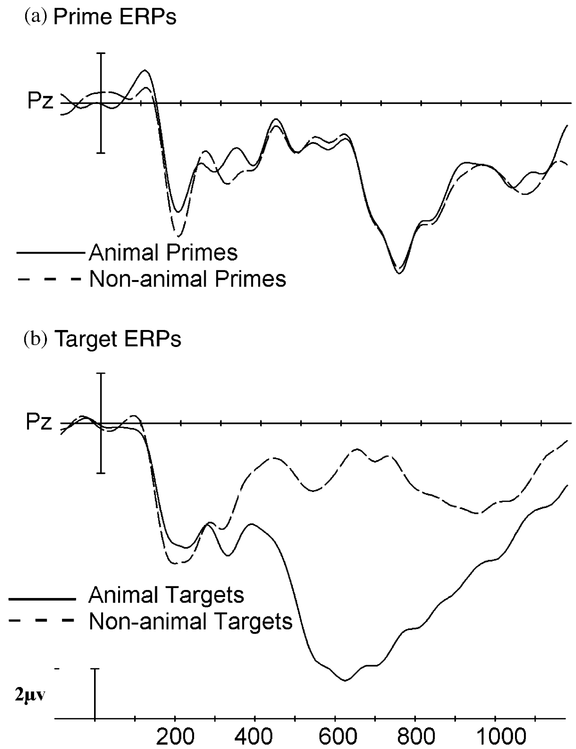

Figure 2. Grand average ERPs to words that were animal names (required a response) versus other (nonanimal) concrete nouns in the masked repetition priming experiment for (a) primes (Type 6 vs. Types 4 and 9) and (b) targets (Types 7 and 8 vs. Type 1) at site Pz. Note that in this and subsequent figures negative voltages are plotted upwards.

Discussion

In this experiment, evidence for robust ERP masked repetition priming was found. This took the form of enhanced P2s and attenuated N400s for target words that were immediate repetitions of words that were masked compared to target words that were immediately preceded by different (unrepeated) masked words. There was, however, no evidence of an enhanced late positive component (LPC) for these same comparisons, although there was an LPC effect for repeated targets that were originally presented as unmasked items several trials earlier.

Multiple sources of converging evidence (behavioral and electrophysiological) suggest that the prime words in this experiment were effectively masked. Thus, the P2 enhancement and N400 attenuation observed for immediate masked repetition priming was likely due to automatic, implicit effects of processing the masked prime rather than by "contamination" of the effects due to some percentage of primes being visible. These results would seem to challenge conceptions of the N400 as requiring controlled semantic access and argue instead for the N400 being sensitive to, at least in part, an automatic lexical-semantic process (see General Discussion for a further discussion of this topic). That waveforms for immediate repetitions of masked words did not display a significant LPC effect supports the notion that this component reflects some aspect of conscious processing of the prime–target relationship.

Surprisingly, targets that were repetitions of a masked prime occurring on average four trials earlier also showed evidence of an N400 repetition effect. Schnyer et al.'s (1997) failure to find a similar effect over a two-item delay and the demonstration in previous behavioral experiments that the interval between a masked prime and its repetition is an important factor in

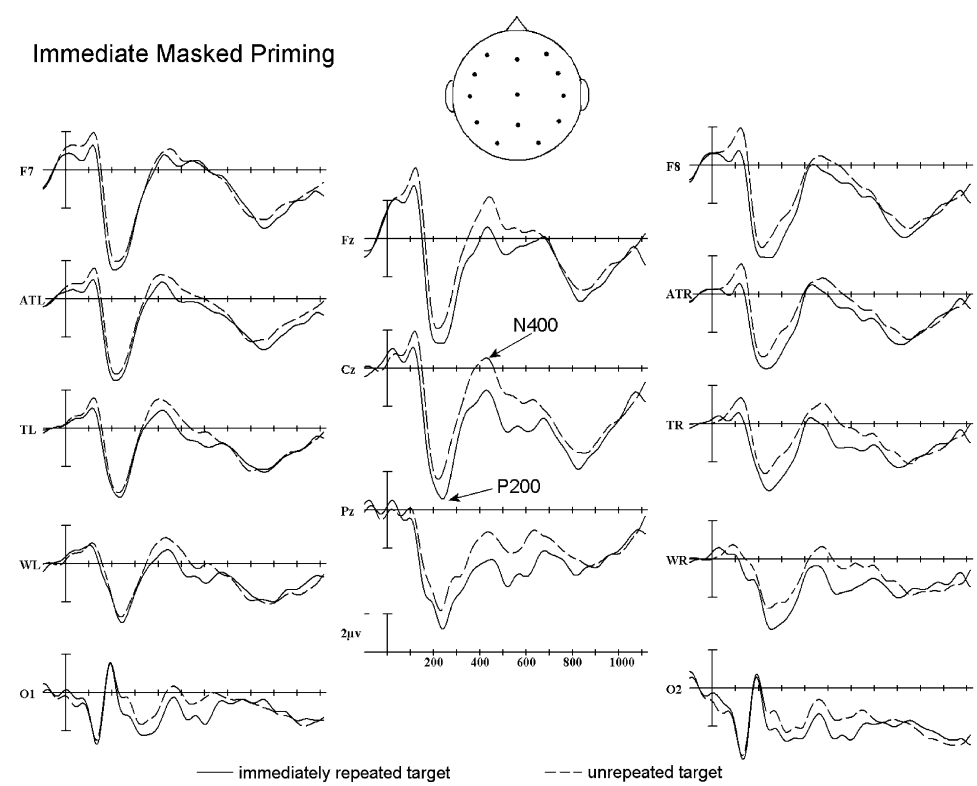

Figure 3. Grand average ERPs to target words in the masked repetition priming experiment: Unrepeated targets that followed a prime word (Types 4 and 9) versus targets that were immediate repetitions of a masked prime (Type 3).

