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Masked Repetition Priming of Words and Nonwords: Evidence for a Nonlexical Basis for Priming

Glen E. Bodner and Michael E. J. Masson

University of Victoria, Victoria, Canada

Lexical decisions for low- and high-frequency words are equally facilitated by masked repetition priming, whereas nonwords typically show no effect of such priming. This pattern of results has been used to argue against an episodic account of masked priming and in favor of a lexical account in which the prime opens the lexical entry of the upcoming target. We propose that an episodic account can be compatible with additive effects of masked priming and word frequency. We also demonstrate that masked priming of nonwords can be reliably produced, indicating that primes operate at a nonlexical level, primarily to facilitate orthographic encoding. The processing fluency created by a masked prime can work against correct classification of nonwords in a lexical decision task, leading either to no effect of priming or to an interference effect when subjects depend heavily on familiarity as a basis for lexical decisions.

Two classes of word identification theories are fundamentally divided by a debate regarding the issue of whether word identification involves access of a stable, abstract, lexical entry corresponding to a word in a mental lexicon, or whether it involves retrieval of episodic memory traces created during previous encounters with the word. The development of these two theoretical frameworks has been shaped in part by demonstrations of repetition priming, whereby word identification is facilitated by a recent previous encounter with that word (e.g., Forbach, Stanners, & Hochhaus, 1974; Kirsner & Smith, 1974; Scarborough, Cortese, & Scarborough, 1977).

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Address correspondence and reprint requests to Michael Masson, Department of Psychology, University of Victoria, P.O. Box 3050, Victoria, British Columbia V8W 3P5, Canada. E-mail: mmasson@uvic.ca.

Lexical accounts of word identification can most easily accommodate repetition priming effects by assuming that presentation of a word results in contact with the lexical representation for that item and in so doing leaves that representation in an excited state for some period of time (e.g., Monsell, 1985; Morton, 1969). If the item is experienced again, before activation of the representation has decayed, responses to that item are facilitated. By this account, repetition priming is a consequence of having made recent contact with a word's lexical representation.

Jacoby (1983; Jacoby & Dallas, 1981) put forward an episodic account of word identification and repetition priming. On this account, skilled word identification is based on retrieval of prior episodes involving the target word, cued by the word's orthographic pattern. In repetition priming, the encoding episode in which a word is first presented (as the prime) should be particularly salient when that word is later presented as a target because there is strong temporal and contextual overlap between the prime and target experiences (Jacoby, 1983).

A number of lexical accounts of repetition priming acknowledge an episodic component in producing the effect (e.g., Feustel, Sala-

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soo, & Shiffrin, 1983; Forster & Davis, 1984; Humphreys, Besner, & Quinlan, 1988; Salasoo, Shiffrin, & Feustel, 1985). This acknowledgment was prompted by a series of empirical findings inconsistent with a purely lexical account. First, a strict abstractionist position is challenged by studies that fail to demonstrate robust cross-modal priming (e.g., Scarborough, Gerard, & Cortese, 1979), although Morton (1979) proposed a revision to his logogen theory to accommodate modality-specific effects.

Second, lexical accounts assume that the effect of a prime on a word's representation decays over time, otherwise the concept of a stable mental lexicon is lost. Scarborough et al. (1977) and Jacoby (1983; Jacoby & Dallas, 1981) have shown that a single presentation of a prime can have a detectable effect on performance over intervening items or even over one or more days. These results show that lexical accounts must at least assume surprisingly long-lasting effects of a single exposure to a word.

Third, like other forms of episodic memory, repetition priming is sensitive to manipulations of context. Jacoby (1983) showed that priming increased with an increase in the proportion of studied words appearing in the test list, a result not predicted by automatic lexical activation. Moreover, repetition priming is reduced or eliminated if the test words were originally read as part of a text rather than in isolation (Levy & Kirsner, 1989; MacLeod, 1989; Oliphant, 1983). Although troubling for a strict lexical account, these results could be explained from a nonlexical, episodic account that allows variable encoding and retrieval of episodic traces corresponding to specific experiences (e.g., Jacoby, 1983; Whittlesea & Dorken, 1993).

An additional problem for certain lexical accounts of priming is the frequency attenuation effect: the observation that low-frequency words benefit more from repetition priming than high-frequency words (e.g., Duchek & Neely, 1989; Forster & Davis, 1984; Jacoby & Dallas, 1981; Norris, 1984; Rajaram & Neely, 1992; Scarborough et al., 1977). Although word frequency should be a stable characteristic of the lexicon and unaffected by a single exposure to a word, Monsell (1985) has argued this effect can be explained within Morton's (1969) logogen theory. Monsell suggested that identification performance is a negatively accelerated function of the number of recent encounters with a word. High-frequency words would have more recent encounters than low-frequency words, so the additional encounter comprising the priming event would have less impact for high-frequency words. Jacoby (1993) pointed out, however, that it is surprising that a single exposure to a low-frequency word can go so far toward closing the performance gap between such a word and high-frequency words that benefit from the effects of a great many more presentations.

The frequency attenuation effect has more serious implications, however, for lexical search theories, which assume that frequency is a stable, organizational property of the lexicon (Becker, 1979; Forster, 1976; Stanners & Forbach, 1973). According to these theories, entries for high-frequency words are searched earlier than entries for low-frequency words. Priming would affect the speed with which an entry is accessed once it has been located in the search, but not the search process itself. Thus, the frequency effect should not be modulated by repetition priming.

The frequency attenuation effect is consistent with the episodic account in that episodic traces of low-frequency word primes may be more distinctive than those of high-frequency word primes. Improved distinctiveness might make an episode easier, and hence faster, to retrieve. Given that word identification is assumed by the episodic account to be based on the recruitment of relevant prior episodes, adding one more episode for a low-frequency word that is captured by relatively few episodes should have a larger impact than one more episode for a high-frequency word that is already part of a great many episodes.

A final problem for the lexical account is the existence of long-term repetition priming effects for nonwords. Although some lexical decision studies have not found long-term nonword priming effects (e.g., Forbach et al., 1974; Rajaram & Neely, 1992), others have (e.g., Besner & Swan, 1982; Kirsner & Smith, 1974; McKone, 1995; Norris, 1984; Scarborough et al., 1977). If repetition priming is due to facilitated use of a lexical entry, nonwords should not show priming effects because they do not have lexical entries. Monsell (1985) has attributed repetition priming of nonwords to conditions that provide subjects time and incentive to learn the nonwords. This learning would either set up the equivalent of a new lexical entry (Feustel et al., 1983) or a temporary lexical entry (Rajaram & Neely, 1992) or would allow the subject to associate a task-specific response with the learned nonword (Monsell, 1985). The episodic account, on the other hand, predicts nonword repetition priming because presentation of nonwords leads to the construction of episodic traces, just as would happen with any novel stimulus. On this account, even conditions that would not permit the learning discussed by Monsell potentially will lead to repetition priming of nonwords.

Taken together, the aspects of repetition priming reviewed here pose a challenge to the view that repetition priming results from temporary activation of a stable lexical entry. Forster and Davis (1984) were particularly concerned, however, with the implications of the frequency attenuation effect for lexical search models. That effect raises serious doubts about the assumption that lexical entries are searched in a consistent order. To handle this problem, Forster and Davis suggested that repetition priming effects obtained with clearly perceived prime words are the result of episodic memory traces formed by the priming event. They further reasoned that lexically based repetition priming could be demonstrated by presenting primes in a manner that prevented the establishment of episodic traces of the priming event.

Forster and Davis (1984) proposed that lexically based repetition priming is a result of the prime word leaving its lexical entry open. When an identical target is presented, lexical access is speeded because the appropriate entry is already open. No interaction with word frequency is expected, however, because the frequency effect arises from the time taken to get to the entry during the sequential search of the lexicon.

To arrange priming conditions that would reveal a lexical repetition priming effect, free of the influence of episodic memory, Forster and Davis (1984) used a masked priming paradigm modeled after the masked word identification paradigm developed by Evett and Humphreys (1981). In the masked priming procedure, a briefly presented (60-ms) lowercase prime is preceded by a pattern mask of some kind, and immediately followed by the target stimulus in uppercase letters which also serves as a postmask for the prime. In the Forster and Davis experiments, subjects then made a lexical decision to the target stimulus.

Masking, in combination with brief presentation, makes the prime difficult to identify, and critically, according to Forster and Davis (1984), ‘‘minimizes’’ any episodic influence of the prime. Moreover, the priming effects observed in this paradigm are said to occur at a processing level beyond perception for several reasons. First, perceptual overlap between primes and targets is low since these items are presented in different case. Second, if priming effects are perceptual, one would expect equal priming for words and nonwords, whereas the results show that words produce more priming than nonwords. Third, masked priming persists over unrelated intervening items (e.g., Forster & Davis, 1984, Experiment 5). Thus, Forster and Davis argued that masked repetition priming effects observed in lexical decision must reflect facilitated lexical access.

