Short-Term Implicit Memory for Words and Nonwords

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A short-term implicit memory effect is reported and interpreted as arising within the word recognition system. In Experiment 1, repetition priming in lexical decision was determined for low-frequency words and pseudowords at lags of 0, 1, 2, 3, 4, 5, 9, and 23 intervening items. For words, a large short-term priming component decayed rapidly but smoothly over the first 3 items (8 s) to a stable long-term value. For nonwords, priming dropped to the long-term value with a single intervening item. This Lag x Lexicality interaction was replicated with a naming task in Experiment 2 and with high-frequency words in Experiment 3. Word frequency affected long-term priming but not the size or decay rate of short-term priming, dissociating the two repetition effects.

In Experiment 4, an old-new decision task was used to test explicit memory. Parallel word and nonword decay patterns were found, dissociating short-term priming from explicit working memory.

It is well-known that a single presentation of a word can facilitate later processing of that word, a phenomenon referred to as repetition priming. Various techniques have been used to demonstrate this effect. For example, repetition has been found to reduce reaction times to a target word in a lexical-decision task (e.g., Kirsner & Smith, 1974) to make the target more likely to be produced on a word completion test (e.g., Warrington & Weiskrantz, 1974) or to increase its chances of being identified from a degraded presentation (e.g., Jacoby & Dallas, 1981). Priming effects revealed in these tasks are taken to reflect implicit memory, defined as being an unconscious, automatic use of memory, rather than explicit memory, which is expressed in tests of deliberate recollection such as recall and recognition (Graf & Schacter, 1985). A wealth of data exists indicating that different processes underlie priming and explicit memory (see Schacter, 1987, for review). A few examples of dissociations between the two forms of memory are as follows: (a) amnesics can demonstrate implicit but not explicit knowledge of prior events (Jacoby & Witherspoon, 1982; Moscovitch, 1982; Warrington & Weiskrantz, 1968), (b) varying levels of processing at study influences explicit but not implicit memory (Graf & Mandler, 1984; Jacoby & Dallas, 1981), and (c) changing the modality of presentation between study and test influences implicit but not explicit memory (Kirsner & Smith, 1974; Roediger & Blaxton, 1987).

Explicit memory has traditionally been divided into separate long-term and short-term memory components (see Baddeley, 1990, for review). One of the better known pieces of evidence for this distinction is the "recency" effect (Brown, 1958; Peterson & Peterson, 1959; Postman & Phillips, 1965), in which recall of target items is found to fall off rapidly as the number of items intervening between the target and the test is increased. This effect has been interpreted as reflecting a distinct short-term memory representation, which dissipates rapidly to leave a fairly stable level of performance that is reached after approximately four or five intervening items. The concept of a temporary store has been elaborated with the discussion of a number of such stores, each specific to a particular domain. For example, it has been proposed by Baddeley and Hitch (1974) that short-term representations may operate separately for a number of processing domains, such as verbal processing (in the form of an auditory rehearsal loop) and visual processing (in the form of a visuospatial sketchpad). This proposed collection of labile explicit memory representations is commonly referred to as working memory.

Implicit Short-Term Memory?

Although the division of explicit memory into short- and long-term components has been a major topic of investigation, the possibility of a similar division in implicit memory has received comparatively little attention. In the majority of studies investigating properties of implicit memory, target presentations have been blocked, with the first occurrence of a target item appearing in a study list and the second appearing in a separate test phase. As a result, most studies have used a relatively long delay of at least several minutes (up to several days) between first and second presentations of each target item. Given that this time scale is within the bounds of what has been considered, for explicit memory, long-term rather than short-term memory, much of the current literature on repetition effects could be seen as investigating an implicit form of long-term memory.

With shorter delays, most studies investigating repetition effects have used a paradigm known as masked priming (e.g., Forster & Davis, 1984; Forster, Davis, Schoknecht, & Carter, 1987), which utilizes extremely short delays. In this procedure, the prime word is presented for less than 100 ms and usually
remains unidentified by the participant. In general, the prime is immediately masked by the target, with a response required to the target only. Masked priming effects are found to fall off very rapidly with delays of a few hundred milliseconds between the prime and the target and have been interpreted as reflecting the merging of prime and target into a single perceptual event, rather than necessarily as a memory phenomenon (Humphreys, Besner, & Quinlan, 1988).

The observation that the bulk of the current priming literature has investigated either extremely short-term repetition effects (lasting well under 1 s) or relatively long-term influences (lasting several minutes or more) invites consideration of the role of implicit memory over intermediate delays of, say, several seconds to a minute. Specifically, the common emphasis on long-term priming leaves open the question of whether there might be an implicit short-term memory effect of similar duration to the recency effect observed in explicit recall and recognition tasks, that is, over a few intervening items.

Effects of Lag on Words and Nonwords

To measure priming over a small number of intervening items, neither the common study-phase–test-phase design nor the masked priming technique is appropriate. Instead, continuous presentation of a list of items can be used (e.g., Kirsner & Smith, 1974), in which a response is required to every item. With this design, targets can be repeated at different lags by varying the number of items intervening between the two presentations, and priming can be measured as the reduction in reaction time on the second occasion compared with the first.

A number of studies have used this method to measure repetition effects for words at short lags; of these, most have used a lexical-decision task, in which the participant is required to make a word–nonword decision to each item in the list. Using this task, Scarborough, Cortese, and Scarborough (1977) have provided the most commonly cited study. They found no significant decay of priming across lags 0, 1, 3, 7, and 15 in their first experiment (lag 0 means immediate repeat, that is, no intervening item). They did, however, find a decay across lags 0, 1, 3, 7, and 31 in their second experiment. Unfortunately, no analysis regarding where this decay occurred was presented, although later writers (e.g., Monsell, 1985) have interpreted Scarborough et al.'s data as showing a labile lag 0 priming component decaying to a stable longer term component from lag 1 onward. This interpretation has loosely been supported by work subsequent to that of Scarborough et al.: Bentin and Moscovitch (1988), using lags 0, 4, and 15; Monsell (1985), using lags 0, 1, 2, 4, 6, 8, 20, and 31; Ratcliff, Hockley, and McKoon (1985), using lags 0, 1, 2, 4, 8, 12, and 16; and Kersteen-Tucker (1991), using lags 0, 1, 4, and 8. All of these authors have concluded that a short-term priming effect exists but that it is restricted to immediate repetition (lag 0). A somewhat different pattern of results was obtained by Kirsner and Smith (1974), who found almost as much priming at lag 3 as at lag 0, with both of these shorter lags showing substantially more priming than lags 15 and 63. In agreement with this, Smith (1968), using a different task, also found a somewhat slower decay of short-term priming.

Although there is reasonable support for the view that priming is larger at lag 0 than at any later lag, suggesting a short-term priming component superimposed on a more stable long-term effect, the conclusion that the short-term effect disappears with a single intervening item appears less well-founded. Most of the experiments reported in the articles cited above have shown a trend toward some decay between lags 1 and 4, despite the fact that the effect has not usually been significant (or has not been tested). A number of factors might account for this general failure to find a significant short-term priming effect lasting beyond immediate repetition. First, the number of items per lag condition (e.g., 6 in Scarborough et al., 1977, or 10 in Monsell, 1985), or the number of participants (4 in Ratcliff et al., 1985), has sometimes been very low, possibly giving the experiments low power. Second, it is not always clear that a particular set of items has appeared in more than one lag condition, leaving the pattern of priming observed open to item-specific effects. Third, the presentation rate of stimuli has often been quite slow (commonly, 4 or 5 s per item). Assuming that any “short-term” traces of a target stimulus decay fairly rapidly over time (as well as possibly through interference from new processing), this lengthy delay may allow such traces to have largely dissipated by the time the item is repeated 8 or 10 s later (i.e., at lag 1).

Turning to the issue of short-term priming for nonwords, the existing data are more scant. In general, those articles reporting lag effects on words have shown less interest in nonwords, although each of the articles cited above has reported nonword data in one experiment. Except for Ratcliff et al. (1985), all studies have reported more priming at lag 0 than at later lags, but again, there is some disagreement regarding whether short-term priming lasts beyond lag 0. (Incidentally, there is also substantial disagreement regarding the existence of non-zero longer term priming for nonwords in these lexical-decision experiments: Estimates of priming at lags 8–15 range from −34 ms to +92 ms.)

The question of whether short-term priming survives beyond lag 0 could clearly benefit from more detailed investigation. There is a need to consider priming for words and nonwords with faster presentation rates, more powerful designs, and better controls for item-specific effects than have previously been used. Such conditions were implemented in the four experiments presented in this article to provide the best chance of finding any short-term priming lasting beyond immediate repetition, and thus of specifying short-term influences on implicit memory.

