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Components of Activation: Repetition and Priming Effects in Lexical Decision and Recognition

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Activation decay functions were examined in two different tasks: lexical decision and word recognition. Activation (amount of facilitation) was measured both for item repetition and for priming between newly learned associates. Results indicate that there are at least three different components of activation: a short-term component that decays with one or two intervening items and that appears to be common to priming and repetition; an intermediate component for repetition in recognition; and a long-term component for repetition.

The notion of activation is of central importance to recent empirical and theoretical work in psychology, artificial intelligence, and neural modeling. A number of models in each of these areas use the construct, activation, as a major processing component. These models can be grouped into two main classes, models that represent concepts as nodes in a semantic network and models that represent concepts in a distributed featural system.

For the semantic network models, activation can serve a number of different functions. In sentence verification, activation has been hypothesized to spread from two concepts in memory: if activation from the two sources intersects, then information about the intersection (and path traversed) becomes available to a decision process (e.g., Anderson, 1976; Collins & Loftus, 1975). So, to decide whether "a robin is a bird," activation spreads from the "bird" node and the "robin" node and when an intersection is detected a "true" response is initiated. The concept of activation is used somewhat differently by Anderson in his 1983 model: activation does not take significant time to spread (Ratcliff & McKoon, 1981a); instead, the level of activation at a node determines the rate at which decision or matching processes that involve that node can proceed. In research in word recognition, McClelland and Rumelhart (1981) have used activation as a central mechanism in a model that assumes orthographic feature, letter, and word levels as nodes and both facilitatory and inhibitory links between the nodes. Activation enters the system at the feature nodes; a word is recognized when activation at the word's node exceeds some threshold.

In feature and neural models, it is assumed that a mental state is a pattern of activation over a group of units (see examples in Hinton & Anderson, 1981). Some models link the units to neural elements or collections of neural elements (e.g., Anderson, Silverstein, Ritz, & Jones, 1977; Grossberg, 1981); others remain more neutral (Hinton, 1981; McClelland, 1983). The models have in common the general assumption that an input sets up a pattern of activation in the units in the system, and this pattern of activation can

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lead to modification of the system. Once the system has been modified, partial input can be sufficient to interact with the modified system in order to reconstruct a pattern of activation similar to that of the original input.

Although the models of the two classes, feature/neural and semantic/node, differ in many respects that are beyond the scope of this article, most of the models in both classes share (or require) some assumption about how activation in the system is dampened down in order to avoid saturation of the system. For example, the models of Anderson (1983), Grossberg (1981), McClelland and Rumelhart (1981), and McClelland (1983) all have explicit continuous dampening mechanisms. These theoretical dampening mechanisms raise questions for empirical research: What is the time course of decay of activation and what kinds of experimental methods and tasks can be used to measure this decay? These questions are the focus of this article.

Activation of one concept by an earlier presentation of the same or a closely related concept (leading to a facilitation in reaction time) has been studied in its own right (Meyer & Schvaneveldt, 1976; Neely, 1977; Ratcliff & McKoon, 1981b). Activation has also been a tool for examining organization and processing in semantic memory and in memory for text. Experimenters have used a number of different paradigms, including, for example, lexical decision (Meyer & Schvaneveldt, 1976), naming latency (Warren, 1977), recognition (Ratcliff & McKoon, 1978), and semantic verification (Collins & Quillian, 1970), and in much of this work, activation has been taken to be a unitary property of a concept. Recently, however, this unitary view has been questioned.

Scarborough, Cortese, and Scarborough (1977) have presented evidence that has been interpreted as showing that different components of activation contribute to repetition effects in lexical decision and in recognition. Two of their experiments are of interest here; both used a continuous paradigm in which test items are presented one after the other and in which items could be repeated with various numbers of other items intervening between repetitions. The first experiment used a lexical decision task in which subjects judged whether an item was a word or not; the second used a recognition task in which the subjects judged whether a word had been presented earlier in the test sequence. In the lexical decision experiment, repetition produced a long-term facilitation effect that was constant from short lags to quite long lags. In contrast, recognition lag functions decayed moderately rapidly.