Using the masked repetition priming paradigm, Forster and Davis (1984) examined two of the repetition priming results that are problematic for a lexically based account of repetition priming: the frequency attenuation effect and previous reports of nonword priming. Consistent with their lexical account, Forster and Davis found additivity between frequency and priming using the masked prime paradigm. In fact, to date all masked repetition priming studies manipulating frequency have failed to reveal an interaction of these variables (Ferrand, Grainger, & Segui, 1994; Forster & Davis, 1984; Forster, Davis, Schoknecht, & Carter, 1987; Humphreys et al., 1988; Humphreys, Evett, Quinlan, & Besner, 1987; Rajaram & Neely, 1992; Segui & Grainger, 1990; Sereno, 1991). Forster and Davis also failed to find evidence for nonword priming, consistent with their lexical account. Although the absence of masked nonword priming has been replicated (Forster, 1987; Forster et al., 1987; Rajaram & Neely, 1992, for nonstudied nonwords), reliable masked nonword priming has since been demonstrated (Forster, 1985, Experiment 1; Masson & Isaak, 1991; Sereno, 1991).

The lexical account of masked repetition priming developed by Forster and Davis (1984) rests on the assumption that the formation of an episodic memory trace of the prime event is precluded. It is possible, however, that episodic traces of masked primes are formed, but do not achieve their full potential for enhancing target identification under the conditions tested by Forster and Davis. If so, it might be possible to create situations in which masked priming episodes have a greater influence on target processing, thereby producing effects inconsistent with the lexical account (i.e., frequency attenuation and priming of nonwords).

To see how such a situation could be constructed, consider that decreasing target discriminability through degradation increases priming effects (e.g., Becker & Killion, 1977; Besner & Swan, 1982; Borowsky & Besner, 1991, 1993; den Heyer & Benson, 1988; Meyer, Schvaneveldt, & Ruddy, 1975; Norris, 1984). Moreover, Whittlesea and Jacoby (1990) found that responses to a target showed greater repetition priming when an interpolated word was visually unfamiliar (e.g., GREEN-pLaNt-GREEN), compared to a condition where it was visually familiar (e.g., GREEN-PLANT-GREEN). Whittlesea and Jacoby argued that presenting the interpolated word in an unfamiliar format made processing of this stimulus more difficult, forcing the priming episode of the first occurrence of GREEN to be ‘‘brought forward’’ to participate in the identification of the interpolated word. With an interpolated word presented in a familiar format, less use was made of the priming episode in processing the interpolated word, so a smaller subsequent repetition priming effect was found on the target word.

The Whittlesea and Jacoby (1990) result is important in the current context because it shows that the contribution of an earlier processing episode to stimulus encoding can vary, depending on the demands of the current encoding situation. We sought to take advantage of this observation by varying the perceptual quality and the discriminability of word and nonword targets in a lexical decision task. When the lexical decision task is made more difficult by either of these manipulations, more use should be made of the priming episodes. Under these circumstances, the frequency attenuation effect and priming of nonwords might be observed just as in experiments that examined long-term repetition priming with clearly presented prime events.

Aside from the degree to which an episodically represented priming event influences classification of a target, another factor is presumed to influence repetition priming of nonwords in the lexical decision task. The processing efficiency provided by masked primes can lead subjects to experience a feeling of familiarity for the target, which is sometimes misattributed to prior exposure (Jacoby & Whitehouse, 1989), repetition or clarity (Whittlesea, Jacoby, & Girard, 1990), or fame (Jacoby, Woloshyn, & Kelley, 1989). In the lexical decision task, a conflict can arise between (1) the sense of familiarity that arises from improved processing efficiency, or fluency, created by repetition priming and (2) the requirement to make a NO response to nonwords (Feustel et al., 1983; Kirsner & Speelman, 1996). Further support for the idea that fluent processing can interfere with correct classification of nonwords comes from the finding that as the degree of similarity between a nonword and known words (as measured by number of neighbors) increases, there is an increase in lexical decision response time and error rate for nonwords (Forster & Shen, 1996). We suggest that, depending on the balance between the amount of processing fluency generated by repetition priming of a nonword and the degree to which subjects rely on a subjective feeling of fluent processing or familiarity in making a lexical decision, nonword priming may or may not be observed. In particular, when subjects rely partly on a feeling of familiarity and partly on an analysis of the target's features in making word/nonword judgments, little or no effect of repetition priming of nonwords is expected. In this case, the reduction in processing time produced by a repetition prime is counteracted by the requirement to discount the experienced sense of familiarity to make a NO response. When subjects are less able to rely on familiarity as a basis for responding, as when targets are presented in an unfamiliar format or when word/nonword discriminability is difficult, a robust priming effect for nonwords is predicted. Under these circumstances, targets are analyzed more fully and the feeling of familiarity plays only a small role in the classification decision. Therefore, little if any time is spent discounting that sense of familiarity in making a NO response to a nonword target, leaving a clear path for processing efficiency due to repetition priming to show itself.

In the experiments reported here, we began with a replication of Forster and Davis (1984, Experiment 1) in which masked repetition priming of clearly presented targets yielded no frequency attenuation effect and no nonword priming. In two subsequent experiments, we presented targets in an unfamiliar format or targets for which word/nonword discriminations were quite difficult. These experiments test predictions about the varying utility of priming episodes. In a final experiment, we test a prediction regarding the trade-off between processing efficiency and discounting the sense of familiarity to correctly classify a nonword target that follows a repetition prime.

EXPERIMENT 1: REPLICATION

Before investigating the effects of manipulating target discriminability, a replication of Forster and Davis (1984, Experiment 1) was carried out. In Experiment 1, we tested low- and high-frequency words with characteristics similar to those used by Forster and Davis in a lexical decision task. Targets (e.g., BRAIN) were presented in the context of masked repetition or unrelated primes (e.g., *brain* vs. *occur*). We expected to replicate two key findings taken by Forster and Davis as support for the lexical account of masked priming: (1) equivalent priming for low- and high-frequency words and (2) no priming for nonwords. Although these results can be explained by the lexical or episodic accounts, it was important to establish that our materials and procedures produce the key results of Forster and Davis.

Method

Subjects. Twenty-four undergraduate students at the University of Victoria participated for extra credit in an introductory psychology course. No subject took part in more than one of the experiments reported here. The median age of the subjects in each of these experiments was between 18 and 19 years.

Materials and design. The targets were 48 high-frequency words (40–60 occurrences per million; Kucera & Francis, 1967) such as TREE and SMILE, 48 low-frequency words (1–2 occurrences per million) such as AJAR and USHER, and 96 pronounceable nonwords such as BREEM and FEAP, each of 4–6 letters in length. Twelve additional practice targets, in equivalent proportions to the critical items, were also selected. These item characteristics and word–nonword ratios were the same as those used in Forster & Davis (1984). An additional set of items was selected to serve as unrelated primes. Forster and Davis did not specify whether their unrelated primes were of the same frequency as the targets with which they were paired. In our experiments, though, each target was paired with a unrelated prime of the same lexical class, length, and frequency class (for words) as the target (e.g., the unrelated nonword prime *sude* was paired with the nonword target FEAP). Unrelated primes shared no more than two, and usually shared zero, letters with their target and shared no letters in the same position. Primes were presented in lowercase letters and targets were presented in uppercase letters. The targets and unrelated primes appear in the Appendix.

The critical words were divided into two lists of 24 low-frequency word targets and two lists of 24 high-frequency words. Half of the nonwords were designated as critical items and were used to form two lists of 24 targets. One list of each type was assigned to the repetition prime condition and the other to the unrelated prime condition. Assignment of these lists to prime conditions was counterbalanced over subjects so that each list was tested equally often in each priming condition. For the remaining 48 nonword targets, designated as filler items, half were always tested with a repetition prime and half were always tested with an unrelated prime.

Procedure. Subjects were tested individually in a single session lasting about 15 min. Items were presented in black 12-point courier font against a white background on a monochrome monitor connected to a Macintosh II computer. Stimulus presentation was synchronized with the raster scan cycle of the monitor to permit exact timing of displays in increments of 15 ms. Subjects were told that each trial would consist of several briefly presented items and that the last item was the target. As in Forster and Davis (1984), no mention was made of the number or nature of items to be presented on a trial. Subjects were instructed to decide whether the target was a real English word.

Each trial consisted of a mask, which was a row of uppercase Xs matched for length with the prime and target, presented for 500 ms, followed immediately by the prime in lowercase letters for 60 ms, followed immediately by the target in uppercase letters. The target remained on the screen until a response was made. Subjects responded by pressing one of two labeled keys on a key pad (YES if the target spelled a word or NO if the target did not spell a word). Subjects used their right hand to press the YES key and their left hand to press the NO key. Following the Forster and Davis (1984) procedure, feedback was given on trials where the subject took too long to make a response (''Error: Too Slow!'' for 1 s, for responses longer than 2500 ms) or made an incorrect response (''Error: Incorrect Response'' for 1 s); the computer also beeped when either event occurred. The next trial began automatically 500 ms after the response. Rest breaks were provided every 32 critical trials. Subjects first were presented the 12 practice trials in random order, followed by a random ordering of the 144 critical and 48 filler trials. At the end of the session, subjects were asked what was seen on each trial, just before the target appeared. The goal of this question was to assess the perceptibility of the primes.

Results

In all experiments, the following conventions were followed. Trials with reaction times shorter than 300 ms or longer than 3500 ms were deleted. This trimming resulted in a loss of 19 of the 19,968 trials (0.1%) across the four experiments, well within the 0.5% recommended by Ulrich and Miller (1994). Mean reaction time in each condition was computed for each subject by averaging over items, and for each item by averaging over subjects. Separate analyses of variance (ANOVA) with subjects as the random variable (F_1) and with items as the random variable (F_2) were performed on the reaction times and error rates for words and nonwords. The type I error rate was set at .05.