Experiment 1

In Experiment 1 I measured repetition effects, using a lexical-decision task, for words and nonwords at lags of 0, 1, 2, 3, 4, 5, 9, 23, and 1,050 intervening items. There were 20 items per lag condition, and items were cycled through conditions across subjects. The delay between the onset of successive items was 2 s. The target items were very low-frequency words and orthographically legal pronounceable nonwords. Low-frequency words were chosen because long-term priming is
greater for these items than for high-frequency words (Scarborough et al., 1977), and thus the chance of finding differences between lag conditions seemed likely to be maximized by using low-frequency words.

Method

Participants. Participants were 18 undergraduate students attending the Australian National University who volunteered in return for credit in an introductory psychology course. All participants in this and subsequent experiments had English as their native language and had normal or corrected-to-normal vision. No participant took part in more than one of the experiments reported in this article.

Design. A 2 × 9 repeated measures factorial design was used, with items of both types of lexical status (words and nonwords) presented under nine different lag conditions (0, 1, 2, 3, 4, 5, 9, 23, and 1,050 items intervening between repetitions). A priming effect was measured as the reduction in lexical-decision time to the second presentation of a target item compared with the first.

Materials. The target words (mostly nouns) were all four letters long, singular, and of very low frequency according to the Kučera and Francis (1967) norms (between 1 and 4 occurrences per million). There exists a population of around 240 such words, but a number were excluded from use in the experiment for the following reasons. Some words were judged by the experimenter as likely to have substantially increased in frequency since 1967 (e.g., disk), and some were judged as more common in Australian English than in the American norms. On the other hand, it was felt that some words were so rare that they might be expected to be unknown to many undergraduate students and, thus, that participants would treat them as nonwords. To address the latter problem, I used the results of an earlier (unpublished) lexical-decision priming experiment to reject those words to which more than 20% of students (5 out of 24) made an incorrect decision on both presentations of the word. This culling procedure left 180 words available for the pool used for target items. To match this set, I developed a pool of 180 target nonwords. These items were four-letter pseudowords that were pronounceable, were single syllable, and obeyed the orthographic rules of English. None were pseudohomophones (i.e., homophonic to a real word).

The 180 target words were divided into nine sets, allowing 20 words in each of the lag conditions. The sets were equated on average lexical-decision time to the first presentation (obtained from the unpublished experiment mentioned above) to keep error variation to a minimum. This division and matching process was repeated for the 180 nonwords. Additional 185 words and 185 nonwords were chosen as filler items. They satisfied the same criteria as specified for the target items, except that the words were allowed to have Kučera and Francis (1967) frequencies of up to 8 counts per million, and a small percentage of the nonwords were pseudohomophones.

All of the target items, but only 10 of the filler items, were repeated in the experimental list, giving a total of 1,100 items in the full list (targets: 180 × 2 types × 2 repeats; fillers: 180 × 2 types + 10 × 2 repeats). Within the complete list, the first 50 and last 50 trials were used to present the lag 1,050 condition in a blocked study-test format. The initial group of 50 contained first presentations of 20 target words and 20 target nonwords plus two presentations of 5 of the 10 repeated filler items. The final group contained second presentations of the target items plus two presentations of the other 5 repeated filler items. The presentation order of the target items differed between the initial and final sets.

The remaining 1,000 trials were used to present target items at lags 0–23, with lag conditions “overlapped” such that the intervening items for one condition were often critical items from another condition. To vary lag in this fashion, it is necessary to strictly control the presentation order. Rather than specify the pattern of conditions for 1,000 trials, a number of sequence templates (i.e., orders of lag conditions) over a limited number of trials were chosen. Specifically, five templates were chosen, each 50 trials long, with each used four times to give 1,000 trials. (It seemed unlikely that participants would show any effect of reuse of response patterns 50 trials long.) Each template contained one occurrence (plus a second presentation) of each of the eight remaining lag conditions (for both words and nonwords) plus 18 unrepeated filler items (9 words and 9 nonwords). A different set of filler items was used on each subsequent use of that template. This procedure ensured that, as each lag condition appeared in each group of 50 trials throughout the experiment, any practice or fatigue effect over the 1,000 trials affected all lag conditions equally.

To avoid a possible confounding of lag with item-specific effects, I prepared nine versions of the full experimental list. In each version, a given set appeared in a different lag condition, thus cycling all items through all lag conditions over the nine versions. The order of conditions (and thus of yes–no responses) was the same for all versions.

Procedure. Participants were individually tested in a single 1-hr session. Each participant was randomly assigned to one of the nine versions of the list, with each version used twice over the 18 participants. Items were presented by using PsychLab software on a Macintosh computer, with a new trial beginning every 2 s. Items remained on the screen until the participant responded with one of two buttons on the keyboard using his or her preferred hand for a yes (word) decision and the other hand for a no (nonword) decision. The key pressed and the response latency from onset of the item were recorded. Participants were instructed to respond as quickly as possible, consistent with being correct. No feedback was given regarding accuracy or speed. If the participant had not responded within 2 s, the next trial commenced; participants were instructed that, should this happen, they could ignore the item they had missed.

The experiment was preceded by a practice trial containing 28 five-letter words and nonwords. Following this, the experimental list was presented in four blocks of 300, 250, 250, and 300 trials. (By using multiples of 50, that is, the length of each sequence template, the splitting of first and second presentations across blocks was avoided in the eight shorter lag conditions.) Each block took approximately 9 min to complete, and a short break was allowed between each block. The total time taken to present all experimental trials, and thus the time between presentations in the lag 1,050 condition, was approximately 45 min.

Results and Discussion

Repetition priming is shown in Figure 1 as a function of lag (the number of items intervening between presentations) for all but the lag 1,050 condition. Reaction times for a target item were excluded if they were less than 300 ms or greater than 1,200 ms or if either response made to the target was incorrect. Error rates in the critical conditions (including errors to either or both presentations) were 6.3% for words and 4.2% for nonwords. The percentage of items excluded as outliers was 1.3% for words and 1.7% for nonwords. Average decision times to first presentations were 659 ms for words and 704 ms for nonwords.

It appears from Figure 1 that priming for words has two components: a short-term labile component that decays rapidly (but smoothly) with intervening items until perhaps lag 4.

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1 For all experiments, means of reaction times to first and second presentations and mean priming scores are presented in the Appendix.
Repetition priming (in milliseconds) as a function of lag for nonwords. The error bar indicates the average standard error of first decision times to presentations were 659 ms for words and 704 ms for low-frequency (LF) words and word-like nonwords. Mean lexicality interaction found here was replicated.

**Table 1**

<table>
<thead>
<tr>
<th>Lag</th>
<th>Lexicality</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>9</th>
</tr>
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<td>Contrast</td>
<td>82</td>
<td>34</td>
<td>16</td>
<td>24</td>
<td>13</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>66.3***</td>
<td>11.0***</td>
<td>2.6</td>
<td>5.1*</td>
<td>1.5</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Nonwords</td>
<td>Contrast</td>
<td>98</td>
<td>66.1*</td>
<td>24</td>
<td>13</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>78.2***</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>1.8</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Note. For words, MSE = 1,593; for nonwords, MSE = 1,941; df = (1, 119) for all comparisons.

**p < .05. ***p < .01.

to the word means. The ideal exponential was found to be

\[ P = 93.5 e^{-0.63L} + 49.1, \]

where \( L \) is the lag, and \( P \) is the amount of priming observed in milliseconds. This curve gave the variance of the predicted means for the eight lags (ms\(_\text{pred} \)) to be 926 ms\(^2\), and the variance of the actual means (ms\(_\text{obs} \)) to be 949 ms\(^2\), indicating that 98% of the variance in the observed means was accounted for by the exponential fit. The exponential function suggests that a short-term priming effect, initially of 93.5 ms (SE = 8.0 ms), is superimposed on a long-term constant value of 49.1 ms. It also implies that, given the decay constant of 0.63 (SE = 0.14), the short-term effect decays to 10% of its initial value after around 3.7 intervening items (9.3 s), confirming the results of the Helmert contrasts; these indicated that decay continues until roughly lag 4. Finally, the exponential fit allows a powerful test of the significance of long-term priming: The long-term value of 49.1 ms was found to have a standard error of 4.9 ms, giving a 95% confidence interval (CI) of 36.6 ms–61.6 ms and indicating that, as would be expected from Figure 1, significant long-term priming was present.