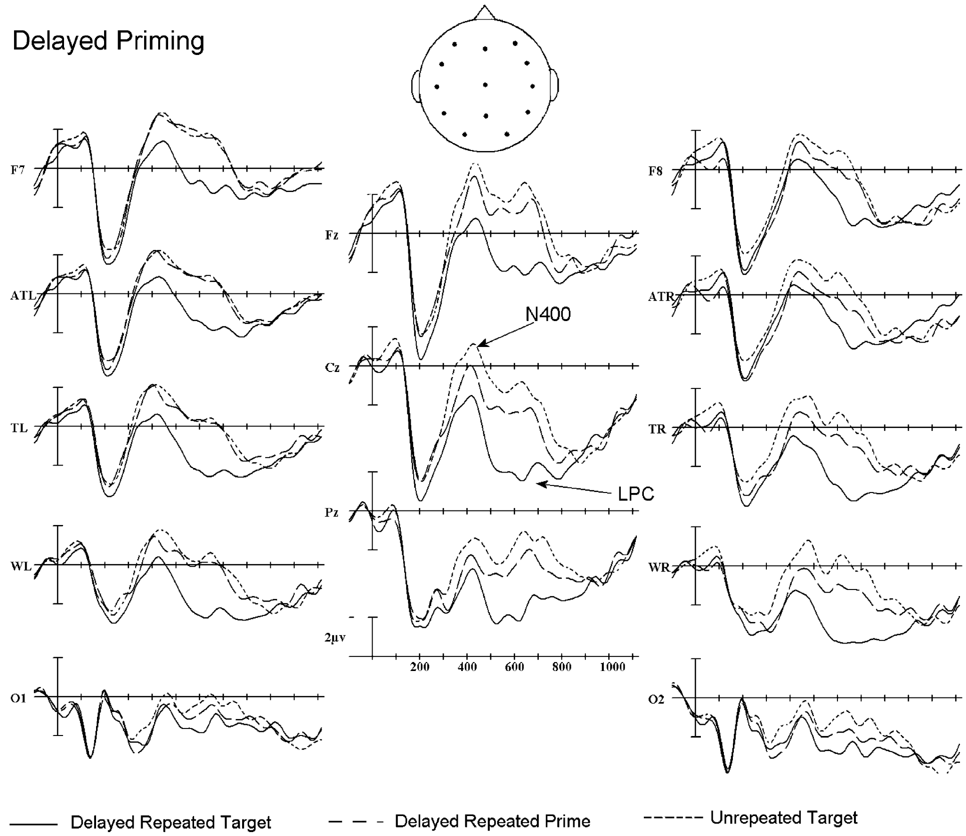

Figure 4. Grand average ERPs to target words in the masked repetition priming experiment: All targets followed blank primes and were either unrepeated (Type 1), delayed repetitions of a previous target (Type 2), or delayed repetitions of a previously masked prime (Type 5).

obtaining an RT effect (e.g., Humphreys et al., 1988) would seem difficult to reconcile with the current finding. Interestingly, we also found RT evidence for a delayed masked repetition effect, albeit on different items than the ERP effect (i.e., on the animal probes). One difference between the current and past studies is that we used a semantic monitoring task. Most previous studies, including Schnyer et al. used either the lexical decision or naming tasks. Semantic monitoring likely results in participants engaging in a deeper semantic processing strategy than these other tasks. Even though the masked primes were not processed consciously in the current study, a general strategy of semantic processing may have resulted in the primes being processed to a deeper level than occurs in lexical decision or naming tasks. This in turn might have boosted the duration of the effect allowing us to observe effects over multiple items. It is important to keep in mind that although the N400 effect for delayed masked priming was reliable, it was significantly smaller than the comparable effect recorded to targets that were delayed repetitions of unmasked words.

Collectively these data seem most consistent with Schnyer et al.'s (1997) conclusion that the N400 recorded in repetition priming tasks is sensitive both to automatic and consciously mediated controlled processes, whereas the LPC is sensitive only to the latter. These results also seem consistent with the notion that the N400 is a sensitive measure of word processing even when the reader is not completely aware that he/she has seen a word. However, although we went to great lengths to assure that primes were effectively masked and therefore not processed explicitly, it is possible that the observed effects and their difference from in-the-clear repetition priming were not due exclusively to the masking procedure per se and therefore do not reflect anything specific about automatic implicit processing. Rather, it is possible that the observed effects were due to the extremely brief nature of the primes.

EXPERIMENT 2

Experiment 2 was conducted to determine how rapidly presented primes that were not masked would affect subsequent target processing. Specifically, was it the duration of primes in Experiment 1 that led to the different patterns of ERP priming for the masked and unmasked conditions? To answer this question, a new set of participants performed the same semantic monitoring task using the same stimuli and recording measures as were used in Experiment 1. In Experiment 2, the prime duration for all participants was 50 ms,[4] and primes were immediately followed by a nonmasking stimulus (a box that surrounded the prime, but did not obscure it). It was predicted that under these conditions, a more typical pattern of ERP repetition priming effects would be observed, including an attenuated N400 and an enhanced LPC, across all types of repetitions (immediate, delayed, and target repetitions).

[4]This value was chosen because it was the nearest possible duration to the average for participants in Experiment 1.

Experiment 2 also allowed us to better evaluate how interitem lag affects repetition effects. Previous studies have shown that the N400 and LPC may be differentially sensitive to prime–target lag (Rugg & Nagy, 1989), and Experiment 1 provided preliminary evidence that the P2 repetition effect observed may also be sensitive to prime–target lag. However, no unmasked immediate repetition condition was included in Experiment 1 with which to compare masked repetition effects. In Experiment 2, in which primes were not masked, it was predicted that the N400 repetition effects would decline as the number of intervening items increased (i.e., immediate vs. delayed), but that the later LPC repetition effects would be unaffected by this manipulation.

Method

Participants

Sixteen right-handed, native-English-speaking undergraduates at Tufts University (8 male, mean age = 18.94, *SD* = 1.24) participated in this experiment for partial course credit. None had participated in the previous masked priming experiment.

Stimuli

Stimulus lists and trial types used for this experiment were identical to those used in Experiment 1 (see Figure 1 and Table 1). However an empty box (□) now appeared where the pattern mask had been present in the initial experiment, thus not obscuring the screen location of the preceding prime word. Pretesting results indicated that this box did not interfere with prime stimulus processing even at very short prime durations.

Procedure and Analysis

All primes were presented for 50 ms and were followed immediately by the box stimulus, which lasted for 200 ms. Target words were presented in the clear for 300 ms exactly 250 ms after the offset of the box (i.e., 500 ms after the onset of the prime). Prime titration was no longer necessary, but practice trials beginning with the lengthened box-target ISIs were still conducted in order to give the subjects experience with the rapid prime presentation rate. After the experiment was completed, participants were again given 5 min to recall any words from the experiment and an 150-item recognition test.

Participants' EEGs were recorded using the same cap configuration and parameters as in Experiment 1. Behavioral responses and ERP averages were also computed as in the initial experiment, and similar statistical procedures were used.