The informal postexperiment probe question regarding the subjects' awareness of the primes revealed that 42% of the subjects in Experiment 1 knew that at least ''something'' other than a row of Xs was being flashed prior to onset of the target. Few subjects, however, were explicitly able to identify any of the primes, consistent with Forster and Davis's (1984) test of prime identifiability.

Word targets. Table 1 shows the mean of subjects' mean reaction times and error rates, for each of the word and nonword conditions and their corresponding priming effects. Data

TABLE 1

MEAN REACTION TIME (RT, IN MS) AND ERROR PERCENTAGE (%E) FROM FORSTER AND DAVIS (1984, EXPERIMENT 1) AND IN EXPERIMENT 1

	Repetition prime		Unrelated prime		Priming effect	
Experiment and target	RT	%E	RT	%E	RT	%E
Forster & Davis (1984, Expt 1)						
High-freq. word	550	2.9	595	4.5	45	1.6
Low-freq. word	646	15.3	684	21.2	38	5.9
Nonword	687	6.9	679	6.0	−8	−0.9
Experiment 1						
High-freq. word	603 (83)	0.2 (0.9)	632 (84)	0.7 (1.6)	29 (48)	0.5 (1.9)
Low-freq. word	778 (120)	15.6 (9.6)	823 (120)	16.8 (9.5)	45 (74)	1.2 (10.0)
Nonword	882 (164)	10.1 (7.3)	875 (139)	8.0 (7.9)	−7 (89)	−2.1 (6.7)

Note. Standard deviations for Experiment 1 are in parentheses. Forster and Davis (1984) did not report standard deviations.

for word and nonword targets were analyzed separately. A two-factor repeated-measures ANOVA with word frequency (low vs high) and priming (repetition vs unrelated) was used to analyze reaction time data for word targets. Repetition primes were found to produce reliably shorter reaction times than unrelated primes (690 ms vs 727 ms), $F_1(1,23) = 13.63$, $MS_e = 2{,}413$, $F_2(1,94) = 11.47$, $MS_e = 4{,}637$. This priming effect of 37 ms is quite close to the 42-ms effect found by Forster and Davis (1984). In addition, reaction time for high-frequency words was less than for low-frequency words (618 ms vs 800 ms), $F_1(1,23) = 200.32$, $MS_e = 3{,}991$, $F_2(1,94) = 113.46$, $MS_e = 16{,}998$. This frequency effect is twice as large as the effect reported by Forster and Davis, and seems to be due, at least in part, to slower responding to low-frequency targets in this experiment.

Despite a trend toward more priming for low-frequency words (45 ms) than for high-frequency words (29 ms), the interaction between frequency and priming and was not significant, $Fs < 1.06$. The power of Experiment 1 to detect an interaction between frequency and priming was estimated by using as a benchmark effect size the interaction effect found by Forster and Davis (1984, Experiment 3) for unmasked primes. In that study, the priming effect for high-frequency words was half the magnitude of the effect for low-frequency words. Using this benchmark, we estimated the power to detect an interaction of word frequency and priming in Experiment 1 in which the priming effect for high-frequency words would be half the size of the effect for low-frequency words. The estimated power values were .29 for the subjects analysis and .26 for the items analysis. Thus, Experiment 1 had relatively little chance of producing a reliable interaction.

A similar ANOVA was applied to error rates for word targets. The only reliable effect in this analysis was the effect of frequency, with far more errors occurring for low-frequency targets (16.2%) than for high-frequency targets (0.5%), $F_1(1,23) = 97.59$, $MS_e = 50.27$, $F_2(1,94) = 50.27$, $MS_e = 238$.

Nonword targets. Reaction times and error rates for nonword targets were analyzed in separate ANOVAs with prime (repetition vs unrelated) as a repeated measures factor. Neither analysis found a reliable effect of priming, $Fs < 1$ for reaction time, $F_1(1,23) = 2.31$, $MS_e = 22.56$, $p = .14$ and $F_2(1,47) = 1.84$, $MS_e = 56.87$, $p = .18$ for error rates. The power of Experiment 1 to detect a reaction time priming effect for nonword targets of the same magnitude as that found for words was estimated to be .54 and .82 in the subject and item analyses, respectively.

Discussion

Experiment 1 successfully replicated the features of the Forster and Davis (1984, Experiment 1) demonstration of masked repetition priming in lexical decision. First, the benefit of a repetition prime was equally strong for low- and high-frequency words. Second, nonwords failed to show an effect of priming. Although these results are consistent with those of Forster and Davis, our Experiment 1 did not have substantial power to detect either an interaction between word frequency and priming or an effect (at least by subjects) of priming among nonwords. It was not possible for us to determine the power of the Forster and Davis experiment for either of these effects. We note, however, that Forster and Davis used only a slightly larger sample size (28 instead of 24) and therefore, it is unlikely that they had substantially more power than we did to detect a frequency attenuation effect, or perhaps even a nonword priming effect. This is problematic because the lexical account of repetition priming put forward by Forster and Davis is grounded on these two null effects. We further address concerns about the power to detect the frequency by prime interaction and priming among nonwords in the subsequent experiments. At this point, the important conclusion to draw from Experiment 1 is that our materials and procedure produce results comparable to those reported by Forster and Davis.

EXPERIMENT 2: CASE-ALTERNATED TARGETS

The objective of Experiment 2 was to assess masked repetition priming of targets presented in an unfamiliar format using case alternation (e.g., lETtEr). The episodic account of priming suggests that this manipulation would force subjects to rely more heavily on information available from the prime to make their response (Whittlesea & Jacoby, 1990). Bringing forward the prime episode to aid target classification might allow low-frequency targets to show more benefit from a repetition prime than would high-frequency targets, if, for example, priming episodes for low-frequency words are particularly salient (e.g., Jacoby & Dallas, 1981). In addition, low-frequency words have more room to show priming than high-frequency words because the latter may be closer to an asymptotic level of performance even without priming (Logan, 1988). Another expected effect of the case-alternation manipulation was to increase the priming effect, as observed with degraded targets in studies of long-term repetition and associative priming (e.g., Becker & Killion, 1977; Besner & Swan, 1982; Borowsky & Besner, 1991, 1993; den Heyer & Benson, 1988; Meyer et al., 1975; Norris, 1984). With a larger priming effect in play, power to detect an interaction with word frequency might be enhanced.

For nonword targets, our prediction was that they would show a priming effect when targets are case-alternated. When a lexical decision response to a target can be made in part on the basis of an immediate sense of familiarity, and when processing of the target is relatively easy, the fluency afforded a nonword target by a repetition prime would misdirect subjects toward an incorrect response. Additional processing time would be incurred to avoid an error, leading to a loss of the potential benefit of the prime (e.g., Feustel et al., 1983). Making target processing more difficult by presenting it in an unfamiliar form was expected to reduce subjects' dependence on an immediate sense of familiarity in classifying the target. At the same time, however, the benefit of information derived from the repetition prime would still enable more efficient processing of the target, relative to the unrelated prime condition. The net result would be more efficient processing of nonwords in the repetition condition, leading to shorter response latencies. These predictions were tested in Experiment 2a using targets that were presented in case-alternated format, as used by Whittlesea and Jacoby (1990). Otherwise, the methodology was the same as in Experiment 1.

One potential concern that arises from the use of case-alternated targets is that the lowercase letters of targets completely overlap the corresponding letters of their repetition primes (e.g., the ‘‘w’’ and ‘‘r’’ in the prime-target pair *word-wOrD* overlap perfectly). Since there is no mask between primes and targets, it is possible to argue that any increased priming effects for word targets and any nonword priming observed in Experiment 2a, relative to Experiment 1, might be the result of this physical match. To address this concern, in Experiment 2b the non-overlapping letters of repetition primes (and letters in the corresponding positions of the unrelated primes) were replaced with different letters (e.g., *word-wOrD* would become *wirk-wOrD*). If the physical overlap produces priming, then the same pattern of priming effects should be found in Experiments 2a and 2b. If priming effects are not observed in Experiment 2b, then the physical overlap explanation can be ruled out.

Method

Subjects. Twenty-four subjects from the same source used in Experiment 1 were tested in Experiment 2a and 24 more were tested in Experiment 2b.

Materials, design, and procedure. For Experiment 2a, the only change from Experiment 1 was that targets appeared in alternating upper- and lowercase letters (e.g., sMiLe, bReEm) instead of appearing in all uppercase letters. The first letter of each target was a lowercase letter. Primes were again presented in lowercase letters.

Experiment 2b was identical to Experiment 2a, except that the lowercase primes were modified to test for physical overlap as the source of the predicted priming effects in Experiment 2a, as described above. For repetition primes, the lowercase prime letters that corresponded to the uppercase letters of the case-alternated targets were replaced with different letters, under the constraint that consonants replaced consonants, and vowels replaced vowels (e.g., *phone-pHoNe* became *ptobe-pHoNe*). For unrelated primes, the letters in the corresponding positions were also modified in this way (e.g., *limit-pHoNe* became *lamot-pHoNe*). Thus, repetition and unrelated primes were always nonwords in Experiment 2b. The replacement procedure did not guarantee that the primes were pronounceable, but note that perceptual overlap, not pronounceability, is the explanation we sought to rule out in Experiment 2b.