**Nonwords.** Helmert contrasts for the decay of nonword priming are also shown in Table 1. Again, the analysis confirmed the pattern apparent in Figure 1: Significant decay occurred only after lag 0, demonstrating an immediate repetition effect followed by decay to a stable baseline with one intervening item. It should be noted for future reference that this interpretation may be an oversimplification: Although the

A problem with this interpretation might arise if the nature of the intervening item(s) at each lag differed for words and nonwords, and, indeed, when the (more or less randomly selected) order of items was examined post hoc, such a confounding was observed. Although one would hope to have roughly 50% words and 50% nonwords at each intervening position, this was not always the case. For lags 2 and 3, the distribution of word and nonword intervening items was reasonably close to this ideal, but for lag 1, 100% of the intervening items were words for word targets, and 80% were words for nonword targets. A more recent experiment (not included in this article) used equal numbers of word and nonword intervening items at lag 1 for each type of target; priming at lag 1 was again observed to be substantially lower for nonwords than for words, and, overall, the form of the Lag \times Lexicality interaction found here was replicated.
effect was far from significant, the negative contrasts at lags 1 and 3 hint that priming at intermediate lags may actually dip below the long-term value.

**Lag 1,050 priming.** It should be noted that the “longer term” of the priming components identified is not necessarily very long term. From the results presented so far, it can only be concluded that this component lasts at least a minute or so. To determine whether priming lasts as long as 45 min, results of the lag 1,050 condition can be examined. Unfortunately, a substantial practice effect was observed during the experiment, indicating that the reaction times to first and second presentations of items in the lag 1,050 condition are not directly comparable. The raw priming effects observed for words and nonwords at lag 1,050 were 59 ms and 52 ms, respectively, but there was an average decrease during the experiment in reaction times to first presentations of 39 ms for words and 42 ms for nonwords. This would suggest that priming after 45 min was, in fact, around 20 ms for words and 10 ms for nonwords. From this, it could tentatively be concluded that long-term priming decays slowly over 45 min but that there is still a moderate effect left after this time. This interpretation agrees with the common finding of very long-term priming, at least for words.

**Error analysis.** Collapsing over lags 0–23, more decision errors were made to first presentations of words (8.4%) than to second presentations (4.4%). For nonwords, however, the error rate for first presentations (3.9%) was very similar to that for repeats (4.2%). This pattern of errors would appear to reflect an initial difficulty in recognizing the low-frequency word stimuli as words, which was overcome on the second presentation.

To investigate any relationship between the patterns of priming observed on lags and error rates at these lags, I conducted a two-way ANOVA on the error scores for second presentations of targets. (Error rates to first and second presentations are included in the Appendix.) The ANOVA revealed no effect of lag (Wilks’s lambda = 0.475), no effect of lexical status (F < 1), and no interaction between the two, F(7,119) = 1.3, MSe = 0.90, p > .1. Thus, the pattern of priming scores reported above cannot be attributed to changes in error rates across lags.

**Summary.** Two components of priming have been identified: a long-term effect showing no decay over at least 48 s (with possible slow decay over 45 min) and, more interestingly, an additional short-term effect lasting roughly 8–10 s (three or four intervening items) for words and 2 s (a single intervening item) for nonwords. The decay of the short-term effect appears to be qualitatively different for items of different lexical status: exponential for words, but sudden for nonwords. The existence of a separate short-term effect agrees with the findings of previous studies using a continuous lexical-decision procedure, but the present results extend these findings in showing that, for words at least, this effect lasts beyond immediate repetition.

**Experiment 2**

The sharp difference between the relative decay patterns of short-term priming for words and nonwords may have important implications for any theoretical interpretation of short-term repetition effects. However, one rather uninteresting explanation of the observed Lag x Lexicality interaction should be considered before any such interpretation is attempted. This is simply that in the lexical-decision task used in Experiment 1, opposite decisions were made to the two types of items; the Lag x Lexical Status interaction in short-term priming may have had nothing to do with priming of a representation of the target per se but may have been due to some record of the decision. A standard way (e.g., Andrews, 1992) of determining whether results gained with a lexical-decision task reflect merely the operation of a decision procedure is to repeat a lexical-decision experiment using a naming task in which the participant is required to read each item aloud as quickly as possible. The logic here is that because both lexical decision and naming require processing the target item, but naming does not require a decision, factors affecting the two tasks in the same way can be interpreted as being independent of decision processes. Thus, to determine if the short-term repetition effect identified with lexical decision is specific to the decision task, I repeated Experiment 1 with priming assessed by a naming task.

**Method**

**Participants.** Fifteen participants were undergraduate students of the Australian National University, who took part in return for credit in an introductory course. A further 4 participants were graduate student volunteers from the psychology department. One undergraduate participant was removed because of excessive error rates, leaving a total of 18 participants.

**Materials and procedure.** The experimental lists and presentation were exactly as described for Experiment 1. Across the 18 participants whose data were retained, each of the nine versions of the list was used twice. The only difference from Experiment 1 was the task used: The participant was required to read each item aloud into a microphone, as quickly and as accurately as possible. Naming time was measured as the latency from onset of the stimulus to onset of the response, and any errors in pronunciation were noted by the experimenter. For nonwords, for which there is not always a clearly “correct” answer, a mispronunciation was recorded if the pronunciation chosen was different from all those of that letter grouping which appear in real words (e.g., finn was accepted if said to rhyme with mint or pinn, but not if said as fent). In addition, an error was recorded when the participant added, missed, or swapped letters or changed his or her pronunciation on the second presentation.

**Results and Discussion**

For the naming data, reaction times were excluded if they fell more than three standard deviations above the mean for each participant, if the participant misrepresented the item, or if the microphone was triggered by an extraneous noise. Data were discarded from 1 participant who misread 20% of the

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3 Because of the severe confounding of lag 1,050 priming with practice effects, the results of this condition are not discussed for later experiments.

4 Throughout this article, multivariate analysis of variance results have been presented when the data violated the sphericity assumption of repeated measures ANOVA.
nonwords (replacing almost all with similarly spelled real words) and whose reaction times were roughly 300 ms slower than those of the other participants. The average "error" rate for the remaining 18 participants (including both genuine errors and technical faults) was 3.4% for words and 5.3% for nonwords. An additional 1.4% of words and 3.0% of nonwords were excluded as outliers. Mean naming times to first presentations were 495 ms for words and 517 ms for nonwords.

Priming in the naming task is shown in Figure 2. The most obvious difference between the lexical-decision and naming results is that the overall magnitude of priming in the latter is very much smaller. Ignoring this for the moment, however, the patterns of decay for words and nonwords appear similar to those found with lexical decision: The words show gradual decay over the first three or so items to a constant long-term effect, whereas the nonwords show substantially more priming at lag 0 than at later lags. An 8 x 2 ANOVA revealed a main effect of lag, F(7, 119) = 3.02, MSE = 422, p < .01, indicating that the short-term effect has dissipated by this time. Again, the decay seems most rapid at the earliest lags, and an exponential decay of the form

\[ P = 18.9 \ e^{-0.44L} + 9.2 \]

gave a good fit to the data, with 84% of the variance in the observed means accounted for by the exponential function (ms\text{lf} = 37.32; ms\text{total} = 44.47). This function indicates that a short-term component of 18.9 ms (SE = 3.9) at lag 0 was superimposed on a stable priming effect of 9.2 ms. This priming effect was found to be significantly greater than zero (SE = 2.3 ms; 95% CI = 3.3 ms–15.2 ms).

Nonwords. Helmert contrasts for nonwords are also shown in Table 2. As was the case with lexical decision, there is substantial decay following lag 0, but no further decay beyond this point, suggesting a sudden decay to a stable baseline. However, again note the hint of a dip below the long-term priming value at intermediate lags of 2, 3, and 4 intervening items.

Comparison of lexical decision and naming. The results of Experiments 1 and 2 agree on the most important issues, namely the existence of a short-term repetition effect and the qualitative differences found between the decay patterns for words and nonwords. In both experiments, the initial magnitude of the short-term effect for words is around twice the long-term priming value, and the decay constants for word priming agree fairly well across lexical decision (0.63; SE = 0.14) and naming (0.44; SE = 0.17), indicating that the short-term priming effect has roughly the same duration in the two tasks. In addition, Experiments 1 and 2 agree that short-term nonword priming disappears with a single intervening item. These results indicate that the effects of lexical status that were obtained with the lexical-decision task are not specific to that task.

The lexical-decision and naming data differ in two ways that should be considered. First, the absolute magnitude of the priming effects in naming is substantially smaller than in lexical decision. A likely explanation of this result is simply that the reaction time to the first presentation of an item was faster in naming than in lexical decision (naming: words = 495 ms and nonwords = 517 ms; lexical decision: words = 659 ms and nonwords = 704 ms). It seems reasonable that the amount of priming would partially depend on the initial speed of response: A slower initial response should allow more “room for improvement” on the second occasion.