Results

Behavioral Results

Probe detection. Participants reported that they were aware that pairs of words were presented in each trial and realized that the first word of each pair was presented for a much shorter time than the second word. In addition, an analysis of animal name hits showed that animals in the prime positions were usually correctly responded to, although at a slightly lower rate than animal targets (see Table 4). Targets and primes showed a significant difference in hit accuracy (primes vs. primed targets: $t(15) = -10.763$, $p = .000$; primes vs. unprimed targets: $t(15) = -7.611$, $p = .000$). However, prime hit accuracy was far higher than in the masked priming study, and meeting criteria for animal hits was somewhat more difficult for words in prime positions than for those in target positions due to the rapid succession of targets after primes. There was no significant difference between performance accuracy for the two types of targets.

Table 4. *Behavioral Results for Experiment 2*

	Mean percent accuracy (*SD*)	Mean reaction time in ms (*SD*)
A. Animal hits		
Primes	69.63 (13.45)	637.73 (58.28)
Delayed repeated targets	88.88 (6.65)	566.09 (74.93)
Unrepeated targets	87.63 (9.89)	626.33 (71.23)
B. Recognition test		
Foils	9.88 (6.83)	—
Primes	32.13 (19.67)	—
Targets	35.88 (18.25)	—

Recognition test. The pattern of performance on the subsequent recognition memory task also suggests primes were available to explicit memory in this experiment, despite their rapid presentation rate (see Table 4). Words that appeared as primes and those that appeared as targets were identified at statistically indistinguishable rates, whereas foil hit rates were significantly lower than for both other groups (foils compared to primes: $t(15) = 6.419$, $p = .000$; foils compared to targets: $t(15) = 9.844$, $p = .000$).

Reaction time results. Reaction time data collected from response trials indicated that there was a significant behavioral priming effect such that repeated animal words were responded to more quickly than unrepeated probes (primes vs. primed targets: $t(15) = 7.124$, $p = .000$; unprimed targets vs. primed targets: $t(15) = 9.804$, $p = .000$). Reaction times to unprimed probes (animal primes and unprimed animal targets) did not differ significantly (see Table 4).

Electrophysiological Results

Electrophysiological results from the same epochs as Experiment 1 were used to identify components of interest: animal prime and target P300s (400–1,000 ms), nonanimal target position N400s (300–500 ms), nonanimal target LPCs (500–750 ms), and nonanimal target position P2s (150–300 ms). Mean amplitudes and standard deviation values for the critical conditions in each epoch (by electrode site) are provided in Table 5.

P300 effects on probe items. P300 effects on the ERPs to animal words supported the conclusion that both primes and targets were processed at a high level. There was a clear P300 to unmasked animal primes as compared to other word primes (midline: $F((1,15)) = 29.384$, $p = .000$; lateral: $F(1,15) = 34.577$, $p = .000$; see Figure 5a). Significant Condition × Channel interactions indicated that these effects were largest at posterior sites (midline: $F(2,30) = 33.552$, $p = .000$; lateral: $F(4,60) = 28.238$, $p = .000$). Simple effects analyses confirmed that the large P300 to animal primes was present at all but the most anterior sites (Cz: $F(1,15) = 33.853$, $p = .000$; Pz: $F(1,15) = 56.511$, $p = .000$; O1/O2: $F(1,15) = 40.395$, $p = .000$; WL/WR: $F(1,15) = 62.761$, $p = .000$; TL/TR: $F(1,15) = 36.245$, $p = .000$; ATL/ATR: $F(1,15) = 8.280$, $p = .012$).

Table 5. *Summary of Mean Amplitude Results for ERP Epochs of Interest in Experiment 2*