Results

In the post-experiment interview, only 25% of the subjects in Experiment 2a, and 8% of subjects in Experiment 2b reported being aware of the presentation of primes. Most of those subjects reported having very little information about the nature of the primes, even though they were aware of their presence.

Analyses of reaction time and error data for word and nonword targets were conducted as in Experiment 1. Means of subjects’ mean reaction times and error rates for all conditions as well as for priming effects in Experiments 2a and 2b appear in Table 2. Relative to Experiment 1, reaction times were substantially longer for words and nonwords in Experiment 2, indicating that the case-alternated targets were more difficult to classify than their uppercase counterparts.

Word targets. First we consider the results from Experiment 2a. Word targets showed a reliable priming effect, $F_1(1,23) = 57.06$, $MS_e = 2{,}378$, $F_2(1,94) = 34.04$, $MS_e = 10{,}746$. Subjects were faster when targets were preceded by repetition (746 ms) than by unrelated (821 ms) primes. As expected, this priming effect with case-alternated targets (75 ms) was substantially larger than that found in Experiment 1 where all target letters were uppercase (37 ms). A main effect of word frequency was observed, with high-frequency targets leading to shorter reaction times (693 ms) than low-frequency targets (874 ms), $F_1(1,23) = 102.48$, $MS_e = 7{,}615$, $F_2(1,94) = 68.82$, $MS_e = 26{,}441$. The magnitude of the frequency effect (180 ms) was nearly identical to that observed in Experiment 1 (183 ms). The additivity of word frequency and format of the target display (e.g., degraded or case-alternated vs normal) in the lexical decision task has been demonstrated by many researchers

TABLE 2

MEAN REACTION TIME (RT, IN MS) AND ERROR PERCENTAGE (%E) IN EXPERIMENT 2

	Repetition prime		Unrelated prime		Priming effect	
Target	RT	%E	RT	%E	RT	%E
Experiment 2a						
High-freq. word	658 (105)	1.1 (1.9)	729 (108)	3.5 (3.2)	71 (56)	2.4 (3.2)
Low-freq. word	834 (129)	15.1 (10.3)	913 (150)	20.5 (10.0)	79 (62)	5.4 (10.8)
Nonword	934 (178)	8.0 (7.8)	1027 (224)	6.6 (6.0)	93 (121)	−1.4 (7.7)
Experiment 2b						
High-freq. word	761 (129)	4.4 (4.2)	750 (124)	4.4 (4.5)	−11 (93)	0.0 (5.9)
Low-freq. word	949 (181)	22.0 (12.3)	967 (203)	20.5 (10.7)	19 (90)	−1.6 (12.8)
Nonword	1074 (268)	10.1 (11.0)	1084 (256)	8.9 (8.4)	9 (59)	−1.2 (6.3)

Note. Standard deviations are in parentheses.

(e.g., Becker & Killion, 1977; Besner & McCann, 1987; Borowsky & Besner, 1991; Stanners, Jastrzembski, & Westbrook, 1975) and suggests that word frequency may not affect perceptual encoding. The interaction between priming and word frequency did not approach significance, Fs < 1. The estimated power to detect an interaction in which the priming effect for high-frequency words was half the size of that observed for low-frequency words was .81 by subjects and .64 by items.

Analyses of error rates for word targets revealed main effects of priming, $F_1(1,23) = 12.32$, $MS_e = 30.03$, $F_2(1,94) = 7.05$, $MS_e = 104$, and frequency, $F_1(1,23) = 88.61$, $MS_e = 65.54$, $F_2(1,94) = 47.78$, $MS_e = 243$, but no interaction, Fs < 1.62. More errors were made on unrelated trials (12.0%) than on repetition trials (8.1%), and more errors were made to low-frequency targets (17.8%) than to high-frequency targets (2.3%). These error rates are comparable to those found in Experiment 1.

The results of Experiment 2b indicate that physical overlap between lowercase letters of the prime and lowercase letters of the target was not enough to produce priming for the word targets, Fs < 1. The estimated power to detect a priming effect for words equal in magnitude to that found in Experiment 2a was .98 by subjects and .99 by items. Therefore, the physical overlap between the lowercase letters in repetition primes and the lowercase letters of their case-alternated targets is not a likely cause of the priming effects observed in Experiment 2a. The effect of target frequency was similar to that in Experiment 2a (202 ms), $F_1(1,23) = 86.96$, $MS_e = 11{,}298$, $F_2(1,94) = 45.41$, $MS_e = 51{,}731$. As in Experiment 2a, there was no interaction between priming and frequency, Fs < 1.24. In the error rate analyses, only the main effect of frequency was significant, $F_1(1,23) = 89.74$, $MS_e = 76.52$, $F_2(1,94) = 41.56$, $MS_e = 331$, with more errors made when responding to low-frequency targets.

Nonword targets. In Experiment 2a, an ANOVA of nonword target reaction times revealed a reliable priming effect, $F_1(1,23) = 14.12$, $MS_e = 7{,}362$, $F_2(1,47) = 30.88$, $MS_e = 6{,}618$, with shorter reaction times on repetition trials than on unrelated trials (934 ms vs 1027 ms). There was no effect of prime on error rate, Fs < 1.

The priming effect for reaction time observed among nonwords was compared to that found with word targets (collapsing across frequency) in an additional ANOVA with lexicality (word vs nonword) and prime (repetition vs unrelated) as factors. The interaction of target type and priming did not approach significance, Fs < 1.

In Experiment 2b, where we controlled for physical overlap, the 9-ms effect of priming for nonword targets was not reliable, Fs $<$ 1.1. The power to detect a nonword priming effect equal to that found in Experiment 2a was estimated to be .98 and .99 by subjects and items, respectively. There was no effect of prime on error rate, Fs $<$ 1.3. Thus, it appears that physical overlap was not responsible for the nonword priming observed in Experiment 2a.

Discussion

In Experiment 2a, case-alternation of targets produced one of the two results predicted by lexical accounts of masked repetition priming: word frequency failed to modulate the priming effect, counter to what might be expected by an episodic account. At the same time, however, nonwords in Experiment 2a produced a reliable priming effect that was at least as large as that obtained with word targets. Masked priming of nonwords in the lexical decision task has been reported previously. Sereno (1991) demonstrated a 29-ms effect, Masson and Isaak (1991) found a 23-ms effect, and Forster (1985, Experiment 1) reported a reliable 24-ms effect. In each of these cases, priming for nonwords was weaker than priming for words, and Forster (1985, 1993) has suggested that effects such as these are unusual or equivocal. In light of this interpretation of earlier priming effects with nonwords, the present robust priming effect for nonwords is important and certainly not equivocal.

A possible explanation of the priming effect observed for nonwords in Experiment 2a was that facilitation was due entirely to the physical match between the lowercase letters of the alternating-case target and the corresponding letters in the repetition prime. The results of Experiment 2b, however, clearly rule out this interpretation. Neither nonwords nor words showed reliable priming when the letters of a repetition prime that spatially corresponded to the uppercase letters of the target were replaced with different letters, even though the lowercase letters of these primes still had perfect physical overlap with the lowercase letters of the target. Moreover, if the physical overlap explanation were correct, nonwords and words in Experiment 2a would be expected to benefit equally from the physical match. Specifically, word targets in Experiment 2a should retain the priming advantage they enjoyed over nonwords in Experiment 1. Contrary to this prediction, although words yielded a larger priming effect than nonwords in Experiment 1, $F_1(1,23) = 5.14$, $MS_e = 4{,}496$, $F_2(1,142) = 5.66$, $MS_e = 10{,}410$, this effect did not hold in Experiment 2a: priming among nonwords was at least as large as among words. This changing pattern of priming effects for words and nonwords provides further support for our claim that the nonword priming observed in Experiment 2a was not the result of the physical match between the lowercase letters of repetition primes and their targets.

Instead, we suggest that presenting targets in an unfamiliar format through case-alternation made lexical decisions more dependent on effortful processing of the target and less affected by an immediate impression of familiarity. The processing efficiency afforded by repetition priming can reduce response latency when subjects are led to ignore the sense of familiarity that accompanies a repetition-primed nonword. As a further test of this account, a different method of reducing target discriminability was used in the next experiment.

EXPERIMENT 3: PSEUDOHOMOPHONE NONWORDS

Rather than altering the appearance of the targets, lexical decisions were made more difficult in Experiment 3 by using nonwords that were word-like. The nonwords in this experiment were pseudohomophones: letter strings that do not spell a real word but sound like a word (e.g., *bocks* does not spell a word, but sounds like *box*). Because pseudohomophones sound like real words, they are more difficult to reject than other pronounceable nonwords (e.g., Davelaar, Coltheart, Besner, & Jonasson, 1978; Parkin & Ellingham, 1983; Stone & Van Orden, 1993). Thus, although the identifiability of word targets in Experiment 3 was not impaired, lexical decisions about these targets were expected to be more difficult than in Experiment 1 because phonological information about the target would not be an adequate basis for lexical decisions and because the orthographic pattern of pseudohomophones might be more word-like. The increased difficulty in making the discrimination between words and nonwords was expected to make subjects more reliant on effortful processing of the targets and on the benefits provided by repetition priming. At the same time, subjects should be less likely to allow a decision to be affected by a mere impression of familiarity with the target. Therefore, it was expected that pseudohomophones, like the case-alternated nonword targets in Experiment 2a, should produce repetition priming.