Second, the relative magnitude of the word and nonword long-term priming effects appears to depend on the task. With lexical decision, no difference in long-term priming was apparent between words and nonwords, F(1, 17) = 2.92, MSE = 1,276, p > .1, on a comparison of lags 4 to 23; whereas, with naming, nonwords showed more long-term priming than words F(1, 17) = 9.25, MSE = 363, p < .01. This difference across tasks may reflect the influence of the decision process on the long-term priming component found with lexical decision. For the lexical-decision task, prior presentation of a target nonword may produce competing positive and negative effects on the ease of making a decision. The processing of an incoming nonword may speed up on a second occasion (an “access” effect), tending to lower response time, while at the same time its increased familiarity may make it more difficult to reject as a word (a “decision” effect), tending to raise the response time. However, in a naming task, in which no decision process is involved, faster processing and increased familiarity should be

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5 Unfortunately, no further analysis of errors in naming is possible, as sessions were not taped, and, with the rapid presentation rate used, it was not possible to fully code errors on-line.
stimuli: These were of very high frequency rather than of very low frequency. A list of 180 target words ranging from 70 to 967 counts per million (M = 275) were selected from the Kučera and Francis (1967) norms and divided up into nine sets of 20 items each. I equated these sets on frequency and neighborhood size, using Coltheart’s N (Coltheart et al., 1977), and then assigned them to each of the nine lag conditions across different list versions, as described in Experiment 1. In addition, high-frequency filler words replaced the low-frequency fillers used in Experiment 1. These had a minimum frequency of 32 counts per million.

Methods

Participants. Eighteen undergraduate participants, from the pool described in Experiment 1, took part for payment of $6.

Materials and procedure. The design of the experiment, the nonword stimuli, the list structure (i.e., order of yes-no responses), and the task (lexical decision) were exactly as for Experiment 1. Again, nine versions of the list were used, with 2 participants given each version. The only departure from Experiment 1 was in the real-word stimuli: These were of very high frequency rather than of very low frequency. A list of 180 target words ranging from 70 to 967 counts per million (M = 275) were selected from the Kučera and Francis (1967) norms and divided up into nine sets of 20 items each. I equated these sets on frequency and neighborhood size, using Coltheart’s N (Coltheart et al., 1977), and then assigned them to each of the nine lag conditions across different list versions, as described in Experiment 1. In addition, high-frequency filler words replaced the low-frequency fillers used in Experiment 1. These had a minimum frequency of 32 counts per million.

Results and Discussion

Priming in lexical decision for high-frequency words and for nonwords is shown in Figure 3 (note that the nonwords were exactly the same items used in Experiments 1 and 2). Reaction times were removed if they were less than 300 ms or greater than 1,200 ms or if either response to that item was incorrect. The average error rate (to either or both presentations) was 3.5% for words and 3.2% for nonwords. The percentage of items excluded as outliers was 1.0% for words and 1.2% for nonwords. Average reaction times to first presentations were 590 ms for words and 653 ms for nonwords.

The basic features of Figure 3 are similar to the decay patterns observed in the first two experiments. For the nonwords, the positive short-term effect is evident, again, only at lag 0. For high-frequency words, the repetition effect appears to conform to the familiar shape of smooth decay over the short term, but it differs from that for low-frequency words in that no long-term priming effect is visible. Most interesting, the short-term priming effect for high-frequency words appears to be of roughly the same magnitude (95 ms) and the same duration (three items) as that found previously for low-frequency words.

A two-way ANOVA, including all lags (0–23), found a main effect of lag, $F(7, 119) = 19.60$, $MSE = 1,662$, $p < .001$, no overall effect of target type ($F < 1$), and an interaction, $F(7,$

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**Table 2**

<table>
<thead>
<tr>
<th>Lexicality</th>
<th>Lag</th>
<th>0</th>
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<td></td>
<td>$F$</td>
<td>10.7***</td>
<td>4.2**</td>
<td>6.0**</td>
<td>2.1</td>
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<td>$&lt; 1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonwords</td>
<td>Contrast</td>
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<td>-1.3</td>
<td>-7.5</td>
<td>-6.1</td>
<td>-9.7</td>
<td>-1.6</td>
<td>3.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$F$</td>
<td>16.2***</td>
<td>$&lt; 1$</td>
<td>1.9</td>
<td>1.2</td>
<td>2.8*</td>
<td>$&lt; 1$</td>
<td>$&lt; 1$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. For words, $MSE = 272$; for nonwords, $MSE = 459$; $df = (1, 119)$ for all comparisons. *$p < .10$. **$p < .05$. ***$p < .01$. working in the same direction to produce faster responses. For real words, these two influences work in the same direction, regardless of the task, having the effect of raising the level of nonword priming (relative to words) in naming compared with lexical decision.

Summary. Despite some differences between naming and lexical-decision results, the important conclusion to be drawn from Experiment 2 is that the dissociation between the short-term decay patterns observed for words and nonwords in this experiment matches that found in Experiment 1. Short-term priming in naming seems to be essentially a scaled-down version of that found with lexical decision. This implies that the Lag x Lexical Status interaction obtained in Experiment 1 did not occur merely because a "no" decision was being made to the former type of item and a "yes" decision to the latter.
Average Priming at Subsequent Lags for Experiment 3

**Note.** \( \text{MSE} = 1,216, p < .001 \). Decay patterns were again examined separately for words and nonwords.

**Words.** Helmert contrasts for word priming are presented in Table 3. These reveal that significant decay occurs following lags 0 and 1, with some hint of further decay after lags 2 and 3. As in Experiments 1 and 2, no decay occurs after lag 4. The finding that lag 2 priming was not significantly above priming at lags 3 to 23, and that lag 3 priming was not significantly (at the .05 level) above that at lags 4–23, could be interpreted as indicating that the short-term priming effect for high-frequency words has dissipated by lag 2. However, this analysis ignores the fact that substantial decay occurs between lags 2 and 3, taken together, and later lags. Evidence that the short-term priming effect does, in fact, last as long for high-frequency words as for low-frequency words comes from fitting an exponential decay function to the data. An equation of

\[ P = 97.2 e^{-0.67L} + 3.7 \]

was found to provide an excellent fit, with 92% of the variance in the observed means accounted for (\( \text{ms}_{\text{exp}} = 1.001; \text{ms}_{\text{real}} = 1.087 \)), and the striking thing about this function is the remarkable similarity of the short-term effect to that found for low-frequency words in Experiment 1. Particularly, there are very close matches in both the magnitude of the short-term effect at lag 0 (97.2 ms and \( SE = 7.6 \) for high frequency; 93.5 ms and \( SE = 8.0 \) for low frequency) and in the decay constant for this effect (0.67 and \( SE = 0.15; 0.63 \) and \( SE = 0.14 \)). Thus, it seems that short-term priming for high-frequency (HF) words takes the same form, and has the same duration, as for low-frequency (LF) words.

The exponential fit also demonstrates that, in contrast to the results for LF words, there was no long-term priming effect for HF words: The long-term priming value of 3.7 was not significantly above zero (\( SE = 4.6 \) ms; 95% CI = −8.1 to +15.5 ms). It is well-known that long-term priming is substantially smaller for HF words than for LF words (e.g., Scarborough et al., 1977), although the complete absence of such an effect is a somewhat unusual finding. The likely explanation of this apparent anomaly is that the words used in Experiment 3 were of substantially higher frequency (mean, Kučera & Francis, 1967, frequency = 275) than those used as "high" frequency in most other experiments. If there is a continuous relationship between frequency and long-term priming, as it would be expected, then words of high enough frequency should show effectively no priming. It seems likely that this is what has occurred in Experiment 3.

**Nonwords.** Helmert contrasts for nonwords, shown in Table 3, reveal that, as previously, there is substantial decay following lag 0 but no further decay beyond this point. (It should be noted that the significant contrast at lag 3 and the marginally significant effect at lag 5 represent a dip below the amount of priming at later lags.) Thus, the pattern of decay for nonwords replicated that found in Experiments 1 and 2.