These results are important for two reasons. First, they identify two components of activation and so call into question the use of a unitary notion of activation to represent facilitation in a paradigm- or task-independent manner. Second, such differential effects in lexical decision and recognition have been used to distinguish between either separate modes of processing (Jacoby & Brooks, 1984) or separate procedural and declarative memory systems (Cohen, 1983). Both views distinguish between information to do with the source of encoding (e.g., perceptual fluency) and the declarative product of encoding (e.g., memory trace). The long-term component of repetition in lexical decision is supposed to reflect either procedural memory (Cohen, 1983) or reliance on memory for source at retrieval (Jacoby & Brooks, 1984).

More recent research by Monsell (1983) has provided evidence for two components of activation effects in repetition in lexical decision: the long-term component observed by Scarborough et al. (1977) and a very short-term component. In Monsell's study, subjects received four study words or nonwords and were postcued as to whether the test was to be recognition or lexical decision. For lexical decision, response times for words that had appeared in the study list were faster than response times for words that had not appeared in any list. This facilitation was constant for words in the first, second, and third positions in the study list, but was greater for the fourth (most recently studied) word. Scarborough et al. (1977) did not observe this very short-term component of facilitation probably because of a long inter-item delay (made necessary by use of a tachistoscope).

In the Scarborough et al. (1977) study, lexical decision and recognition memory tasks were performed in different experiments. Thus it is possible that the effects were the result of different strategies in the two tasks;

subjects might have encoded items differently for later recognition than for lexical decision. In Monsell's (1983) study, lags up to four intervening items were studied but not the longer lags used in the Scarborough study. We designed our first two experiments to extend Monsell's results and to rule out the possibility that subjects used different encoding strategies. Recognition and lexical decision test items were mixed in a continuous task. Each item was preceded by a cue indicating whether the decision about the item should be recognition (OLD for items previously presented in the list, NEW for items appearing for the first time) or lexical decision (WORD or NONWORD). Because any item tested for either recognition or lexical decision could be repeated later in the list for either recognition or lexical decision, encoding conditions could be systematically related to test conditions in order to look for performance differences as a function of first presentation. Lists, however, were constructed so that subjects were unable to predict what the second test of an item was to be, based on the first test. The repetitions occurred with various lags (numbers of intervening items), so we could examine both long- and short-term components of repetition effects.

Our third and fourth experiments were designed to examine the relation between priming and repetition effects in recognition (Experiment 3) and in lexical decision (Experiment 4). We use *priming* to mean the facilitation given by one concept to a related concept; two concepts were related if they occurred in a sentence studied by the subjects, for example, "the man kicked the dog." Presenting the word "dog" twice as a test item should lead to facilitation on the second test, a repetition effect. Presenting "man" as a test item and then "dog" as a later test item should also lead to facilitation on the test item "dog," a priming effect (Ratcliff & McKoon, 1978; McKoon & Ratcliff, 1980). Priming and repetition effects were compared at various lags in order to compare short- and long-term components of activation.

Experiment 1

In this experiment we used a continuous procedure: the items in a list were presented one after the other without a break until all items had been presented. Each item was preceded by a cue indicating whether the response to the item was to be recognition or lexical decision. Subjects were instructed to make the appropriate decision and indicate that decision by pressing a response key. They also were to remember the item so that they could respond correctly if the item appeared later for a recognition test.

Each item of experimental interest was presented twice in a list. It could be presented for lexical decision or recognition on the first test and for lexical decision or recognition on the second test, yielding four possible combinations of tests. The second presentation followed the first by 0, 1, 2, 4, 6, 8, 12, or 16 intervening items. Thus, for both lexical decision and recognition, response time and accuracy could be measured for responses to a second test as a function of lag and as a function of the kind of decision required on the first test.

From the previous research of Monsell (1983) and Scarborough et al. (1977), we would expect the results of Experiment 1 to show three different effects for items on second test. For lexical decision items, a very short-term facilitation effect should be observed at Lag 0, and a smaller but constant facilitation across the longer lags. For recognition, the amount of facilitation should gradually and continually decrease across all lags.

Method

Subjects. The subjects were 4 right-handed University of Toronto undergraduates who were paid for their participation. Each subject completed one practice and 10 experimental sessions, each session lasting no more than 1 hr.