If masked priming effects are generated by the formation and retrieval of the masked prime episode, an interaction between priming and target word frequency would be expected. The failure to find such an interaction in Experiment 2a, however, suggests that the interaction is not likely to appear in Experiment 3. One reason that word frequency might not modulate masked repetition priming in the same way it does long-term repetition priming is that masked priming might have its primary effect on relatively early stages of word processing. In particular, suppose a masked prime creates an episode that has a rich orthographic representation but only a rudimentary semantic component (although substantial enough to produce semantic or associative priming; Carr & Dagenbach, 1990; Sereno, 1991). This scenario is plausible because the brief time devoted to the masked prime might allow for very little information beyond the orthographic level to be incorporated into the episode. If word frequency effects depend on processes beyond the orthographic level (e.g., Besner & Smith, 1992; Borowsky & Besner, 1993), then the bulk of the facilitation produced by a masked prime episode would not vary with the frequency of the target word. Thus, the interaction between word frequency and priming would be very small and hard to detect.

Comparing the size of the priming effect found in Experiment 2a and any priming effect found in Experiment 3 would provide a preliminary test of this idea. Reducing target discriminability in Experiment 2a created an opportunity for masked repetition primes to make a substantial contribution to the formation of an orthographic representation of the target. The large facilitation effect found in Experiment 2a (about twice the size of the effect obtained in Experiment 1) is consistent with this account. In contrast, targets were not directly altered in Experiment 3, although response times were expected to be long as in Experiment 2a because nonwords consisted of pseudohomophones. Because target identifiability is not impeded in any way, however, there is less potential for orthographic processing to benefit from masked priming. Therefore, if masked repetition primes have their primary effect on formation of an orthographic representation, the priming effect in Experiment 3 should be less than that found in Experiment 2a.

Method

Subjects. Twenty-four students from the same source as Experiments 1 and 2 were tested.

Materials and design. The design was the same as Experiment 1, except that 96 pseudohomophones, paired with 96 additional unrelated pseudohomophone primes, were used as the nonword targets and required NO responses in the lexical decision task. These pseudohomophone stimuli are presented in the Appendix. Six additional pairs of pseudohomophones were prepared for practice trials. The pseudohomophones sounded like words, although their spelling did not fit any known word. Care was taken to select orthographically regular pseudohomophones such as REER and WERSE, as recommended by Seidenberg & McClelland (1989). The pseudohomophones were created from base words with normative frequencies of at least 40 per million (Kucera & Francis, 1967). The word targets were the same as in the earlier experiments. As in Experiment 1, primes were pre-

TABLE 3

Mean Reaction Time (RT, in ms) and Error Percentage (%E) in Experiment 3

	Repetition prime		Unrelated prime		Priming effect	
Target	RT	%E	RT	%E	RT	%E
High-freq. word	672 (125)	1.2 (2.4)	708 (146)	2.1 (2.8)	36 (77)	0.9 (3.9)
Low-freq. word	864 (171)	13.9 (6.8)	914 (177)	17.1 (9.7)	51 (70)	3.2 (7.7)
Pseudohomophone	871 (165)	9.9 (7.3)	909 (186)	7.6 (6.5)	38 (73)	−2.2 (6.4)

Note. Standard deviations are in parentheses.

sented in lowercase letters, and targets were presented in uppercase letters. Counterbalanced assignment of items to priming conditions and was carried out as in the earlier experiments. There were 24 high-frequency words, 24 low-frequency words, and 48 pseudohomophones in each priming condition.

Procedure. The procedure was identical to the previous experiments. Subjects were told to classify the pseudohomophones as nonwords because although they sounded like real words, they did not spell real words.

Results

Awareness of the identity of the primes was once again estimated by asking subjects what they saw in the display just before the target was presented. This questioning revealed that 46% of the subjects reported being aware that some sort of stimulus had been embedded between the row of Xs and the target.

Means of the subjects' mean reaction times and error rates for each priming condition for word and pseudohomophone targets are shown in Table 3. In general, the use of pseudohomophones as nonwords had the anticipated effect of slowing subjects' lexical decisions, relative to Experiment 1. Separate ANOVAs were computed for word targets and for pseudohomophone targets to assess priming effects.

Word targets. Reaction times were analyzed in an ANOVA with prime and frequency as factors. There was a reliable 43-ms repetition priming effect, $F_1(1,23) = 13.71$, $MS_e = 3,306$, $F_2(1,94) = 15.06$, $MS_e = 6,383$, and a reliable word frequency effect (690 ms for high- and 889 ms for low-frequency words), $F_1(1,23) = 142.10$, $MS_e = 6,700$, $F_2(1,94) = 103.90$, $MS_e = 20,845$. The interaction between priming and frequency was not significant, Fs < 1. The power to detect an interaction producing half as much priming for high- as for low-frequency words was .26 and .38 for subjects and items, respectively.

Another ANOVA was used to analyze error rates for word targets. Identity priming reduced error rates, although the effect was marginal in the items analysis, $F_1(1,23) = 6.95$, $MS_e = 13.98$, $F_2(1,94) = 3.15$, $MS_e = 62.41$, $p = .08$. Errors were more common for low-frequency targets than for high-frequency targets, $F_1(1,23) = 87.17$, $MS_e = 52.53$, $F_2(1,94) = 75.01$, $MS_e = 122$. The interaction was not significant, Fs < 1.38.

To test the prediction that the identity priming effect would be smaller in Experiment 3 than in Experiment 2a, an additional ANOVA with experiment, prime, and frequency was applied to the reaction time data. This ANOVA found no main effect of experiment, indicating that overall reaction time was similar in the two experiments. There were reliable effects of prime and frequency, but of greatest interest was the reliable interaction between experiment and prime, $F_1(1,46) = 4.25$, $MS_e = 2,841$, $F_2(1,94) = 6.03$, $MS_e = 7,352$. This interaction confirms the prediction that the priming effect was larger with the case-alternated targets of Experiment 2a than with the normal targets used in Experiment 3. The effect of priming on the mean error rates for the two experiments was slightly larger in Experiment 2a than in Experiment 3, ruling out speed–accuracy trade-off as an explanation for the interaction in the reaction time data.

Pseudohomophone targets. An ANOVA with prime as the only factor was used to analyze reaction time data for the pseudohomophone targets. This analysis revealed a reliable 38-ms repetition priming effect, $F_1(1,23) = 6.51$, $MS_e = 2{,}661$, $F_2(1,95) = 6.11$, $MS_e = 10{,}834$. A similar ANOVA applied to error rates indicated that there was no significant effect of priming on errors.

The priming effect in reaction time observed for pseudohomophones was compared to the priming effect for word targets (collapsing across frequency) in an ANOVA with lexicality and prime as factors. The interaction of target type and priming was nonsignificant, $F\text{s} < 1$, indicating that words and nonwords benefited equally from repetition primes.

Discussion

Using pseudohomophones was an effective method of increasing the difficulty of making lexical decisions, as indicated by the relatively long reaction times in Experiment 3 as compared with Experiment 1. Although both prime and word-frequency had reliable effects, these two factors did not interact. The power of Experiment 3 to detect an interaction, however, was rather low. To produce a more powerful test of the interaction, the reaction time data from Experiments 1, 2a, and 3 were combined in a single ANOVA. This analysis also failed to find a significant interaction between frequency and priming, $F\text{s} < 1.9$. The power of this analysis to detect an interaction in which the priming effect for high-frequency targets was half the magnitude of that for low-frequency targets was estimated to be .88 in the subject analysis, and .79 in the item analysis. Thus, even with a test that achieved a reasonable degree of power (Cohen, 1988), the interaction was not found.

The lack of interaction is consistent with the lexical account of repetition priming and places an important constraint on the episodic account. To accommodate the lack of an interaction similar in magnitude to that found in long-term repetition priming, we propose that a much weaker interaction or no interaction at all would occur if (1) a masked prime creates an episode dominated by a representation of the prime's orthography and (2) word frequency has little or no effect on the formation of an orthographic representation of a letter string. In support of the first of these two assumptions, the priming effect was significantly larger in Experiment 2a than in Experiment 3, even though overall reaction time was very similar in the two studies. We attribute the larger priming effect in Experiment 2a to the use of visually unfamiliar, case-alternated targets and a greater reliance on repetition primes in constructing an orthographic representation of the targets.

Although an interaction between frequency and priming was not obtained, as predicted by the lexical account of masked priming, that account runs into difficulty with the other major result of Experiment 3. The pseudohomophone nonwords yielded a reliable repetition priming effect, replicating the result of Experiment 2a which used standard pronounceable nonwords. By the lexical account, nonwords should not show repetition priming in the lexical decision task because they have no lexical entry to be opened by the identity prime. The fact that nonwords once again produced as much priming as words indicates that a process other than opening a lexical entry played a fundamental role in generating the facilitation associated with repetition priming. The proposed contribution of masked repetition priming to the construction of a target's orthographic representation is consistent with the finding of robust priming effects among nonwords.

A proponent of the lexical account, however, might explain the masked priming of pseudohomophones by arguing that on repetition trials, the lexical entry for the pseudohomophone's base word was opened. Detection of the mismatch between the orthography of the spelling code in the opened lexical entry and the orthography of the pseudohomophone target would facilitate NO responses on these trials. If this argument were valid, then one would expect even more facilitation of NO responses on trials where the pseudohomophone target is unrelated to its pseudohomophone prime. This prediction follows because the unrelated prime would open the lexical entry of its base word (recall that unrelated primes were also pseudohomophones). The mismatch between the spelling code of that opened entry and the unrelated pseudohomophone target's orthography would be even greater than in the case of repetition primed pseudohomophone targets. The orthographic mismatch hypothesis must therefore predict an interference effect for pseudohomophone targets (i.e., shorter reaction times in the unrelated condition relative to the repetition prime condition). The large positive priming effect for pseudohomophones in Experiment 3 clearly rules out this line of argument.