For nonwords, the only difference between the results of Experiment 1 and Experiment 3 was the reduced magnitude of the long-term priming effect: The long-term value (lags 1–23) appeared roughly 20 ms lower in Experiment 3 (see Figure 3), although it was still substantially above zero at around 18 ms. This reduced LT value may seem surprising given that the same set of nonwords, and the same task, were used in both experiments. A likely explanation for the difference lies in the reaction times to first presentations across the two experiments: As might be expected, participants found lexical decisions more difficult in Experiment 1, when pseudowords were contrasted with extremely low-frequency words (initial decisions times to nonwords = 704 ms), than they did in Experiment 3, when the same nonwords were contrasted with far more familiar items (653 ms). As was pointed out with respect to the naming data, it is reasonable to assume that shorter initial reaction times allow less room for improvement on the second occasion, and so they lead to somewhat smaller priming effects.

**Error analysis.** Roughly equal numbers of decision errors were made to first presentations of words (4.1%), second presentations of words (2.7%), first presentations of nonwords (3.3%), and repeats of nonwords (3.0%). A two-way ANOVA on the error rates to second presentations revealed no effect of lag, \( F(7, 119) = 1.26, \text{MSE} = 0.55, p > .2 \), no effect of lexical status (\( F < 1 \)), and no interaction between the two (Wilks's lambda = 0.574), \( F(7, 11) = 1.17, p > .2 \). Thus, as in Experiment 1, the pattern of priming scores observed cannot be attributed to changes in error rates across lags.

**Summary.** For nonwords, the essential findings of Experiments 1 and 2 have been replicated; that is, a short-term priming effect was significant only at lag 0 (although see the Combined Analysis of Experiments 1, 2, and 3 section for a modification of this conclusion). For real words, the short-term decay of high-frequency words appeared to match that found earlier for low-frequency words, although the LT baseline value was substantially lower.

One implication of the pattern of results obtained across Experiments 1, 2, and 3 is that the short-term and long-term priming components appear to be independent and additive: Word frequency influences the long-term component substantially but apparently has no effect on short-term priming. A second implication is that the decay shape of short-term priming is determined primarily by whether the target item has a representation as a whole: Words decay at the same rate despite large differences in frequency, whereas word-like nonwords decay far more rapidly.

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### Table 3

<table>
<thead>
<tr>
<th>Lag</th>
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<td>&lt;1</td>
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<td>&lt;1</td>
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</tr>
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**Note.** For words, \( \text{MSE} = 1,296; \) for nonwords, \( \text{MSE} = 1,583; \text{df} = (1, 119) \) for all comparisons.

\( *p < .10 \) \( **p < .05 \) \( ***p < .01 \)
Combined Analysis of Experiments 1, 2, and 3

Given that the decay patterns of short-term repetition priming observed in Experiments 1, 2, and 3 were remarkably similar, I decided to combine the data from all three experiments to gain extra power in the investigation of the short-term priming effect. Particularly, I felt that this procedure would (a) give a clearer indication of the exact duration of the short-term effect for words; (b) allow further examination of the possible dip below the long-term priming value at intermediate lags, which was hinted at in the nonword data; and (c) allow a reasonably powerful analysis of errors.

Reaction Time Data

Before a combined analysis of the priming data can be attempted, it was necessary to rescale the data to weight each experiment equally: Simply combining the raw data would give far more importance to the results of Experiment 1 (which had the largest overall priming effects) than to Experiment 2 (which had the smallest). To achieve equal weighting, I converted the condition means for each participant in each experiment to $z$ scores, which were calculated relative to that participant’s performance across all lag-lexicality conditions. The standardized scores were then analyzed with a three-way ANOVA, which included experiment number as a third variable in addition to lag and lexical status. No three-way interaction was found ($F < 1$), although the expected interaction between lag and lexicality was present (Wilks’s lambda = 0.329), $F(7, 45) = 13.10, p < .001$; these findings indicate that the form of the Lag $\times$ Lexical Status interaction did not differ across experiments. This is shown graphically in Figure 4.

Words

Helmert contrasts for the combined word data (treating lag as a repeated measures variable) are presented in Table 4.

![Figure 4](image_url)

Figure 4. Priming (in z-score units) as a function of lag for combined analysis of standardized data from Experiments 1–3 for (a) words and (b) nonwords. Expt = experiment.

Table 4

<table>
<thead>
<tr>
<th>Lag</th>
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<th>5</th>
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<td>3.6*</td>
<td>&lt;1</td>
<td>10.1**</td>
<td>&lt;1</td>
<td>3.4*</td>
</tr>
</tbody>
</table>

Note. For words, average MSE = 0.68; for nonwords, average MSE = 0.83; df = (1, 119) for all comparisons.

Although individual experiments did not always show significant differences between lags 2 or 3 and later lags (although all showed a trend in this direction), it can be seen from Table 4 that the contrasts at each of these lags are significant when the data from all 54 participants are combined. The obvious reason for the lack of significance in individual experiments is that the decay of the short-term effect is exponential, and thus the size of the effect becomes rapidly smaller at longer lags. (Another reason is that Helmert contrasts may not pick up decay in situations in which, for example, lags 2 and 3 are similar but together are higher than subsequent lags.) However, even with data from 54 participants, there is no hint of significant decay occurring beyond lag 3.

Nonwords

The pattern of short-term decay evident for nonwords in Figure 4b suggests that the conclusion drawn from each individual experiment, namely that the short-term effect exists only with immediate repetition, may be an oversimplification.
In fact, it can be seen that the slight dip below the long-term value, suggested at intermediate experiments, is consistent across all three. Helmer contrasts for the combined nonword data are shown in Table 4. Although only one point, lag 3, is significantly below successive lags, the contrasts are somewhat negative at all intermediate lags (i.e., lags 1–5), suggesting a general trend upward from lag 1 onward. This pattern is consistent with a dip following immediate repetition to a minimum at around lag 3 (or possibly earlier), with a return to the long-term value by lag 9. To investigate the statistical significance of this apparent dip, I conducted a “screening” ANOVA on the nonword priming scores, excluding lag 0. There were significant differences amongst the means, $F(6, 318) = 2.46, \text{MSE} = 0.86, p < 0.025$, and thus follow-up tests were conducted. These revealed that average priming at lags 1, 2, 3, 4, and 5 was lower than at lags 9 and 23, $F(1, 318) = 6.35, p < 0.025$, with lag 3 priming lower than that at lags 4 and 5, $F(1, 318) = 4.84, p < 0.05$, but not significantly different from that at lags 1 and 2 ($F < 1$). Thus, nonword priming appears to show a dip below the long-term priming value, which is centered somewhere between lags 1 and 3.

**Error Data**

As described earlier, error rates for second presentations in Experiments 1 and 3, taken individually, were found to be unaffected by either lag or lexicality. (Note that no detailed error data were available for Experiment 2.) However, the error rates in all conditions were low, suggesting that these null findings may merely reflect a lack of power in the analyses. Therefore, the error data from the two experiments were combined. This was done without rescaling, as the overall error rates were similar in the two experiments (giving each experiment roughly equal weight by simply collapsing the raw scores).

For the combined data, a significant effect of lag was revealed, $F(7, 245) = 2.79, \text{MSE} = 0.69, p < 0.01$, with no main effect of lexicality ($F < 1$), and an interaction between the two (Wilks's lambda = 0.618), $F(7, 29) = 2.56, p < 0.05$. Figure 5 indicates that this interaction is of the same form as was apparent in the reaction time data: A repetition advantage at lag 0 decays gradually for words but precipitously for nonwords. Thus, the errors at which participants responded most quickly on the second presentation (i.e., that showed the largest priming effect) were also those at which they were the most accurate. In other words, the short-term repetition effect can be seen as a temporary improvement in both accuracy and speed of response, with equivalent effects of target lexicality apparent on both measures.

**Conclusions**

Overall, the three experiments showed remarkably similar patterns of decay of short-term repetition effects, as measured by reaction times or error rates. For words, short-term priming survived across three intervening items (i.e., 8 s). For nonwords, the increased power available from combining Experiments 1, 2, and 3 has allowed the conclusion that short-term priming actually dipped below the long-term value at intermediate lags. Although it is not at all clear what factors may give rise to such an effect (see the General Discussion section for some consideration of this issue), the implication of this dip is that some form of short-term influence must remain after lag 0 to pull the level of priming back up to the long-term level. However, whatever the explanation of this dip might be, its presence does not change one important conclusion drawn from the results of all three experiments, namely that short-term priming is heavily dependent on lexical status.

**Experiment 4**

Experiments 1–3 have provided evidence that the observed short-term priming effect is robust, is not specific to a single task, and is independent of long-term priming. In addition, it is clear that short-term decay for words and nonwords differs substantially in shape. It would appear possible from these results that the short-lasting repetition effect observed may reflect a short-term form of implicit memory. However, this theoretical interpretation requires the assumption that it is some sort of automatic retrieval that underlies the short-term priming effect. This assumption may not necessarily be valid. Participants in Experiments 1–3 commonly reported, after the experiment, that they explicitly recognized that items were repeats, suggesting that perhaps short-term repetition effects were related to short-term explicit, or working, memory rather than to some form of implicit retention.