Materials. Words were selected randomly without replacement for each session (a different randomization for each subject) from a pool of 500 common two-syllable nouns not more than eight letters in length. Nonwords were also selected randomly without replacement for each session from a pool of 500 pronounceable nonwords. The words and nonwords chosen for a session were assigned to conditions of the experiment randomly.

Design and procedure. List generation, display, and response recording were controlled by a PDP-12A laboratory computer. The stimuli were displayed in uppercase on a CRT screen. Subjects responded on the two outer keys of a six-key response panel.

Each session consisted of two lists of items. Each list was 288 items in length. Each item was cued (for 1 s) to indicate the nature of the following test. The cue for a lexical decision test was WORD, and for a recognition

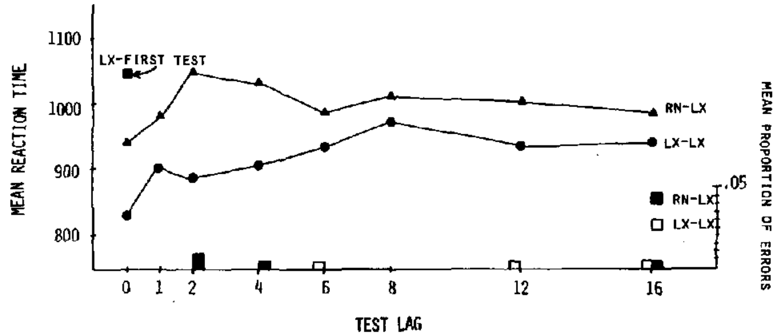

Figure 1. Experiment 1: Response times and error rates for lexical decision words on their second test as a function of type of first test and lag.

test, it was OLD/NEW?. Then, after a 500 ms blank interval, the test item was presented for a minimum duration of 2 s, but if a response had not been made by 2 s, then the display persisted until a response was made. A blank interval of 1.5 s intervened between the offset of the test item and the onset of the cue for the next test item.

For the lexical decision test items, subjects were instructed to press KEY 1 on the left of the response panel if the probe was a nonword and KEY 6 on the right of the panel if the probe was a word. For the recognition test items, KEY 1 indicated that the test item had not appeared earlier in the list (a *NEW* item) and KEY 6 that it had appeared earlier (an *OLD* item). Subjects used the index finger of each hand in responding. They were instructed that both speed and accuracy were important, and they received feedback on the total number of correct responses at the end of each list.

Within each list of 288 items, both recognition and lexical decisions were tested. The critical conditions were those in which an item was presented twice, and there were four critical test pairs: lexical decision–lexical decision, lexical decision–recognition, recognition–lexical decision, and recognition–recognition. There were eight possible lags (the number of items intervening between presentations of a test item): 0, 1, 2, 4, 6, 8, 12, and 16. For each of the four kinds of test pairs, each lag was represented three times in a list, a total of 192 items; the remaining 96 items were nonwords. Over all 288 items, there were 192 lexical decisions (half positive and half negative) and 96 recognition tests (half positive and half negative). Items were assigned to positions in a test list randomly except for the constraints of the lag conditions. A nonword was never presented more than once in a session.

Results

Mean response times and error rates for correct responses were calculated for each subject in each condition. For the second tests of repeated items, means of these individual subject means are shown in Figures 1 and 2. Standard errors were calculated for each mean for each subject; the average of these was 30 ms; standard errors differed very little as a function either of test condition or lag. Means for first tests were as follows: words presented for lexical decision, 1,046 ms with standard error 8.6 ms and 0.8%

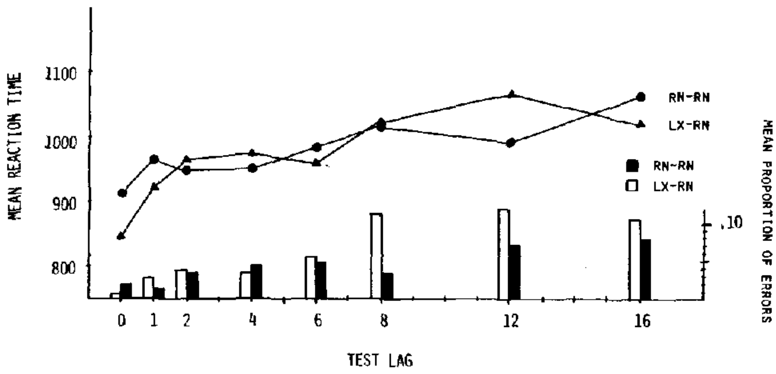

Figure 2. Experiment 1: Response times and error rates for recognition words on their second test as a function of type of first test and lag.