We conclude that when lexical decisions are made more difficult, causing subjects to rely more on effortful target processing, the benefits of masked repetition priming for nonwords can be reliably demonstrated. This effect is obscured when lexical decisions are based on a more superficial analysis of targets combined with the influence of a sense of familiarity engendered by repetition. That sense of familiarity, if used as a basis for a word/nonword decision, acts against making the correct decision in the case of nonwords. This conflict is assumed to counteract the processing benefit that repetition priming would otherwise bestow upon nonwords, leading to the null effect of masking priming on nonwords that has been observed in the lexical decision task (e.g., Experiment 1; Forster & Davis, 1984). If this trade-off account is correct, it should be possible to construct conditions under which the processing benefit of repetition priming is outweighed by the cost of discounting the feeling of familiarity, so that an interference effect, rather than a facilitative effect, will be found with nonwords. The purpose of the final experiment was to create such a situation.

EXPERIMENT 4: REVERSAL OF FORTUNE FOR NONWORDS

If a masked repetition prime enhances perceived processing fluency and, hence, a sense of familiarity with the target letter string, it should be possible for that familiarity to slow responses to nonwords. Increased response times would arise because the familiarity produced by repetition priming of a nonword could be misconstrued as evidence in favor of classifying the nonword as a word (e.g., Feustel et al., 1983; Kirsner & Speelman, 1996). This interference effect should occur if lexical decisions are predominantly influenced by an immediate sense of familiarity. Whereas subjects in Experiments 2 and 3 were forced to process targets effortfully, making the word/nonword discrimination easier than in those experiments should produce a relatively greater dependence on a sense of familiarity for targets.

In Experiment 4, the lexical decision task was made much easier by using words of only very high frequency and nonwords that consisted of consonant strings. Given the high degree of distinctiveness between these two sets of items, it was expected that subjects would exert less effort processing the targets, and would instead rely primarily on the apparent familiarity of the target. The familiarity of the orthography of targets would be an adequate basis for making responses in this situation (James, 1975; Shulman & Davidson, 1977). Although the overall degree of familiarity with word targets experienced under these circumstances might be less than that produced when word meaning plays a larger role in making lexical decisions, when contrasted with nonpronounceable nonwords there would be greater differentiation between word and nonword targets with respect to orthographic familiarity. That sense of familiarity is assumed therefore to play a larger role in driving lexical decisions than is the case when nonwords are pronounceable. By depending mainly on familiarity, subjects would be seriously misled by the fluent processing associated with repetition-primed nonwords. The sense of familiarity created by repetition priming would be inconsistent with the evidence provided by a nonword target's orthographic pattern, thereby slowing the production of a correct response. Although the effect of masked priming on nonwords might instead be revealed in error rates, an effect on reaction time seemed more likely, given the ease of the discrimination required by the materials used here.

In addition to expecting an interference effect for repetition-primed nonwords, we anticipated that word targets would continue to show a facilitative repetition effect. The priming effect for words in Experiment 4 might be smaller than that observed in earlier experiments because the discrimination task is much easier, reducing reliance on the primes (Whittlesea & Jacoby, 1990).

Method

Subjects. Thirty-two subjects from the same source as Experiments 1–3 were tested.

Materials and design. Targets were 96 words of very high frequency (100–400 occurrences per million; Kucera & Francis, 1967), such as DOOR and FAITH, and 96 nonword consonant strings such as TWLT and SHTGS, of four or five letters in length. For each target, an unrelated prime of the same type (i.e., word or consonant string) was selected, as in the previous experiments. Unrelated primes shared no letters with their corresponding targets. These word and nonword materials are presented in the Appendix. Two lists of 48 word targets and two lists of 48 nonword targets were created, with one list of each type assigned to each priming condition. This assignment was counterbalanced across subjects so that each item appeared equally often in each priming condition. An additional 12 pairs of primes and targets were created for use as practice items (six word pairs, six nonword pairs).

Procedure. The procedure was the same as the previous experiments, with the following exceptions. To persuade subjects to rely more on the familiarity they experienced when making their decisions, instructions emphasized speed rather than both speed and accuracy. Also, no feedback was given for incorrect responses, although feedback was provided as in earlier experiments on trials where subjects took longer than 1 s to respond. To discourage random responding, subjects were told that a summary of their performance would be shown to them following the experiment. The 12 practice trials were presented in random order, followed by 192 critical trials in random order. Rest breaks occurred after every 64 critical trials.

Results

When asked about visual events occurring just before each target, 38% of the subjects reported being aware that a something had been flashed before the target was presented. As in the earlier experiments and as in Forster and Davis (1984), however, subjects could report few details about the nature of the primes (e.g., whether they were words, whether they were in upper- or lowercase letters).

Table 4 shows the means of subjects' mean reaction times and error rates for each of the priming conditions for word and nonword targets. A comparison of reaction times in Table 4 with those in the earlier experiments (Tables 1–3) indicates that the subjects in Experiment 4 were much faster in making lexical decisions. Reaction time and error data were analyzed separately for word and nonword targets.

Word targets. An ANOVA with prime as the only factor was used to analyze the reaction time data for word targets. This analysis revealed that lexical decisions were reliably faster on repetition trials (491 ms) than on unrelated prime trials (514 ms), $F_1(1,31) = 78.45$, $MS_e = 101$, $F_2(1,95) = 47.85$, $MS_e = 512$. As expected, the size of this priming effect (22-ms) was somewhat smaller than in Experiments 1–3. A smaller effect suggests that the ease of the discrimination required in Experiment 4 made subjects less dependent on the benefits of the prime to classify words. Another possibility is that because responses were made in such a short time frame, the potential amount of benefit that priming could generate was reduced.

Error rates for word targets were very low. An ANOVA indicated that there was no effect of priming on errors, $F\text{s} < 1$.

Nonword targets. As predicted, the fluency

TABLE 4

Mean Reaction Time (RT, in ms) and Error Percentage (%E) in Experiment 4

	Repetition prime		Unrelated prime		Priming effect	
Target	RT	%E	RT	%E	RT	%E
Word	491 (44)	1.7 (2.1)	514 (45)	2.2 (2.5)	22 (14)	0.5 (2.7)
Nonword	519 (48)	2.0 (2.6)	510 (50)	2.0 (2.6)	−9 (23)	0.0 (3.0)

Note. Standard deviations are in parentheses.

granted by a repetition prime worked against appropriate responding for nonword targets. This effect appeared in an ANOVA of the reaction time measure as an increase in reaction time on repetition trials relative to unrelated prime trials (519 ms vs 510 ms by subjects; 521 vs 511 by items), $F_1(1,31) = 5.03$, $MS_e = 265$, $F_2(1,95) = 5.30$, $MS_e = 826$. Although the size of this interference effect is small and comparable to nonsignificant priming effects observed in other experiments reported here, it occurred in an environment associated with much less variability in performance both between and within subjects. Thus, the interference effect was statistically reliable and consistent, appearing in the data for 24 of the 32 subjects. As with word targets, there were no effects of priming in the error rates, Fs < 1.

Discussion

By making the word/nonword discrimination almost trivial, we argue that subjects came to rely heavily on an immediate sense of familiarity or fluency in making lexical decisions. This approach to the task became a liability when nonword targets were preceded by repetition primes. The familiarity generated by priming nonwords ran counter to the classification response that was required, thereby slowing responses.

Although it might seem counterproductive for subjects to use fluency as a basis for responding because it would lead them astray on nonword repetition trials, there are at least three reasons why subjects would have adhered to this approach. First, nonword repetition trials represented only 25% of the trials, so the fluency strategy would be appropriate for a large majority of the trials. Second, the fluency strategy was encouraged by the emphasis on rapid responding. Third, given the small magnitude of the priming effect for nonwords, it is most probable that subjects were unaware of their hesitation on nonword repetition trials.

The demonstration that priming nonwords can slow responding lends support to a nonlexical account of failures to find masked priming of nonwords. On the nonlexical account, encoding of nonwords benefits from masked repetition priming, but that processing benefit serves as evidence in favor of classifying the nonword as a word. Discounting that evidence takes time, thereby counteracting the benefit produced by the prime. Although explanations that depend on this kind of balancing trade-off are justifiably met with skepticism regarding the good fortune supposedly required for a perfect balance to be struck, we have shown that the scales can be evenly balanced or tipped in either direction.

The finding that repetition priming of nonwords can be manipulated by inducing subjects to use or to avoid using fluency as a basis for lexical decisions runs counter to an important assumption made by the lexical account, namely that masked repetition primes have their effect by opening a target's lexical entry prior to the presentation of the target. By this account, nonwords should not show effects of repetition priming. Contrary to this proposal, we have demonstrated that nonwords are sensitive to masked primes and that

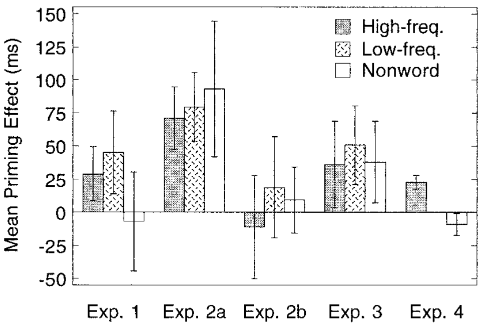

FIG. 1. Mean priming effect (in ms) Experiments 1–4. Error bars indicate the 95% confidence interval for the priming effect.

the effect of this priming can be influenced by varying the manner in which subjects perform lexical decisions.