In Experiment 4, I investigated whether working memory for word and nonword targets decayed in the same fashion as the short-term repetition advantage apparent in the “implicit” lexical-decision and naming tasks. This was done by repeating Experiments 1 (low-frequency words) and 3 (high-frequency words) with a recognition task (old–new judgment) used in place of the lexical-decision task (word–nonword judgment). Were it the case that the short-term priming effect revealed in Experiments 1–3 reflected the use of explicit rather than implicit memory, it would be expected that decay patterns...
found with explicit recognition would match those found with lexical decision and naming. In particular, the interaction between lag and lexical status observed with the priming tasks should be replicated with recognition.

**Method**

**Participants.** Eighteen undergraduate participants, from the pool described in Experiment 1, took part in return for credit toward an introductory psychology course.

**Materials and procedure.** The stimulus lists and presentation format were exactly as for Experiment 1 (9 participants) or Experiment 3 (9 participants). Experiment 4 differed only in the task used. Instead of making a lexical decision, participants were given a recognition task, in which they were required to determine whether each item had appeared anywhere earlier in the list. Participants responded “old” (i.e., the second presentation of an item) with their preferred hand and “new” (i.e., the first presentation) with the other. Reaction time and accuracy scores were taken.

**Results and Discussion**

Averaged across lags 0–23, error rates for first presentations of targets (i.e., false alarms or falsely recognizing a new item as old) were 16% for high-frequency words, 18% for low-frequency words, 17% for nonwords mixed with high-frequency words, and 12% for nonwords mixed with low-frequency words. Error rates for second presentations (i.e., misses or failing to recognize a repeated item as old) were 11% for high-frequency words, 13% for low-frequency words, 12% for nonwords mixed with high-frequency words, and 23% for nonwords mixed with low-frequency words. These error rates were somewhat above those found for lexical decision. Nevertheless, recognition performance was well above chance. This indicates that participants can, on a reasonable number of occasions, recollect an earlier presentation of a particular item in a continuous list (at least when they have been instructed to do so).

To investigate whether this knowledge could have influenced priming in lexical decision or naming, I have presented reaction times to correctly recognized old items, along with lexical-decision times (to second presentations) determined from Experiments 1 (low frequency) and 3 (high frequency) in Figure 6. Only lags 0–9 are plotted, as it is the decay of short-term priming and recognition which is of interest; means of all conditions are presented in the Appendix. (Note that, for lexical decision, plotting reaction times to second presentations is conceptually equivalent to plotting priming scores: The only difference is that the decay of the short-term priming effect is reflected in a rise in reaction times rather than in a decrease in priming.)

**Low-frequency words, and nonwords.** Across all eight lags, the explicit recognition times for old items in this experiment were slower than the equivalent lexical-decision times in Experiment 1: The advantage for lexical decision was 63 ms for words (lexical decision: 585 ms; recognition: 648 ms) and 28 ms for nonwords (lexical decision: 653 ms; recognition: 681 ms). A two-way ANOVA, including the recognition times for words and nonwords at all lags, found no interaction between lag and item type (Wilks’s lambda = 0.031), $F(7, 2) = 8.92, p > .1$. Figure 6a demonstrates this lack of interaction: In contrast to the sharp dissociation observed between word and nonword data in lexical decision, recognition memory seems to decay smoothly, and at the same rate, for both words and nonwords.

**High-frequency words, and nonwords.** The results for nonwords and high-frequency words were similar. Specifically, lexical-decision times for second presentations were substantially faster than recognition times for old items: 156 ms faster for words (lexical decision: 562 ms; recognition: 718 ms) and 104 ms faster for nonwords (lexical decision: 625 ms; recogni-

![Figure 6](image-url)
tion: 729 ms). In addition, no interaction was found between lag and item type for the recognition data (F < 1), as can be seen for short lags in Figure 6b.

**Error analysis.** As only second presentations of targets would be expected to be influenced by lag between repeats, only miss errors were subject to analysis. For the low-frequency words, and nonwords, a two-way ANOVA on these scores revealed a main effect of lag, $F(7, 56) = 12.29$, $MSE = 3.18$, $p < .001$, representing a decline in accuracy with increasing lag, and a main effect of lexical status, $F(1, 8) = 16.34$, $MSE = 10.34$, $p < .01$, such that words were recognized more accurately than nonwords. More important, no interaction was observed between lag and lexical status, $F(7, 56) = 1.35$, $MSE = 2.54$, $p > .2$. A similar pattern of error scores was apparent for the high-frequency words, and nonwords, with an effect of lag, $F(7, 56) = 7.37$, $MSE = 3.11$, $p < .001$, no main effect of lexical status (F < 1), and, again, no interaction between the two (F < 1). This lack of interaction confirms the pattern observed in the reaction time data: Short-term explicit memory is apparent as both a temporary increase in accuracy and a temporary decrease in recognition time, but the decay of the effect is not influenced by lexical status under either measure.

**Conclusions.** The failure to replicate the Lag $\times$ Lexicality interaction with explicit recognition provides evidence that working memory can be dissociated from short-term priming on the basis of the effects of lexical status. This dissociation indicates that short-term priming does not simply reflect explicit working memory and, more strongly, suggests that working memory and short-term repetition priming might rely on different processes. Although the dissociation observed between recognition and priming does not entirely rule out the possibility of there being some relationship between working memory and short-term priming, it suggests that any such relationship is certainly not a simple one. At this stage, it would appear justified to assume that short-term priming does, indeed, represent a short-lasting form of implicit, rather than explicit, memory.

This is not to say, of course, that participants given lexical-decision or naming tasks do not have explicit working memory representations of recently presented items: Clearly they do. The slower overall reaction times for explicit recognition than for lexical decision (or naming) may have some bearing on this issue of the relationship between short-term priming and working memory. The observed difference indicates that explicitly recognizing a previous item is more difficult than determining its lexical status (or reading it aloud), suggesting perhaps that explicit knowledge of earlier items is available but arrives too late to influence processing in lexical decision or naming tasks.

**General Discussion**

The experiments reported in this article have extended those of previous studies in three important ways: by demonstrating that short-term priming can last beyond immediate repetition, by more clearly specifying the effects of lexical status on short-term priming, and by dissociating short-term repetition effects from explicit working memory. Specifically, the findings were as follows. First, short-term word priming was observed to last for roughly 8 s with three intervening items, regardless of the task used or the frequency of the target items. Second, short-term priming for nonwords was initially as large as for words but remained positive only with immediate repetition; negative priming (compared with the long-term value) at intermediate lags indicated that some short-term influence of the target was retained for perhaps 12 s with five intervening items. Third, the results suggest that the short-term effect identified is independent of standard longer term priming, partly by demonstrating that the decay rate of short-term priming is much faster than that for long-term priming and partly by demonstrating that word frequency influences long-term but not short-term repetition effects. Finally, short-term repetition priming was dissociated from explicit working memory by showing that the unusual effect of lexicality observed in the priming tasks was not replicated with a recognition task.

Before considering the theoretical implications of these results, one difference between the present results and the conclusions commonly drawn from previous studies should be considered. This difference is the finding of postlag 0 short-term priming: Earlier studies have generally concluded that a labile effect is present only with immediate repetition. One likely explanation of this discrepancy is the fact that most previous experiments have used relatively long delays between presentations of successive target items. A lag of one item corresponds to a time delay of 8–10 s, with the commonly used 4 or 5 s between stimuli, and, given the present results showing no short-term effect beyond 8 s (lag 3 here), it is perhaps not surprising that no effect was present at lag 2 or beyond with these longer interitem delays. In addition, as was previously noted, most earlier articles show a trend toward more priming at (at least) lag 1 compared with later lags, and the fact that this effect was generally not significant (if it was tested) may partly reflect low power in these previous designs.

The results presented in this article have a number of theoretical implications, both for the structure of human memory and for the explanation of short-term repetition effects. These are described below, but they can be summarized as follows. First, short-term priming appears to reflect a short-term form of implicit memory. Second, short-term priming can be interpreted as arising at a lexical level of processing and seems consistent with a type of lexical-activation effect. Third, the properties of short-term priming may have implications for particular models of lexical access and, at this stage, seem more consistent with views advocating localized rather than distributed word representations. It should be noted in advance that all of these theoretical views can be criticized on some grounds; however, they are raised as perhaps the most reasonable interpretations of the data as they currently stand.