		Fz	Cz	Pz	F7	F8	ATL	ATR	TL	TR	WL	WR	O1	O2
P300 (400–1,000 ms)														
Animal primes	Mean	−2.55	4.80	7.86	−0.95	0.38	0.86	1.75	2.37	3.23	3.98	4.96	4.12	3.87
(Type 6)	*SD*	5.14	3.79	4.11	3.97	3.68	2.72	2.42	2.68	3.09	3.53	3.91	4.24	4.19
Nonanimal word primes	Mean	−3.20	1.51	2.90	−1.54	0.32	−0.37	0.77	−0.05	0.93	0.33	1.19	0.30	−0.04
(Types 4 & 9)	*SD*	4.60	2.86	3.29	3.29	3.75	1.90	2.55	1.89	2.88	2.46	3.16	3.55	4.03
All animal targets	Mean	3.23	9.63	9.90	2.98	4.29	2.99	4.23	4.68	5.94	6.60	7.34	3.36	3.82
(Types 7 & 8)	*SD*	5.73	5.31	5.45	3.73	4.64	3.41	3.95	3.79	3.97	4.04	4.53	4.07	4.62
Unrepeated target	Mean	2.86	6.31	4.51	1.91	3.67	1.81	2.93	2.32	3.11	2.51	2.84	−0.31	0.48
(Type 1) blank prime	*SD*	4.02	4.55	4.60	3.10	4.27	2.76	3.10	2.72	3.02	3.13	3.15	3.42	3.69
P2 (150–300 ms)														
Immediately repeated target	Mean	6.26	9.16	6.81	5.60	5.76	4.78	4.56	4.72	4.51	4.79	4.65	0.74	1.26
(Type 3)	*SD*	4.26	3.99	2.73	2.87	3.40	2.11	2.69	1.80	2.68	2.01	2.70	2.95	3.48
Unrepeated target	Mean	4.73	7.53	5.59	5.04	4.90	4.29	3.91	4.44	3.55	4.11	3.50	−0.19	0.18
(Types 4 & 9) word prime	*SD*	4.71	4.79	3.31	3.56	3.69	3.00	2.92	2.69	2.85	2.65	3.07	2.66	2.95
Unrepeated target	Mean	7.30	8.28	6.58	5.94	6.02	4.52	5.03	3.87	4.50	3.57	4.28	0.32	1.21
(Type 1) blank prime	*SD*	2.71	3.01	2.68	2.38	3.22	2.25	2.76	2.29	2.73	2.16	2.45	2.84	2.73
Delayed repeated target	Mean	7.58	8.79	7.10	6.30	6.25	5.02	5.32	4.40	4.94	4.00	4.82	0.89	1.74
(Type 2)	*SD*	2.79	3.22	3.02	2.01	3.00	1.95	2.68	1.64	2.72	2.29	2.76	3.35	3.16
Delayed repeated prime	Mean	7.41	8.67	6.88	6.26	6.34	4.92	5.20	3.89	4.69	3.68	4.63	0.77	1.50
(Type 5)	*SD*	2.62	3.65	3.56	1.92	2.87	1.89	2.71	2.27	2.83	2.66	3.03	3.53	3.28
N400 (300–500 ms)														
Immediately repeated target	Mean	5.65	8.24	6.69	3.88	4.94	3.27	4.01	3.73	5.18	4.72	6.19	1.72	2.50
(Type 3)	*SD*	3.36	3.14	2.94	2.80	3.03	2.06	2.18	2.06	1.92	2.05	2.23	2.88	3.28
Unrepeated target	Mean	1.66	3.03	2.19	2.14	3.53	1.08	2.37	1.11	2.24	1.24	2.31	−0.64	−0.19
(Types 4 & 9) word prime	*SD*	2.62	2.51	2.38	2.66	2.52	2.31	1.82	2.20	1.75	2.26	2.08	2.66	2.66
Unrepeated target	Mean	0.54	3.01	3.54	−0.03	1.63	−0.48	1.29	−0.42	1.59	0.24	2.11	−0.26	0.35
(Type 1) blank prime	*SD*	5.17	5.16	3.87	4.15	4.99	3.40	4.25	3.07	3.90	3.03	3.46	3.62	3.78
Delayed repeated target	Mean	2.00	5.39	5.43	1.00	1.89	1.03	1.73	1.39	2.53	2.03	3.44	0.71	1.32
(Type 2)	*SD*	4.38	4.56	3.82	3.25	4.21	2.58	3.72	2.49	3.62	2.74	3.51	3.40	3.57
Delayed repeated prime	Mean	1.33	4.45	4.75	0.99	1.93	0.78	1.54	0.64	2.14	1.37	2.95	0.62	1.03
(Type 5)	*SD*	5.16	4.91	4.06	3.97	4.54	3.24	4.22	3.11	3.96	3.08	3.63	3.98	3.99
LPC (500–750 ms)														
Immediately repeated target	Mean	6.06	7.24	4.82	5.40	6.33	4.49	5.02	5.01	5.57	5.07	5.48	0.61	1.45
(Type 3)	*SD*	4.13	4.44	3.62	3.48	4.17	2.51	2.99	2.36	2.90	2.68	3.32	3.05	3.93
Unrepeated targets	Mean	3.34	5.01	2.49	3.84	4.55	2.93	3.26	3.21	2.97	2.83	2.44	−0.69	−0.20
(Types 4 & 9) word prime	*SD*	3.58	3.89	3.16	3.27	4.07	2.53	2.89	2.23	2.45	2.28	2.68	2.61	3.28
Unrepeated target	Mean	2.43	6.74	5.11	1.52	3.15	1.76	2.81	2.54	3.34	2.81	3.37	0.15	0.93
(Type 1) blank prime	*SD*	4.59	5.12	4.78	3.47	4.39	3.00	3.48	3.08	3.32	3.53	3.34	3.55	3.83
Delayed repeated target	Mean	3.03	8.32	6.84	2.51	3.43	2.95	3.29	3.95	4.17	4.28	4.70	1.10	2.11
(Type 2)	*SD*	4.49	4.14	4.35	3.33	3.81	2.59	3.01	2.46	2.98	3.06	3.33	3.13	3.39
Delayed repeated prime	Mean	2.40	7.59	6.12	2.20	3.36	2.59	2.85	3.26	3.72	3.74	4.07	1.07	1.82
(Type 5)	*SD*	4.18	4.30	4.27	3.25	3.20	3.12	2.79	2.63	2.67	2.79	3.00	3.32	3.61

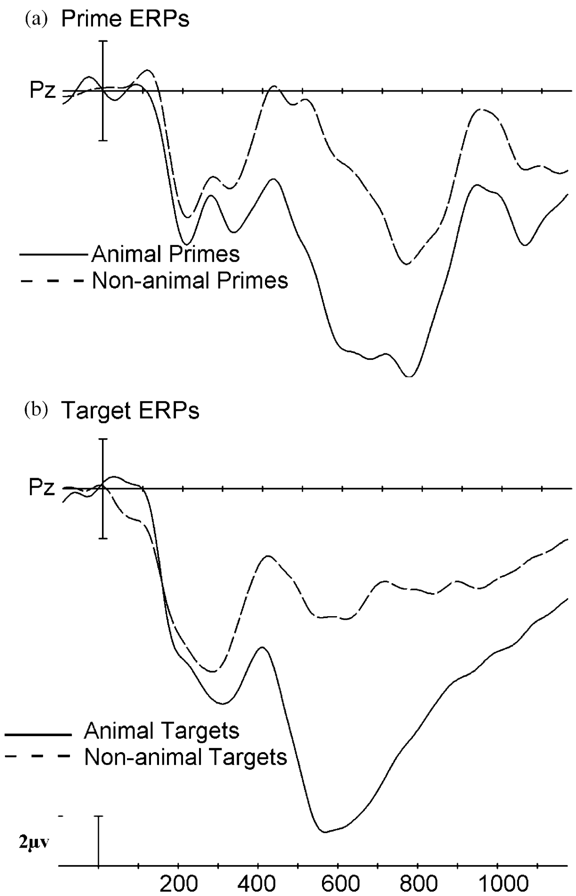

Figure 5. Grand average ERPs to words that were animal names (required a response) versus other (nonanimal) concrete nouns in the unmasked repetition priming experiment for (a) primes (Type 6 vs. Types 4 and 9) and (b) targets (Types 7 and 8 vs. Type 1) at site Pz.

Animal targets also showed a clear P300 effect as compared to nonanimal first presentation target words (midline: $F(1,15) = 14.451$, $p = .002$; lateral: $F(1,15) = 23.935$, $p = .000$; see Figure 5b). Again, significant Condition × Channel interactions reflected the lack of effect at frontal sites (midline: $F(2,30) = 34.676$, $p = .000$; lateral: $F(4,60) = 37.245$, $p = .000$), which was confirmed by simple effects analyses (Cz: $F(1,15) = 17.111$, $p = .001$; Pz: $F(1,15) = 41.870$, $p = .000$; O1/O2: $F(1,15) = 67.594$, $p = .000$; WL/WR: $F(1,15) = 43.697$, $p = .000$; TL/TR: $F(1,15) = 19.566$, $p = .000$; ATL/ATR: $F(1,15) = 5.044$, $p = .040$).