errors; nonwords presented for lexical decision, 863 ms with 4.8 ms standard error and 0.3% errors; and words presented for recognition, 1,117 ms with 9.1 ms standard error and 3.4% errors. It should be noted that the response times for words were relatively slow. Two subjects had response times on the order of 1,300 and 1,400 ms; the other two had response times about 700 ms. Both pairs of subjects showed the same trends across experimental conditions. In addition, an analysis of the data by sessions showed no changes in the trends beyond a generalized decrease in reaction time.

Figures 1 and 2 show mean response times and error rates for the second tests of repeated items as a function of lag conditionalized on the prior test, for lexical decision tests and for recognition tests (correct response was *OLD*), respectively. Overall, for lexical decision, an initially large amount of facilitation is followed by a constant smaller amount of facilitation; for recognition, facilitation decreases gradually and continually over the range of lags; and lexical decision shows a compatibility effect such that responses on second test are faster when the first test was lexical decision than when the first test was recognition.

For lexical decision, the amount of facilitation for a repetition can be obtained by subtracting from response time for correct first test responses (1,046 ms). This difference shows an initial facilitation at Lag 0 and a constant but smaller amount of facilitation at the longer lags. When the first test was lexical decision, the difference shows an initial facilitation of 215 ms and then a constant facilitation of 120 ms. When the first test was recognition, the corresponding figures are 105 ms and 38 ms. The reaction times for Lag 0 were significantly different from the mean of reaction times for Lags 1 through 16, $z = 3.3$, for lexical decision first test, and $z = 2.7$, for recognition first test, both $p < .05$, based on standard errors from the approximately 250 observations for each data point. The constant facilitation when the first test was recognition (38 ms) was significantly different from the control (1,046 ms), $z = 3.3$.

For recognition, the pattern is quite different. Figure 2 shows that response times increase (and so facilitation decreases) gradually and continually over the range of lags. This difference between the lexical decision and recognition functions appeared in analysis of variance as an interaction between type of test and lag, $F(7, 21) = 2.85$, $p < .05$.

Given this overall difference between the lexical decision and recognition functions, more detailed analyses can be performed by fitting linear functions to the data. These functions were fit to Lags 1 through 16, excluding Lag 0 in order to exclude the initial facilitation for lexical decision. For lexical decision, these functions are as follows (with RT for response time and L for lag): conditionalized on correct recognition on the prior presentation, the linear function is RT = 1,021 − 1.5L; conditionalized on correct lexical decision on the prior presentation, RT = 899 + 3.6L. Neither slope is different from zero; t values with 5 degrees of freedom are −0.8 and 1.94, respectively, $p > .05$. For recognition, conditionalized on correct lexical decision on the prior test, RT = 932 + 7.2L; and, conditionalized on correct recognition on the prior test, RT = 929 + 8.0L. Slopes for these functions are significantly different from zero, $t = 3.1$ and 2.4, respectively (5 degrees of freedom), $p < .05$. (The recognition decay function is, of course, not generally linear but a linear function provides a reasonable approximation and test over the range of lags used here.)

The data also show that, for recognition on second test, decision on first test has little effect (the intercepts for the functions do not differ significantly; see Figure 2). But for lexical decision, the type of first test does have an effect (see Figure 1); when the first test was lexical decision, reaction time was faster than when the first test was recognition; for the intercepts of the linear functions, $t = 4.9$, 6 degrees of freedom, $p < .05$ (and the difference was consistent across subjects). This indicates that for lexical decision on second test, compatibility of the first test and second tests is important. It might be argued that this compatibility simply reflects a response effect: with lexical decision on first and second tests, both responses are positive. But a response effect per se should also be apparent in recognition, where with lexical decision on first test and recognition on second test, both responses are positive. Nevertheless, there is no compatibility effect in recognition, and so the effect must be the result of similarity of decision processes.