**Short-Term Priming and Short-Term Implicit Memory**

The finding that short-term priming can be dissociated from both long-term implicit memory and explicit working memory suggests that short-term repetition effects can be thought of as reflecting a distinct short-lasting form of implicit memory. This implies that the short-term–long-term distinction and the
implicit–explicit distinction might be orthogonal to each other and that implicit memory, just like explicit memory, might usefully be divided into long- and short-term components. (It should be noted here that the present data have been interpreted as showing that, at short lags, both implicit memory components are influencing the observed priming scores; it is not that one operates at short lags and the other only at long lags.)

Furthermore, the duration of short-term implicit memory appears to be similar to that found for short-term explicit memory, that is, a few intervening items. This finding is in conflict with conclusions drawn from earlier studies. For example, Ratcliff et al. (1985) suggested that there are three separate components to repetition effects in lexical decision and explicit recognition: an immediate repetition component common to both tasks, an intermediate component apparent in explicit recognition only, and a long-term repetition advantage for lexical decision only. The present results, however, appear to show that both priming and explicit recognition tasks show intermediate (i.e., lag 1–4) components of repetition and thus suggest that lag 0 priming is continuous with, rather than distinct from, intermediate-lag priming.

Although the conclusion that short-term priming is, in fact, short-term implicit memory would appear to provide the most natural interpretation of the pattern of results, it should be kept in mind that there are at least two possible problems with the present data. The first regards the evidence for the short-term implicit–explicit dissociation. This dissociation relies on the fact that a Lag × Lexicality interaction was observed in the priming tasks but not in explicit recognition. As was discussed earlier, this interaction may occur for lexical decision because of competing positive and negative effects of repetition on decision times for nonwords: Repetition might be expected to speed up identification time for nonwords but at the same time make it more difficult to reject the item because of its increased familiarity. The lack of an interaction in explicit recognition may simply reflect the fact that, in this case, no such conflict arises for nonwords. The argument presented earlier against this interpretation was that the Lag × Lexicality interaction occurs in naming as well as in lexical decision, and that increased familiarity should not have any inhibitory component in this task, given that naming does not require an overt decision on the lexical status of the item. However, although the argument that naming does not involve a decision process is a standard one (e.g., see Andrews, 1992), it is always possible that this task involves a kind of covert lexical decision to ensure that the item is read aloud correctly. Thus, the observed dissociation between short-term priming and recognition should perhaps be treated with some caution. Ideally, this dissociation should be backed up in the future by the identification of factors that affect only short-term priming and not working memory, and vice versa.

A second possible problem involves the evidence for the short-term–long-term implicit memory dissociation. Although it does seem relatively clear that these differ in decay rate, the finding that word frequency influences only long-term priming is open to some question because of the fact that high-frequency and low-frequency words were compared only across experiments. Particularly, the similarity between short-term low-frequency and high-frequency word priming may reflect the nature of the interfering items in addition to the nature of the target itself: Because of the across-experiment comparison, low-frequency targets necessarily had low-frequency words (and nonwords) intervening between repetitions, whereas high-frequency targets had high-frequency words (and nonwords) as intervening items. Conceivably, it could be the case that high-frequency targets intrinsically show a longer lasting priming effect, but that these same words also cause more interference in their role as intervening items. Thus, it may be simply a chance result that the short-term decay rate of "stronger" items (high-frequency words) with stronger interference was found to equal that of "weaker" items (low-frequency words) with weaker interference. On the other hand, the fact that long-term priming disappeared altogether in Experiment 3, while a nonzero short-term effect remained, adds weight to the argument that the short-term and long-term effects are dissociable.

Short-Term Priming and Lexical-Level Processing

As noted earlier, the identification of short-term repetition effects as short-term implicit memory seems a natural interpretation of the dissociations observed in the present experiments (given the caveats outlined above). However, even if this identification is valid, it does not, of itself, provide any clues regarding the factors that give rise to short-term priming. Clearly, some explanation of the basis of such priming needs to be considered. The first point to make here is that, given that short-term repetition effects were observed to last beyond lag 0, it is apparent that short-term implicit memory does not simply represent a temporary "buffer" used for storing the last item processed.

A more interesting interpretation of short-term priming arises from the finding of an interaction between lag and lexical status. A priori, it would seem likely that short-term priming could be due to a trace of the stimulus left at a number of possible levels. At a rather low level, short-term priming could result from a purely visual record of the target item; this view, however, would predict no influence of lexical status, as, visually, words and nonwords are equivalent stimuli. At a much higher level, short-term priming could represent an explicit memory phenomenon, such as the deliberate rehearsal of target items in an auditory loop; again, this view would not seem to predict any influence of lexical status, and, indeed, no such effect was found in Experiment 4. Instead, the observed dissociation between word and nonword short-term priming appears to locate the effect as a lexical-level phenomenon, presumably reflecting traces left within the word recognition system. (It should be noted here that a "lexical" level of processing does not imply that short-term priming is specific to words; the term is merely meant to distinguish word-like processing from other domains, such as visual records, object recognition processes, face recognition processes, letter identification, and so on. Thus, short-term priming for nonwords could arise where these items are able to, for example, partially activate real-word representations.)

If short-term implicit memory indeed represents traces left
SHORT-TERM IMPLICIT MEMORY

within a word-like processing domain, there would seem to be a number of possible forms such a trace could take. One major argument that has emerged in the interpretation of long-term implicit memory, which may be relevant here, is whether such traces are historic or ahistoric (see Richardson-Klavehn & Bjork, 1988, for review). A historic trace is one that preserves all details of the original encoding episode. Proponents of the view that such traces underlie long-term implicit memory (e.g., Jacoby, 1983; Kolers & Roediger, 1984) have provided evidence that long-term priming is sensitive to the degree of overlap between the form of first and second presentations of a repeated target, suggesting that maximum priming arises from reuse of a complete, context-specific processing trace.

Proponents of the view that ahistoric traces underlie priming (e.g., Graf & Mandler, 1984; Mandler, 1980; Morton, 1969, 1979) have generally seen such a trace as representing leftover activation of an abstract preexisting representation (e.g., a word unit). This view clearly has problems in accounting for first–second presentation mismatch effects, but, even more seriously, it cannot account for the observed magnitude of long-term priming. Such priming effects can often remain at some tens of milliseconds after many minutes (e.g., Forbach, Stanners, & Hochhaus, 1974; Kirsner & Smith, 1974); if it were the case that every exposure to a target word (regardless of context) left sufficient activation in a common abstract representation to produce effects of this size, then levels of activation of many common words would quickly reach ceiling in normal reading. This would be expected to leave the system in a state in which the interference from recently seen items is so severe that no processing of new words can be achieved (see Grossberg, 1980, and McClelland & Rumelhart, 1988, p. 16, for discussions relating to this issue).

In the existing literature, the discussion of whether priming arises from historic or ahistoric traces has been restricted to explanations of long-term priming (and, it should be noted, this article has nothing to contribute to this debate). At this point, there is no direct evidence regarding whether short-term priming arises from historic or ahistoric traces. However, the magnitude of this effect at lag 0, in combination with its rapid decay over a few intervening items, makes short-term priming look tantalizingly like some form of short-lived modification of lexical-level representations, such as an activation effect.

Short-Term Priming and Activation

As pointed out above, it is clear that activation (or other transient modification) effects cannot last for an indefinite period, or they would cause catastrophic interference to the processing of subsequent items. Thus, any model of word recognition must include some mechanism for fairly rapid decay of leftover influences, although it is not clear exactly how fast this decay must be to avoid severe interference. The first lexical-processing model to explicitly address the issue of the decay rate of activation following word recognition was that of Morton (1969). Morton assumed that lexical access was achieved by parallel activation of whole-word units, and he chose to set a decay rate for activation of these units such that practically all activation had disappeared 1 s after a stimulus was removed. This, obviously, would allow only extremely short-lived repetition effects, such as those found with masked priming, to be produced by leftover activation. (Interestingly, Morton justified this very rapid decay partly on the basis of the failure of two pre-1969 studies to obtain any long-term repetition effect.) Most later models of word recognition (e.g., McClelland & Rumelhart, 1981; Seidenberg & McClelland, 1989) have followed Morton’s lead with activation commonly assumed to decay within a second, to be cleared completely after successful identification of a word, or both.

Although it is apparent from theoretical considerations that activation cannot last for many minutes, the a priori assumption that it can last at most a second seems just that: an assumption. The duration of short-term priming reported in this article seems not inconsistent with an activation effect that lasts somewhat longer than previously proposed (up to 8 s as compared with less than 1 s) and raises the interesting possibility that the word recognition system can demonstrate the ability to “retain” more than one word at a time. In addition, the results suggest that, in processing each incoming word, the operation of the lexical system may be influenced substantially by traces of processing of previous items. It remains to be seen whether current word recognition models are able to successfully recognize new stimuli with such a high degree of leftover activation from past items present within the system.