GENERAL DISCUSSION

The main results of Experiments 1–4 are summarized in Fig. 1, which shows priming scores calculated as the difference between mean reaction time for unrelated-prime trials and mean reaction time for repetition-prime trials. Two main features of the data are apparent in the figure. First, there is no reliable evidence for a frequency attenuation effect under masked prime conditions. Second, repetition priming of nonwords was shown to vary across experiments, ranging from a facilitative effect, through no effect, to an interference effect. The general implications of these two findings are discussed in turn.

Additivity of Frequency and Priming

As highlighted in Fig. 1, Experiments 1, 2a, and 3 provided more examples of additivity of word frequency and priming in the masked repetition priming paradigm (see also Ferrand et al., 1994; Forster & Davis, 1984; Rajaram & Neely, 1992; Segui & Grainger, 1990; Sereno, 1991). Additivity of frequency and priming was also found by Humphreys et al. (1987, 1988) in the masked word identification paradigm. In assessing the implications of a null effect, it is important to consider the power of statistical tests to detect the effect. None of the experiments reported here, when taken individually, had substantial power to detect an interaction between frequency and priming. The combined analysis of Experiments 1, 2a, and 3, however, had adequate power to detect an interaction of the size found in long-term repetition priming but failed to do so. Neither of the methods we used to make target processing difficult, and ostensibly more dependent on the prime episode, produced greater priming for low- than for high-frequency words (see also, Besner & McCann, 1987; Mayall & Humphreys, 1996).

In view of the fact that frequency and priming do not appear to interact under masked conditions, the episodic account is constrained in an important way. Our conjecture is that the episodic representation of a masked prime is primarily invested in the orthographic form of the prime. This proposition is consistent with the finding of reliable priming effects for words and nonwords in Experiment 2a, where the orthographic forms of the primes are maintained, but not in Experiment 2b, where the orthographic forms of the primes were modified by changing the prime letters that corresponded to the uppercase target letters. This proposition is also consistent with the finding of an increasing monotonic relation between the number of letters in common between a masked prime and a target in the masked word identification task (Humphreys, Evett, & Quinlan, 1990). If episodic traces of masked primes contain primarily orthographic information, then the failure to find a frequency attenuation effect may be due to word frequency having little impact on the construction of an orthographic representation of a letter string (Besner & Smith, 1992; Borowsky & Besner, 1993). Frequency attenuation effects observed in long-term repetition priming presumably arise from episodic representations that have captured substantial aspects of the meaning and perhaps other aspects of the prime word, a result enabled by longer prime presentation durations. Thus semantic or associative information would be responsible for producing the interaction between frequency and priming in long-term repetition priming.

Specifically, we suggest that the interaction occurs because the episodic trace of a low-frequency repetition prime that contains semantic information is more distinctive than a comparable trace formed by a high frequency prime. Because of this greater distinctiveness, the representation of the priming event will play a greater role in affecting subsequent processing of the matching target word.

Masked priming cannot be claimed to leave the episodic trace devoid of semantic or associative elements because small but reliable semantic or associative priming has been observed with masked primes (Carr & Dagenbach, 1990; Sereno, 1991). On the proposal put forward here, any interaction between word frequency and repetition priming would have to be supported by this higher level information. The episodic trace of a masked prime, however, would have very little information of this type and would therefore be capable of supporting at best a weak frequency attenuation effect relative to that seen in long-term repetition priming. A small effect would be very difficult to detect given the power of the experimental designs typically used to examine masked priming.

If this modified episodic account is correct, an informative test between that account and the lexical account of masked priming would involve manipulation of a variable sensitive to information assumed to dominate the episodic trace hypothesized to be formed by a 60-ms masked display. Case-alternation of the prime provides such a testing ground. Besner & Swan (1982) first described such an experiment, ‘‘It would be interesting to know whether RaBbIt would prime RaBbIt more than rAbBiT’’ (p. 323). Long-term repetition priming with words printed in transformed typography or a novel font has confirmed this prediction (Horton & McKenzie, 1995; Masson, 1986). If masked priming turns out to produce a similar result (with, for example, a suitable mask intervening between prime and target), the episodic account would gain substantial support. From an abstractionist perspective, the prime makes contact with its lexical entry if either case-alternated version of the prime is presented, hence priming should be equal in these two conditions. From an episodic perspective, on the other hand, priming should be stronger for the matched-case prime condition because that condition provides the greatest similarity between the processing applied to the prime and that applied to the target (Jacoby, 1983).

Nonword Priming

The second major result apparent in Fig. 1 is the impressive variability of priming effects for nonword targets, highlighting the importance of the factors that were manipulated across experiments. We systematically introduced conditions under which masked repetition priming of nonwords showed no effect of priming (Experiments 1 and 2b), facilitative priming (Experiments 2a and 3), and interference (Experiment 4). Although the absence of masked priming of nonwords has previously been attributed to a lexical basis for priming in the absence of the formation of episodic traces (e.g., Forster, 1987; Forster & Davis, 1984; Forster et al., 1987), the reliable nonword priming effects reported here and elsewhere (Forster, 1985; Masson & Isaak, 1991; Sereno, 1991) provide evidence that challenges the lexical account of masked priming. According to that account, nonword primes should not have had an effect on lexical decisions because nonwords are not lexically represented, and there was not adequate opportunity to learn the nonwords so that priming could occur at a lexical level (Feustel et al., 1983; Monsell, 1985; Rajaram & Neely, 1992).

One explanation for facilitative priming of nonwords is that nonwords, relative to words, have more room to benefit from repetition priming, because nonwords normally require longer response times. By this argument, however, low-frequency words should have shown more repetition priming than high-frequency words, and although the trend was in this direction, the interaction of frequency and priming never approached significance in our experiments.

A more plausible explanation is that the magnitude and direction of nonword priming effects in lexical decision are determined by the balance between the relative contributions of the sense of familiarity and the enhanced efficiency of target encoding produced by a repetition prime. Facilitative effects of masked priming of nonwords is expected under conditions in which processing fluency induced by a repetition prime is experienced during relatively challenging target processing, as in Experiments 2 and 3. When targets must be thoroughly analyzed before an accurate response can be given, the immediate sense of familiarity or novelty produced by a letter string has much less impact on the lexical decision. Interference effects, in contrast, will be obtained when superficial processing of target letter strings is adequate to yield accurate lexical decisions. Under these conditions, as in Experiment 4, decisions are determined in large part by the sense of familiarity invoked by a target letter string. To classify correctly a nonword in this case requires discounting the effect a repetition prime will have on a nonword target, thereby slowing the final response.

This explanation of the variable pattern of nonword priming is not compatible with the lexical account of masked repetition priming, but fits well with an episodic account. On that account, the effect of a masked prime is to create an episodic trace that improves processing fluency when task demands cause the trace to be recruited from memory. The resulting fluency makes processing of the target, particularly the establishment of an orthographic representation, go forward more efficiently and instills a feeling of familiarity in the subject.

A prediction of this account of masked priming of nonwords is that when the constraints of lexical decision are removed, it should be possible to observe a clear facilitative effect of masked repetition priming on nonwords. In line with this prediction, Masson (1996) has found that words and nonwords show comparable facilitative effects of masked repetition primes in a naming task. This result occurred even when precautions were taken to ensure that unrelated primes had the same onsets as repetition primes, thereby eliminating the Stroop-like interference effect that can produce spurious masked priming effects when unrelated primes and targets have different onsets (Forster & Davis, 1991).

Conclusion

On the episodic account of masked repetition priming developed here, masking primes does not eliminate the formation and influence of episodic traces on lexical decisions. We note that Forster and Davis (1984) have not claimed that masking a prime completely eliminates episodic influences. Indeed, Forster, Booker, Schacter, and Davis (1990) suggested that this may not be possible. Instead, we argue that masking serves to constrain the nature of information that can be encoded into an episodic trace. We further suggest that episodic traces of masked primes contain primarily orthographic information, which is sufficient to produce nonword priming but which is not adequate to support an attenuation of the word frequency effect.

In the context of the tachistoscopic word identification paradigm, Humphreys et al. (1988) suggested that masked repetition effects may not be lexical at all. The present experiments provide convincing evidence to extend this conclusion to the masked lexical decision paradigm as well. Although additivity of frequency and priming is consistent with both lexical and episodic accounts of masked priming, the orderly pattern of nonword priming effects found here clearly is not compatible with the lexical account.

APPENDIX

Materials Used in the Experiments

Experiments 1, 2a, and 3: High- and Low-Frequency Word Targets and Their Unrelated Primes. (Materials for Experiment 2b can be recreated by replacing the appropriate letters in the primes as described in the method section of that experiment.)