The main results from Experiment 1 can be summarized as follows: first, previous results (Monsell, 1983; Scarborough et al., 1977) were replicated by the demonstration of both a very short-term component and a longer-term constant component of facilitation due to repetition in lexical decision, and a continuously decreasing facilitation due to repetition in recognition. Second, the long-term component of facilitation in lexical decision was affected by compatibility of decisions: when the first and the second test were both lexical decision, reaction time was faster than if the first test was recognition, different from the second test.

Experiment 2

In Experiment 1, nonwords were never repeated in a list. We were concerned that this might have led subjects to adopt strategies (based on responding *OLD* or *WORD* upon detecting a repetition) that could have distorted the results of the experiment. Experiment 2 was designed to replicate the important conditions of Experiment 1 and, at the same time, include repetitions of nonwords.

The procedure was the same as in Experiment 1; items were presented continuously, each one cued as to whether the decision required was lexical decision or recognition. Again, for repeated items, there were four possible combinations of tests. Half of the repeated items were words, and half were nonwords. The second test for a repeated item followed the first by 0, 1, 2, 4, or 8 intervening items.

Method

Subjects. Four right-handed University of Toronto students served as subjects and were paid for their participation. Each subject completed 1 practice and 10 experimental 1-hr sessions.

Materials, design, and procedure. List generation, display, and response recording were controlled by an IBM PC computer. The stimuli were presented in uppercase on a BMC (Model KG-12C) video monitor. Subjects used the "/" and "\" keys on the left and right sides of the keyboard to respond.

The word and nonword pools were the same as those used in Experiment 1. For each session for each subject, words and nonwords were chosen randomly without replacement from the pools.

Each session consisted of three lists of items. Each list was 240 items in length. Each list item was preceded by a cue presented for 1,200 ms; the cue for a lexical decision test was *WORD?*, and the cue for a recognition test was *OLD?*. The cue was followed by a 500-ms blank interval; then the test item was displayed until 500 ms after a response was made. A blank interval of 1,200 ms intervened between the offset of the test item and the onset of the cue for the next test item.

Each list consisted of 60 words presented twice and 60 nonwords presented twice. For both words and nonwords, there were four possible combinations of first and second tests: lexical decision–lexical decision, recognition–lexical decision, recognition–recognition, and lexical decision–recognition. Thus, half of the tests were lexical decisions, and half were recognition decisions, and half of the tests required positive responses and half negative responses. Each combination of first and second tests for both words and nonwords was represented three times in each list at each lag (0, 1, 2, 4, or 8 intervening items). The order of test combinations and test lags and the assignment of items to conditions was random within each list.

For the lexical decision tests, subjects were instructed to press the "\" (left) key for a nonword and the "/" (right) key for a word. For recognition, the "\" key indicated the test item had not been presented earlier in the list (a *NEW* item), and the "/" key indicated the test item had been presented previously in the list (an *OLD* item). Subjects used the index finger of each hand in responding. They were encouraged to respond as quickly and accurately as possible, and they received feedback on the total number of correct and incorrect responses for each task at the end of each list.

Results

Mean response times and error rates for correct responses were calculated for each subject in each condition. For the second tests of repeated items, means of these individual subject means are shown in Figures 3 and 4. The standard error (averaged across subjects as in Experiment 1) on the means in the figures is 25 ms, which did not differ in any consistent way across conditions. Means for first tests were as follows: words presented for lexical decision, 662 ms with standard error 7 ms and 1.7% errors; words presented for recognition, 838 ms with standard error 9 ms and 2.7% errors; nonwords presented for lexical decision, 703 ms with 8 ms standard error and 0.3% errors; and nonwords presented for recognition, 781 ms with 9 ms standard error and 0.4% errors. These response times are faster than those in Experiment 1 because three subjects were faster than the faster subjects in Experiment 1; only