If, indeed, short-term priming is due to activation left within the word recognition system, this raises the question of the nature of the representation being activated. Particularly, short-term priming may arise from activation of either semantic or orthographic (or phonological) representations. There is no very direct evidence available to exclude either of these possibilities, although two findings suggest an orthographic rather than a semantic locus. The first comes from data reported in Kirsner and Smith (1974), apparently showing that short-term priming is modality specific: The short-term advantage over long-term priming that was present in their study with repeated visual presentations disappeared when the modality of presentation was changed from auditory (on the first presentation) to visual (on the second). The second is the finding of postlag 0 (negative) short-term priming for nonwords in the present experiments: It seems reasonable that word-like nonwords may cause some activation of orthographic representations of similarly spelled words (e.g., see McClelland & Rumelhart, 1981), leading to a priming effect, but it is less likely that nonwords would gain access to semantic representations.

Short-Term Priming and Models of Word Recognition

Given the interpretation of short-term implicit memory as being due to activation within the word recognition system, both the duration of short-term priming and the form of its decay observed for words and nonwords may place constraints on approaches to the operation of this system. In particular, the results would seem to be of relevance to one major issue currently under debate with respect to models of lexical access, namely, whether words have (orthographic) representations as wholes.

Traditionally, word recognition has been conceptualized as
a process that requires matching the input string to one of a collection of discrete whole-word representations stored in a mental lexicon. Although both serial search (e.g., Forster, 1976, 1989; Rubenstein, Garfield, & Miliken, 1970) and parallel mechanisms (e.g., Becker, 1976; McClelland & Rumelhart, 1981; Paap, Newsome, McDonald, & Schvaneveldt, 1982) have been proposed as methods for access to this lexicon (see Taft, 1991, for review), both approaches share the assumption of localized word representations. Given that a system containing only such representations is incapable of allowing pronunciation of nonwords, an additional rule-based procedure (Venezky, 1970) has commonly been assumed (e.g., Coltheart, 1978, 1980; Coltheart et al., 1977) that converts individual graphemes in the written form to individual phonemes in the spoken form. Evidence for this dual-route approach comes from a double dissociation in cases of acquired dyslexia; some patients show poor reading of words with irregular spelling-to-sound correspondences (which presumably require whole-word knowledge) in conjunction with relatively intact reading of nonwords (Coltheart, Masterson, Byng, Prior, & Riddoch, 1983), whereas others show the opposite pattern (e.g., Funnell, 1983).

In contrast, Seidenberg and McClelland (1989) have recently proposed that no “whole-word units” exist but that irregular words, regular words, and nonwords are all processed within a single system. Their model encodes generalities of spelling-to-sound correspondences in English, plus the irregularities of individual words, in a single set of weights, which link orthographic input units to phonological output units via a set of hidden units. The strongest evidence in favor of such single-route theories is that processing of nonwords can be influenced by their degree of similarity to real words (e.g., Andrews, 1989; Coltheart et al., 1977; Glushko, 1979; Rumelhart & McClelland, 1982), a finding difficult to reconcile with the view that nonwords are processed in an entirely distinct fashion.

The duration of the short-term priming effect reported in this article, and thus of the activation of processing units that has been assumed to underlie this, may be of relevance to the localized versus distributed representation debate. As noted above, activation must decay fairly rapidly to avoid interfering too strongly with subsequent processing, but the present results suggest that this activation can survive through at least three intervening items. It is not clear, without full computer simulation, whether current models that are based on either localized or distributed representations could cope with an activation decay rate slow enough to allow short-term priming over this duration, but it would seem to be more of a problem for models utilizing distributed representations. Here, many units are required to process every word, and there is substantial sharing of these units across different words, making it seemingly more likely that the temporary activation of a target representation will be replaced by processing of even one subsequent item. By contrast, a model including localized representations has units available to “store” traces of each target word separately, perhaps making it more likely that priming can survive later interference and thus last beyond immediate repetition.

The Nonword Dip

If, indeed, one or more word recognition models are found to allow postlag 0 (but short-lived) priming that is due to leftover activation, then such models could also be tested for their ability to reproduce the observed effects of lexicality on this short-term priming. In particular, two issues would need to be addressed: (a) Why decay for words occurs at the same rate regardless of vast differences in frequency (although see the earlier discussion of possible problems with this conclusion), whereas nonwords show a substantially different decay pattern; and (b) Why short-term priming for nonwords is actually negative at intermediate lags.

The second of these findings seems particularly counterintuitive, and so it deserves some attention here despite the fact that the field is far from being able to explain genuinely a nonword dip in terms of current word recognition models. The unusual aspect of the nonword dip is that it suggests, at first glance, an inhibitory short-term repetition effect. (Remember that it occurs in naming as well as lexical decision and so is not simply the result of repetition making it more difficult to say “no” to nonwords.) How would a repetition effect ever be negative? A possible answer lies in the role of the intervening items. Presumably, priming for a target is influenced not just by activation leftover from processing that item (reduced by some decay factor over time) but also by competing activation that is due to other items. Thus, it may be that the dip in priming is due to a situation in which interfering items (temporarily) have more activation than the target item but in which the (negative) influence of the interfering items on the target decays more rapidly than does the (positive) influence on the target from its earlier presentation. This means that words and nonwords might show different decay patterns because nonwords are more sensitive to interference, and, in fact, this increased sensitivity for nonwords could be so marked that (at lags 1–5) the interference temporarily overcomes the positive effect of target repetition.

Conclusions

Although there is clearly a need for further study of the behavior of repetition priming over short delays, the experiments reported in this article have raised a number of important issues. Perhaps the most significant implication is that there exists an implicit form of short-term memory, which is distinguished from longer term implicit memory partly by its very rapid decay and partly by the relative influence of word frequency, and which is distinguished from short-term explicit memory by its unusual decay pattern for nonwords.

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6 Note that both distributed and localized approaches should be capable of explaining the substantial positive priming observed for nonwords at lag 0: With distributed representations, nonwords can leave activation of hidden units to speed up their processing on repetition; with localized whole-word representations, nonwords can potentially leave activation of similarly spelled real words (e.g., McClelland & Rumelhart, 1981).

7 See McCloskey and Cohen (1989) for a similar idea regarding long-term learning.
Second, it appears that short-term priming arises from traces left within the word recognition system, possibly as transient modification (e.g., activation) of orthographic representations. One implication of such a theoretical position is that the word recognition system may be able to retain more than one word at a time. Another is that studying the decay of short-term priming as a function of the properties of different types of words and nonwords may be useful as a technique for adjudicating between competing models of lexical access.

Finally, although in this article I have concentrated on demonstrating short-term implicit memory for verbal materials, there seems no reason to assume that the effect could not equally well be demonstrated by using priming tasks in other domains. Just to take two examples, it is possible that the decay of any short-term priming for different types of “possible” and “impossible” objects might be of relevance to models of object recognition (see Schacter, Cooper, Delaney, Peterson, & Tharan, 1991, and Schacter, 1990, for similar ideas with respect to long-term priming) or that short-term priming for “faces” and “nonfaces” might reveal something about the process of face recognition (see Bentin & Moscovitch, 1988). This carries the wider implication that the usefulness of short-term priming as a method of studying the operation of particular processing modules is not limited to investigations of the lexical access system, but that the nature of this priming within other domains may provide a window into the operation of a whole range of processing modules.

References


### Mean Reaction Times (in Milliseconds) and Error Rates (in %) for First and Second Presentations in Experiments 1–4

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### Appendix (continued)

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| Nonword | | | | | | | | | |
| Reaction time | 759 | 771 | 767 | 756 | 743 | 765 | 748 | 756 | — |
| First presentation | 659 | 695 | 715 | 751 | 742 | 734 | 761 | 775 | — |
| Second presentation | 16 | 17 | 18 | 16 | 16 | 18 | 14 | 17 | 1 |
| Error rate | 7 | 4 | 9 | 9 | 13 | 12 | 19 | 22 | 64 |
| Misses | 16 | 17 | 18 | 16 | 16 | 18 | 14 | 17 | 1 |
| False alarm | 7 | 4 | 9 | 9 | 13 | 12 | 19 | 22 | 64 |

*Note.* Dashes indicate that error rates for this condition were very high for second presentations. LF = low frequency; HF = high frequency.  
*No error analysis was possible in this experiment.*

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