High-frequency pairs				Low-frequency pairs			
Target	Prime	Target	Prime	Target	Prime	Target	Prime
august	origin	forget	twelve	amulet	beggar	pacify	cobalt
tour	mail	anger	bible	crease	parrot	sultry	grovel
tall	spot	poem	sale	gnome	banal	jalopy	nibble
strike	plenty	skill	throw	yearn	gusto	plaid	heron
cook	here	symbol	honest	tofu	shim	arid	rash
cousin	anyway	yellow	attend	duct	fern	baffle	heresy
grass	blind	hole	ring	rudder	magpie	memoir	parcel
liquid	driven	pilot	crowd	cider	graze	birch	cameo
soil	iron	pair	soul	gulley	carnal	pawn	dent
phone	limit	listen	device	senile	rafter	maxim	tango
seat	pink	review	useful	loon	ajar	whim	poke
lawyer	struck	agree	chest	morose	squint	dire	clap
artist	flight	female	taught	mauve	scour	adore	stump
medium	pocket	milk	suit	bonus	flail	beige	smear
truck	alive	weapon	artery	rabid	shill	ensue	drawl
pull	loan	gold	shut	thong	grail	garish	octave
wheel	pride	smile	grown	stifle	anemic	invert	embryo
muscle	abroad	double	switch	yoga	meld	mural	polio
uncle	shook	stone	apply	oblong	maiden	cove	feud
brain	occur	chain	trust	tint	smog	thug	lily
award	shift	snow	wave	awry	moan	curd	bait
lake	bond	motor	grand	kelp	edit	usher	melon
brush	apart	bear	path	glint	manic	frolic	sombre
tree	sell	skin	tiny	coax	plum	ajar	lame

Experiments 1 and 2a: Nonword Targets and Primes. (Critical targets are shown with their unrelated primes; each filler target was always paired with either a repetition or an unrelated prime, as shown.)

Critical pairs				Filler pairs			
Target	Prime	Target	Prime	Target	Prime	Target	Prime
breem	dafot	jasant	riquen	norbat	norbat	veeze	omand
nent	wule	karfal	dogend	pait	pait	sivert	fellop
blyner	whafon	harbed	trinab	shret	shret	voamig	meesan
beasal	yoffer	faije	lomit	lokes	lokes	tolph	binte
perd	swib	dawp	quat	queck	queck	yoment	urroil
blait	morga	heest	koowe	lovink	lovink	triner	colpok

APPENDIX—*Continued*

Critical pairs				Filler pairs			
Target	Prime	Target	Prime	Target	Prime	Target	Prime
serm	hoob	goap	yins	rurola	rurola	tunce	rinas
casoil	wergat	gurst	kelil	nung	nung	virck	fetop
deece	mawer	frooze	nimagi	queler	queler	slamph	cindle
burse	comap	beal	jilk	prott	prott	trufe	yason
demmit	glucer	nazz	woll	klite	klite	dess	jola
emazen	ocella	gotist	quafel	merse	merse	flot	puwa
feap	sude	kaize	plobi	drim	drim	clud	opit
bruve	pliem	hirth	vayme	lukner	lukner	wackel	misrot
croop	houde	frouch	kammer	grib	grib	jurt	houd
berge	hozas	furve	plort	vole	vole	birl	peba
jaul	swof	poan	ivek	phoyce	phoyce	turth	shomp
awel	koye	jinge	aselk	doad	doad	cait	leem
dight	irrol	loatch	cendes	faws	faws	haik	brup
wote	pril	mong	gliv	prokol	prokol	srinal	wertov
branel	huspit	pide	foet	preet	preet	bool	uwit
yait	dife	lestek	wavort	mont	mont	wirch	ameng
averme	bliven	vawl	nert	kerth	kerth	snocke	jirgal
bogget	varcol	jasum	klewt	marhol	marhol	strow	kumfa

Experiment 3: Pseudohomophone Targets and Unrelated Primes.

Target	Prime	Target	Prime	Target	Prime	Target	Prime
taxiz	kongo	ahpra	luice	werld	oftin	mutch	brott
ontu	hewj	drawma	moshun	cince	tryal	trew	moov
angree	wrapid	lickor	souled	saim	erth	becaim	truble
angull	ekstra	mewn	lukk	plaice	meerly	streat	methid
gard	lyze	saik	fule	hoam	lyfe	tern	payd
afoard	shurly	luvlee	creait	wunce	kosts	cort	ayge
handal	beegun	atim	pikk	duzz	eest	forse	basik
reer	stik	ajent	kross	corse	groop	voyce	amung
duzzen	smewth	rair	gest	werk	kold	senter	commin
palis	chooz	proov	joynt	sistem	akross	frunt	peece
burdin	sampul	smoak	laten	erlee	sitty	surfis	traide
wyer	poap	wery	bott	daiz	werd	meen	kair
teech	pryme	spyte	kownt	faice	leest	entyre	levill
dryver	phlesh	katch	shews	wight	caise	sune	keap
gaims	kween	sede	gunz	cherch	simpal	spaice	normil
afrade	pourch	oxagin	dauler	servis	maibee	hoap	leev
celf	sawt	prizin	balley	doar	sezz	persin	studee
sikk	ajes	fale	ryed	sence	klass	staige	culler
drah	eeze	mear	looz	naim	luvv	feal	syde
slite	minut	mentle	trupes	gaiv	dunn	markit	eyland

APPENDIX—*Continued*

Target	Prime	Target	Prime	Target	Prime	Target	Prime
payce	bujit	klawth	atomik	sertin	aibull	purpis	laiter
rufe	trak	obtane	eazier	haff	neer	reddy	cleer
scail	funee	werse	grais	munny	kwite	squair	morill
bredd	ackts	vytal	smeer	shure	eetch	frend	howse

Experiment 4: Word Targets and Unrelated Primes.

Target	Prime	Target	Prime	Target	Prime	Target	Prime
force	clear	daily	lower	paper	bring	hair	club
peace	third	play	type	late	read	look	city
light	thing	list	fear	mean	gone	color	ready
child	total	cent	talk	bill	step	river	doing
west	turn	brown	stage	name	help	court	value
fine	sort	group	point	past	seen	heart	basic
party	short	plan	hard	below	stock	woman	close
heavy	visit	door	kind	board	known	study	heard
green	image	death	local	free	real	piece	wrong
human	whole	side	felt	land	feel	size	army
dark	hope	young	white	love	full	paid	hour
wife	seem	plane	doubt	music	level	alone	basis
keep	sure	wall	move	cold	rest	radio	chief
meet	hear	blue	deal	sound	leave	true	cost
face	best	speak	price	town	rate	south	major
story	final	floor	range	book	fire	call	near
idea	soon	month	cause	plant	truth	voice	front
lead	note	feet	gave	earth	stand	table	black
trade	moral	space	union	start	issue	road	view
girl	able	money	field	food	hall	find	room
lost	data	show	line	blood	march	word	week
large	power	care	hold	class	north	body	half
fall	sent	faith	staff	trial	maybe	horse	seven
open	case	want	mind	hotel	press	east	live

Experiment 4: Nonword Targets and Unrelated Primes.

Target	Prime	Target	Prime	Target	Prime	Target	Prime
rgprt	ksnks	skwcr	rsdds	flshn	twfgb	qtfn	vsdl
grvll	jgmgh	dlrt	wrtk	vlnm	bnmd	crlbn	sdktd
rcvb	kdfg	fmpms	kltch	rpth	wmld	prvts	wnlkn
hssh	flnr	twlt	dldl	dplk	lrjr	zcrk	krfl
rlrd	ttbn	lrngr	fdflt	jrts	rvmr	tlgt	xtch
nnmc	rgsl	sfnln	rflng	bfvm	lppl	nbln	rtns
glrtn	rrtbs	shtgs	ndlff	nshbd	sdkgh	drwth	tlrnn

APPENDIX—*Continued*

Target	Prime	Target	Prime	Target	Prime	Target	Prime
srtp	rtgh	lrrg	wsth	zvcb	lsdg	ftrk	krpt
frwnd	sdlpr	brjt	chlp	rtld	mrth	tldzs	knpfl
mnkld	ntnbc	whcll	bcvmd	plrns	fknmd	sdths	krvmd
tfgd	vhkm	blnc	fhtl	hgrt	gbsd	twgff	vmpnl
twtr	sksk	trwtt	cvhdl	ddgr	gtcd	frsds	gtllr
gkln	lvfb	sdhmk	nckld	sckrs	dbcdc	bkbnm	cfflc
tqlcs	strlt	trltt	jngdc	hrlrq	ghplm	rtlr	gpgl
rdbr	ffgh	bhwp	cjln	vnmbn	kjdws	dfggh	rvltm
nlrt	bnmg	cbngd	mvbnl	nwrs	rmfb	nwrtn	lkglr
jrtts	fhnmp	qwcth	lsfdt	zcxnd	kssdq	rctnd	knscf
frch	rmtm	nmngg	dlssd	snsm	gbln	fbbr	pgdw
dllp	lsdh	lklt	mvbv	knwl	trts	wpdlt	bxcsm
fnrrn	hrbmd	plmbb	rvlth	brtr	sgrt	bcnmc	kfsdd
wwmf	glhd	cllkn	krfft	twph	wtrn	nmsd	grbr
rnrl	kllb	flmmr	rtkrm	lvfln	rnvcc	rdgl	ttsk
ffds	mgll	wrths	nnglk	msdfr	gwrng	wrnrl	qvklm
trplp	fgzpw	whxw	gsdl	rtmb	svth	prwd	fghp

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