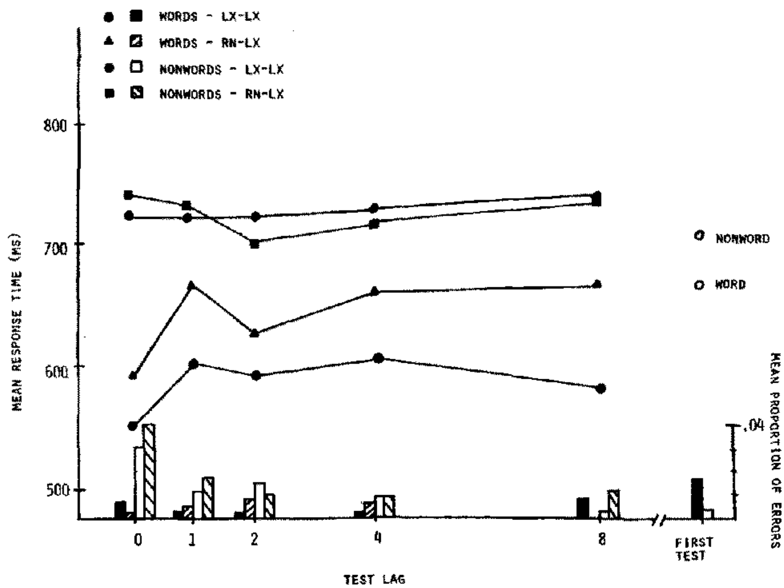

Figure 3. Experiment 2: Response times and error rates for lexical decision items on their second test as a function of type of first test and lag.

one was slower. As in Experiment 1, trends across conditions did not differ between the faster and slower subjects, and did not differ across sessions except for a general decrease in reaction times.

In general, Figures 3 and 4 show the same patterns as were found in Experiment 1. For lexical decision on words, an initially large amount of facilitation is followed by a constant smaller amount; for recognition, facilitation decreases gradually and continually over the range of lags. Again there is a compatibility effect for lexical decision on words but not for recognition.

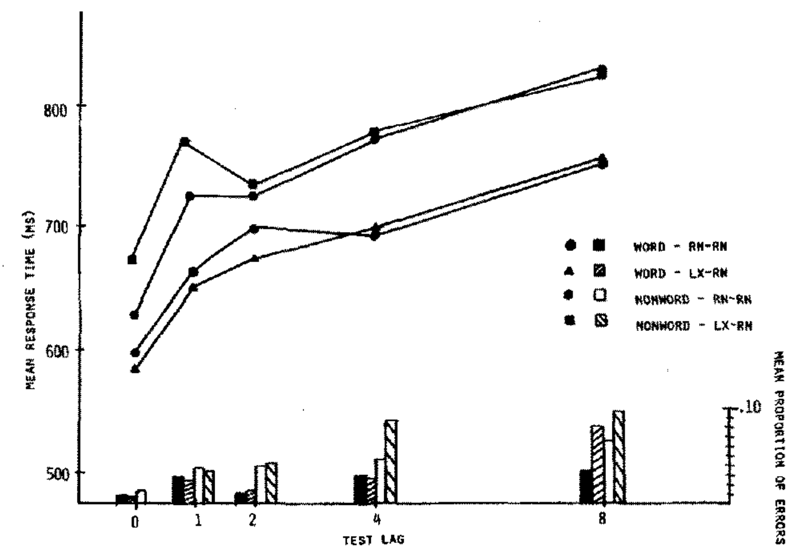

Figure 4. Experiment 2: Response times and error rates for recognition items on their second test as a function of type of first test and lag.

For lexical decision on words, the amount of facilitation was obtained by subtracting from response time for correct first test lexical decision responses (662 ms). When the first test was lexical decision, the difference shows an initial facilitation of 110 ms and then a constant facilitation of 69 ms. This pattern is the same as that obtained in Experiment 1. But when the first test was recognition, the corresponding figures are 66 ms and 4 ms. Although there was still the initial facilitation at Lag 0, the long-term facilitation effect did not appear. Statistically, the reaction times for Lag 0 were different from the mean of reaction times for Lags 1 through 8, $z = 1.46$, $p = .072$, for lexical decision first test and $z = 2.9$, $p < .05$, for recognition first test based on standard errors from the approximately 250 observations for each data point.

For recognition on words, the pattern followed that of Experiment 1, with response times increasing gradually and continually over the range of lags. In analysis of variance, the difference between the lexical decision and recognition functions appeared in the interaction between type of test and lag, $F(4, 12) = 3.26$, $p < .05$.