Immediate prime–target repetitions. As also observed in Experiment 1, unrepeated targets following a different prime word (Types 4 and 9) differed from targets that were immediate repetitions of a prime (Type 3) in the P2 epoch (150 to 300 ms). There was a significant main effect of this comparison at all sites (midline: $F(1,15) = 8.627$, $p = .010$; lateral: $F(1,15) = 7.355$, $p = .016$), reflecting a more positive waveform for the repetitions (see Figure 6). In addition, immediately repeated targets showed a significant N400 attenuation as compared to unrepeated targets (lateral: $F(1,15) = 37.958$, $p = .000$, midline: $F(1,15) = 42.484$, $p = .000$) in the 300 to 500-ms epoch. A significant interaction between electrode site and condition was also observed for this comparison at lateral sites, $F(4,60) = 8.472$, $p = .003$, reflecting the fact that the differences between these two conditions in the N400 epoch were most pronounced at temporal-parietal sites. Simple effects analyses revealed significant condition effects at each set of channels (O1/O2: $F(1,15) = 25.838$, $p = .000$; WL/WR: $F(1,15) = 43.607$, $p = .000$; TL/TR: $F(1,15) = 32.278$, $p = .000$; ATL/ATR: $F(1,15) = 24.811$, $p = .000$; F7/F8: $F(1,15) = 13.112$, $p = .003$); in each case repetitions were more positive than targets following unrelated primes.

Comparisons of immediately repeated and unrepeated targets revealed that repetitions also enhanced the LPC, with significant effects at both lateral, $F(1,15) = 22.331$, $p = .000$, and midline, $F(1,15) = 14.696$, $p = .002$, sites in the 500 to 750-ms epoch. Significant interactions were also observed between condition and electrode site, $F(4,60) = 4.121$, $p = .035$, and condition and hemisphere, $F(1,15) = 4.832$, $p = .044$, at lateral sites. Simple effects analyses by channel found that the conditions were significantly different at each channel (O1/O2: $F(1,15) = 13.495$, $p = .002$; WL/WR: $F(1,15) = 29.708$, $p = .000$; TL/TR: $F(1,15) = 23.329$, $p = .000$; ATL/ATR: $F(1,15) = 14.521$, $p = .002$; F7/F8: $F(1,15) = 10.537$, $p = .005$), although the largest LPC effects for repeated items were at temporal-parietal sites. Simple effects analyses by hemisphere resulted in significant differences between the conditions in each hemisphere (LH: $F(1,15) = 17.794$, $p = .001$; RH: $F(1,15) = 23.977$, $p = .000$), with right hemisphere sites showing larger LPC effects than left hemisphere sites.

Delayed target–target repetitions. The delayed repeated targets (Type 2) showed significant effects of condition in both the N400 (lateral: $F(1,15) = 8.941$, $p = .009$, midline: $F(1,15) = 9.809$, $p = .007$) and the LPC (lateral: $F(1,15) = 15.615$, $p = .001$, midline: $F(1,15) = 11.232$, $p = .004$) epochs when compared to unrepeated targets (Type 1), but there were no significant effects in the P2 epoch (see Figure 7). Repetitions showed both an attenuated N400 and an LPC enhancement. Significant Condition × Hemisphere × Channel interactions for both the N400, $F(4,60) = 3.901$, $p = .019$, and the LPC, $F(4,60) = 3.163$, $p = .039$, epochs were also found. For the N400 epoch, simple effects analyses showed that differences between the conditions were significant at all lateral electrodes except the frontal sites (O1/O2: $F(1,15) = 4.839$, $p = .044$; WL/WR: $F(1,15) = 13.944$, $p = .002$; TL/TR: $F(1,15) = 12.248$, $p = .003$; ATL/ATR: $F(1,15) = 6.083$, $p = .026$). Furthermore, significant interactions between electrode site and hemisphere were observed at the temporal sites (TL/TR: $F(1,15) = 4.838$, $p = .044$; ATL/ATR: $F(1,15) = 6.401$, $p = .023$) in these post hoc analyses. Further tests performed to compare the hemispheres for these sites showed significant differences only at left hemisphere sites for both comparisons (TL: $F(1,15) = 29.500$, $p = .000$; ATL: $F(1,15) = 16.244$, $p = .001$). Simple effects analyses used to evaluate the three-way interaction in the LPC epoch showed a similar pattern of results, with significant effects of condition at all but the most anterior sites (O1/O2: $F(1,15) = 6.537$, $p = .022$; WL/WR: $F(1,15) = 33.524$, $p = .000$; TL/TR: $F(1,15) = 16.507$, $p = .001$; ATL/ATR: $F(1,15) = 6.286$, $p = .024$), although no Condition × Hemisphere interactions were revealed by this analysis.

Delayed prime–target repetitions. A comparison between the delayed prime–target repeated targets (Type 5) and unrepeated targets (Type 1) showed no statistically significant differences between these conditions in any of the epochs.

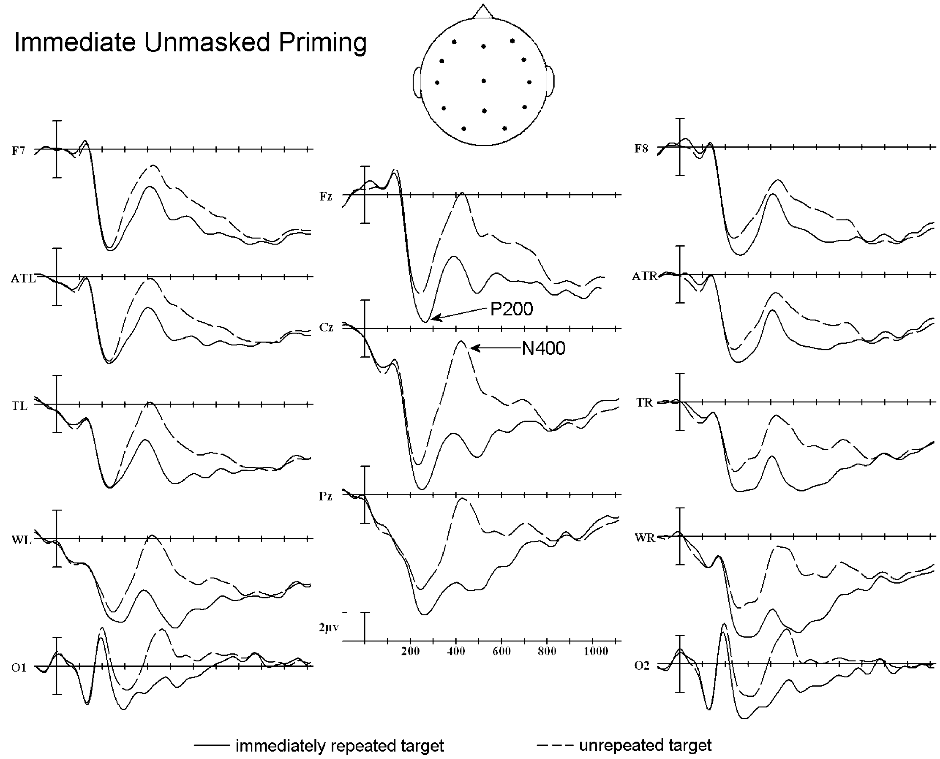

Figure 6. Grand average ERPs to target words in the unmasked repetition priming experiment: Unrepeated targets that followed a prime word (Types 4 and 9) versus targets that were immediate repetitions of a prime (Type 3).

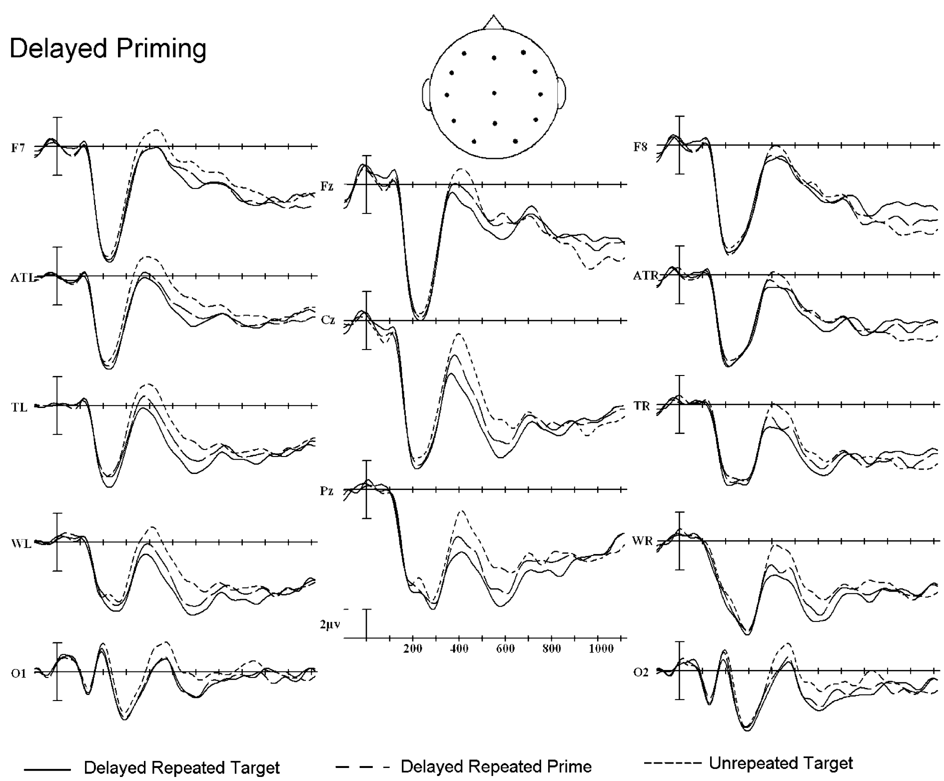

Figure 7. Grand average ERPs to target words in the unmasked repetition priming experiment: All targets followed a blank prime and were either unrepeated (Type 1), delayed repetitions of a previous target (Type 2), or delayed repetitions of a previous prime (Type 5).

Between Experiment Comparisons

Mixed design ANOVAs were used to compare priming effects between the two experiments in each of the three measurement epochs. Priming effects (the difference between a repeated target ERP and its unrepeated control ERP) were used in these analyses to equate for differences in the physical nature of the prime stimuli between experiments (i.e., masked vs. unmasked primes). Such differences make direct comparisons of ERPs between experiments problematic. The first comparisons involved contrasts of the immediately repeated (masked) priming effect (Experiment 1) and the immediately repeated (unmasked) priming effect (Experiment 2). We also compared the delayed target–target repetition effect between experiments as well as the delayed masked prime repetition effect (Experiment 1) with the delayed short prime repetition effect (Experiment 2). There were no significant between-experiment differences in the P2 (150–300 ms) window for any of the three priming effects. However, in the 300–500-ms epoch (N400), Experiment 2 produced a larger immediate priming N400 effect than did Experiment 1 (main effect of experiment, midline: $F(1,30) = 15.15$, $p = .001$; lateral: $F(1,30) = 15.97$, $p = .000$; see Figure 8). There were no significant differences between the experiments in the N400 window for either of the delayed repetition effects. However, in the LPC window, Experiment 2 produced a larger immediate priming effect than did Experiment 1 at lateral sites (main effect of experiment, lateral: $F(1,30) = 7.82$, $p = .009$). And although there were no differences between the experiments in the delayed masked/short-prime priming effects in the LPC window, Experiment 1 produced a significantly larger LPC priming effect than did Experiment 2 in the delayed unmasked priming conditions (midline: $F(1,30) = 14.28$, $p = .001$; lateral: $F(1,30) = 8.06$, $p = .008$).

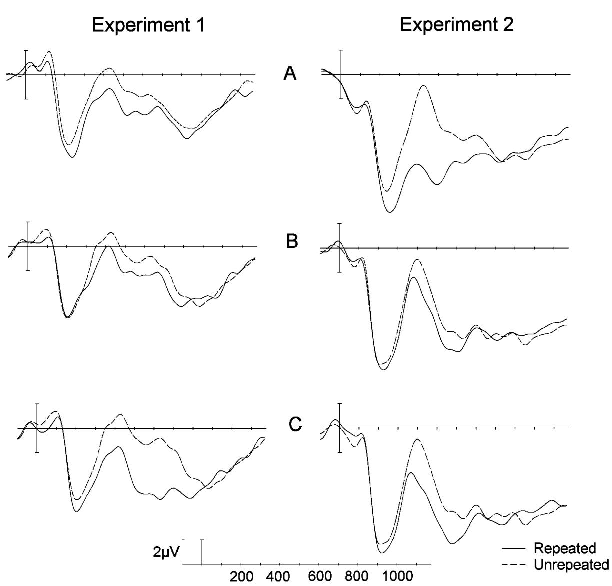

Figure 8. Grand average target ERPs from the Cz electrode site for the masked prime (Experiment 1, left) and unmasked prime (Experiment 2, right) experiments. A: Compares unrepeated and immediately repeated items. B: Contrasts unrepeated and delayed repetitions of a previous prime. C: Contrasts unrepeated and delayed repetitions of a previous target item.

Discussion

Experiment 2 verified that rapid presentations of primes alone could not account for the pattern of priming effects observed for masked primes in Experiment 1. Both the immediate prime–target repetition and delayed target–target repetition conditions in this experiment showed expected attenuations of the N400 followed by LPC enhancements, consistent with previous reports of ERP effects of unmasked repetition priming. In fact, immediate unmasked repetition priming using the intervals from Experiment 1 showed ERP repetition effects on the N400 that were significantly larger than when the primes were masked (Experiment 1). Moreover, unlike Experiment 1, there was now also a strong LPC effect for targets that were immediate repetitions of primes. These results suggest that ERP repetition effects for masked repetitions differ from those for unmasked repetitions, even when unmasked primes are presented for a very brief (50 ms) amount of time. Furthermore, these results indicate that the pattern of effects in Experiment 1 was not due to the brief duration of prime stimuli.

In Experiment 2, significant differences on the P2 were again noted for immediate repetition targets as compared to unrelated targets but were not seen when repetitions were delayed. This result suggests that rapid prime–target temporal proximity may be required to generate these early ERP repetition effects. An alternative explanation of the P2 effect is that it actually reflects an earlier onset of an N400 attenuation under conditions of immediate repetition. These competing accounts will require additional experimentation.

Also important for the interpretation of Experiment 1 is the finding in Experiment 2 of robust P300 components to animal probe words in the prime position. This finding lends support to the interpretation that, had participants in Experiment 1 been aware of the prime words, they too would have shown larger P300s to prime animal probe words. In Experiment 1, there were no discernable differences between the P300s to animal and nonanimal prime probes.

The effects of repeating words over a delay of one to eight trials appeared to be smaller in this experiment than in Experiment 1, although the between-experiment contrast was only significant for the delayed target–target comparison in the LPC epoch. Such differences between experiments may have been due to the unmasked prime words in Experiment 2 influencing the perceived distribution of items. In other words, because prime words were clearly visible and consciously processed in Experiment 2, they now became part of the perceived total trial structure and thus lengthened the item intervals or ‘‘lag’’ for the delayed priming conditions.

General Discussion

This series of experiments provides evidence that N400 priming effects are sensitive to repetitions of words that originally occurred outside of conscious awareness. Moreover, it was demonstrated that these masked priming effects cannot be explained solely on the basis of the rapid presentation rate of the primes, as Experiment 2 showed that repetitions of briefly presented unmasked primes produce effects consistent with repetitions of words presented for longer durations. Significant ‘‘contamination’’ of results from trials that occurred within the realm of conscious perception can also be ruled out as a contributor to the reported effects: Converging evidence from behavioral accuracy scores, a recognition posttest, and P3 effects in Experiment 1 indicated that conscious prime processing was successfully minimized in the masked priming condition. The results obtained also support the view that the LPC priming effect depends at least in part on conscious perception and recollection of an item. Immediately repeated masked primes attenuated the N400 component in a manner similar to that observed with unmasked primes. However, a consistently enhanced LPC was only manifested for repeated unmasked words. Together these results provide further evidence that the N400 ERP repetition effect is sensitive to automatic, implicit processing associated with this type of priming, whereas the LPC effect relies on conscious, recollective processes. In addition, a P2 enhancement was observed on targets that were immediate repetitions of their primes, regardless of whether or not the primes were masked. This result suggests that this early component may also be sensitive to automatic processes occurring during masked priming.

Experiment 1 also found evidence that masked repetition priming N400 effects may persist over a significant lag (i.e., targets occurring one to eight trials after the initial presentation of the word). This result was observed in parallel with behavioral effects for reaction time to repeated masked words that were also apparent over several intervening items. Immediate and delayed masked repetition priming both showed N400 attenuations in the absence of LPC enhancements when compared to their relevant control conditions. However, only the immediate masked repetitions showed evidence for an enhanced P2 component, suggesting that this early component relies to some degree on temporal proximity of prime and target. The observation of this P2 enhancement for immediate repetitions in Experiment 2 supports this contention and suggests that the P2 is not a specific index of masked priming processes.

Implications for the Functional Significance of the N400 and LPC

Brown and Hagoort (1993) failed to find N400 effects for masked semantic priming. They concluded that this implies that the N400 reflects a postlexical semantic integration process. As reviewed above, several more recent studies have reported repetition and semantic masked priming effects on the N400 (Deacon et al., 2000; Kiefer, 2002; Schnyer et al., 1997). At least one of these reports reached the seemingly opposite conclusion, that the N400 reflects a prelexical automatic process (Deacon et al., 2000). How can these conclusions and findings be reconciled? One possibility is that Brown and Hagoort's interpretation was based on a type II error and that the automatic interpretation is the correct one. However, evidence from a variety of other sources argues that the N400 does not reflect a purely prelexical automatic process (e.g., the fact that the N400 can be recorded to pictures that do not have lexical entries; cf. McPherson & Holcomb, 1999). We propose, consistent with Brown and Hagoort's conclusion, that the N400 reflects a postrecognition semantic process whereby the meaning of a consciously processed stimulus is integrated into a prior semantic context. The one twist on the Brown and Hagoort position we are proposing here is that, under certain circumstances, items processed outside of awareness can provide a context sufficient to support priming. According to this account, priming results when the meaning of a subsequently presented above threshold target word is more easily integrated into this context.

One remaining question is why Brown and Hagoort did not find an N400 effect? One possibility is that their masked primes did not provide a sufficient context for producing differential integration. This could have been because masked primes, although capable of setting up a context, do so in a generally weaker manner than do fully perceivable primes (i.e., prime perceptibility modulates context rather than operating on an all-or-none basis). Consistent with this view is our finding of a relatively smaller priming effect for masked than in-the-clear priming. When added to the fact that semantic priming effects are usually smaller than repetition effects, it is perhaps not surprising that Brown and Hagoort did not report significant N400 masked semantic priming.

But what about the LPC? Why was it not similarly sensitive to the context set up by the masked prime? Previous studies of ERP repetition priming have concluded that the LPC reflects a recollective process whereby the participant consciously recognizes that the target is a repetition of a previous stimulus. This type of process would require that both the prime and target be consciously registered, as was the case in Experiment 2.

One prediction from our revision of the N400 integration hypothesis is that masking target words should obliterate any semantic or repetition priming effect. This should be true both if the prime is masked or if it is presented in the clear because unlike setting up a context, deep conscious registration of the target is required before it can be integrated (e.g., West & Holcomb, 2000; Chwilla et al., 1995). Because both prime and target need to be consciously registered to obtain an LPC effect, there should not be significant LPC effects for masked targets as well.

REFERENCES

Barnea, A., & Breznitz, Z. (1998). Phonological and orthographic processing of Hebrew words: Electrophysiological aspects. *Journal of Genetic Psychology*, *159*, 492–504.

Brown, C., & Hagoort, P. (1993). The processing nature of the N400: Evidence from masked priming. *Journal of Cognitive Neuroscience*, *5*, 34–44.

Cheesman, J., & Merikle, P. M. (1984). Priming with and without awareness. *Perception and Psychophysics*, *36*, 387–395.

Cheesman, J., & Merikle, P. M. (1985). Word recognition and consciousness. In D. Besner, T. G. Waller, & G. E. Mackinnon (Eds.), *Reading research* (Vol. 5, pp. 311–352). Orlando, FL: Academic Press, Inc.

Chwilla, D. J., Brown, C. M., & Hagoort, P. (1995). The N400 as a function of the level of processing. *Psychophysiology*, *32*, 274–285.

Deacon, D., Hewitt, S., Yang, C.-M., & Nagata, M. (2000). Event-related potential indices of semantic priming using masked and unmasked words: Evidence that the N400 does not reflect a post-lexical process. *Cognitive Brain Research*, *9*, 137–146.

Dorfmueller, M. A., & Schumsky, D. A. (1978). Retrieval of attribute information as a function of processing depth. *Bulletin of the Psychonomic Society*, *12*, 303–306.

Düzel, E., Yonelinas, A. P., Mangun, G. R., Heinze, H.-J., & Tulving, E. (1997). Event-related brain potential correlates of two states of conscious awareness in memory. *Proceedings of the National Academy of Sciences, USA*, *94*, 5973–5978.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research*, *27*, 203–233.

Forster, K. I. (1999). The microgenesis of priming effects in lexical access. *Brain & Language*, *68*, 5–15.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *10*, 680–698.

Holcomb, P. J. (1988). Automatic and attentional processing: An event-related brain potential analysis of semantic priming. *Brain and Language*, *35*, 66–85.

Holcomb, P. J., Coffey, S. A., & Neville, H. J. (1992). Visual and auditory sentence processing: A developmental analysis using event-related brain potentials. *Developmental Neuropsychology*, *8*, 203–241.

Holcomb, P. J., & Neville, H. J. (1990). Semantic priming in visual and auditory lexical decision: A between modality comparison. *Language and Cognitive Processes*, *5*, 281–312.

Humphreys, G. W., Besner, D., & Quinlan, P. T. (1988). Event perception and the word repetition effect. *Journal of Experimental Psychology: General*, *117*, 51–67.

Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, *30*, 513–541.

Kahan, T. A. (2000). Negative priming from masked words: Retrospective prime clarification or center-surround inhibition? *Journal of Experimental Psychology: Learning, Memory and Cognition*, *26*, 1392–1410.

Kiefer, M. (2002). The N400 is modulated by unconsciously perceived masked words: Further evidence for an automatic spreading of activation account of N400 priming effects. *Cognitive Brain Research*, *13*, 27–39.

Kučera, H., & Francis, W. N. (1967). *Computational analysis of present-day American English*. Providence, RI: Brown University Press.

Marcel, A. J. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology*, *15*, 197–237.

McCarthy, G., & Nobre, A. C. (1993). Modulation of semantic processing by spatial selective attention. *Electroencephalography & Clinical Neurophysiology: Evoked Potentials*, *88*, 210–219.

McPherson, W. B., & Holcomb, P. J. (1999). An electrophysiological investigation of semantic priming with pictures of real objects. *Psychophysiology*, *36*, 53–65.

Neely, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner & G. W. Humphreys (Eds.) *Basic processes in reading: Visual word recognition* (pp. 264–336). Hillsdale, NJ: Lawrence Earlbaum Associates.

Otten, L. J., Rugg, M. D., & Doyle, M. C. (1993). Modulation of event-related potentials by word repetition: The role of visual selective attention. *Psychophysiology*, *30*, 559–571.

Ratcliff, R., Hockley, W., & McKoon, G. (1985). Components of activation: Repetition and priming effects in lexical decision and recognition. *Journal of Experimental Psychology: General*, *114*, 435–450.

Rugg, M. D. (1985). The effects of semantic priming and word repetition on event-related potentials. *Psychophysiology*, *22*, 642–647.

Rugg, M. D. (1990). Event-related brain potentials dissociate repetition effects of high- and low-frequency words. *Memory and Cognition*, *19*, 367–379.

Rugg, M. D., Doyle, M. C., & Wells, T. (1995). Word and nonword repetition within and across modality: An event-related potential study. *Journal of Cognitive Neuroscience*, *7*, 209–227.

Rugg, M. D., & Nagy, M. E. (1989). Event-related potentials and recognition memory for words. *Electroencephalography and Clinical Neurophysiology*, *72*, 395–406.

Schacter, D. L. (1992). Priming and multiple memory systems: Perceptual mechanisms of implicit memory. *Journal of Cognitive Neuroscience*, *4*, 244–256.

Schnyer, D. M., Allen, J. B., & Forster, K. I. (1997). Event-related brain potential examination of implicit memory processes: Masked and unmasked repetition priming. *Neuropsychology*, *11*, 243–260.

Squire, L. R. (1992). Declarative and nondeclarative memory: Multiple brain systems supporting learning and memory. *Journal of Cognitive Neuroscience*, *4*, 232–243.

Stark, C. E. L., & McClelland, J. L. (2000). Repetition priming of words, pseudowords, and nonwords. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *26*, 945–972.

Tulving, E., & Schacter, D. L. (1990). Priming and human memory systems. *Science*, *247*, 301–306.

Van Petten, C. (1993). A comparison of lexical and sentence-level context effects in event-related potentials. *Language and Cognitive Processes*, *8*, 485–531.

Van Petten, C., Kutas, M., Kluender, R., Mitchiner, M., & McIsaac, H. (1991). Fractionating the word repetition effect with event-related potentials. *Journal of Cognitive Neuroscience*, *3*, 131–150.

West, W. C., & Holcomb, P. J. (2000). Imaginal, semantic and surface-level processing of concrete and abstract words: An electrophysiological investigation. *Journal of Cognitive Neuroscience*, *12*, 1024–1037.

Winer, B. J. (1971). *Statistical principles in experimental design*. New York: McGraw-Hill.

Yamagata, S., Yamaguchi, S., & Kobayashi, S. (2000). Event-related evoked potential study of repetition priming to attended and unattended words. *Cognitive Brain Research*, *10*, 167–171.

(Received April 17, 2001; Accepted July 15, 2002)