As in Experiment 1, linear functions were fit to the data, for Lags 1 through 8 (excluding Lag 0). For lexical decision for words, these functions are as follows: conditionalized on correct recognition on the prior presentation, the linear function is RT = 651 − 1.2L; conditionalized on correct lexical decision on the prior presentation, RT = 602 + 2.5L. Neither slope is different from zero, t values with 3 degrees of freedom are −1.5 and 0.3, respectively, $p > .05$. For recognition, conditionalized on correct lexical decision on the prior test, RT = 644 + 13.2L; and, conditionalized on correct recognition on the prior test, RT = 660 + 10.6L. Slopes for these functions are significantly different from zero, $t = 18.9$ and 3.8, respectively, $p < .05$.

For lexical decision for words, the same compatibility effect was found as in Experiment 1. Response times were faster on second test if the first test was lexical decision than if it was recognition; for the intercepts of the linear functions, $t = 2.4$, 6 degrees of freedom, $p < .05$.

For nonwords on second test, lexical decision showed no effects of repetition. Although on average, there was a 22 ms inhibition for second tests over first tests (averaged over lexical decision and recognition first tests), this inhibition was not reliable across the four subjects: one subject showed a reliable 38 ms facilitation; one showed a reliable 94 ms inhibition; and the other two subjects showed unreliable inhibition effects of 19 ms and 9 ms, respectively. The linear functions fit to the data were RT = 721 + 1.2L, for lexical decision on first test and RT = 711 + 1.8L, for recognition on first test, both slopes not significantly different from zero.

For recognition on second test for nonwords, the functions across lag paralleled the functions for words. The linear functions fit to the data were RT = 703 + 16.2L, for recognition on first test and RT = 735 + 11.2L, for lexical decision on first test, both slopes significantly different from zero.

The results of Experiments 1 and 2 for recognition are essentially the same: repetition of items led to a continuously decreasing amount of facilitation across lag, for both words and nonwords, and the effect was independent of the compatibility of the decision made on the first and second tests. For lexical decision, the very short-term component of facilitation was observed for words in both experiments. But in Experiment 2 the constant long-term component of facilitation was observed only when the decisions on first and second test were compatible (both lexical decision).

Experiment 3: Recognition

Experiments 3 and 4 were designed to study the relation between repetition and priming effects in recognition (Experiment 3) and lexical decision (Experiment 4). The study materials were short sentences (these were found in pilot work to provide stronger associations than word pairs). In Experiment 3, subjects were given a series of study–test lists, each consisting of four sentences to study followed immediately by 25 recognition test words. For each test word, subjects were to respond *Old* if the word had appeared in any one of the four studied sentences or *New* if it had not. An example study–test list is shown in Appendix A.

Repetition effects were examined by presenting a word twice in the test list, with 0, 1, 2, or 4 other words intervening between the two occurrences. Priming effects were examined by placing two different words from the same sentence in the test list, with 0, 1, 2, or 4 other words from other sentences intervening. From previous research (e.g., Ratcliff & McKoon, 1978), it is known that one word from a sentence will speed response time to another word from the same sentence if no other test items intervene, and it appears (from analysis using test items uncontrolled by experimental design) that this priming effect decays by Lag 2. The present experiment was designed to examine the decay function of this priming in a controlled procedure and compare it with the decay function for repetition.

It should be noted that in Experiments 3 and 4 the lag variable is defined differently from the way it was in Experiments 1 and 2. In all of the experiments, lag was the number of items intervening between the first and second tests of an item, but in Experiments 3 and 4, for words that had appeared in the studied sentences the tests were actually the second and third presentations of the words.

Method

Subjects. The subjects were 21 Yale undergraduates who participated in the experiment for extra credit in an introductory psychology course. Each subject participated in one session lasting no more than an hour.

Materials. The sentences were taken from those used by Ratcliff and McKoon (1978; Type 2). Each sentence was made up of two propositions and took the form "(Article) Noun Verb (Article) Noun Conjunction (Article) Noun Verb (Article) Noun," where articles were optional. Examples are shown in Appendix A. Sentences for each consecutive third of the test lists for the experiment were drawn from different pools of sentences. Nouns and verbs were not repeated in the sentences of one pool, but could be repeated across the three pools. Only nouns and verbs (not articles or conjunctions) were used as test words. There were also three sets of words (nouns and verbs) presented as new items in the test lists (negatives). For a particular test list, the negative words had not appeared in any of the sentences of the pool used to make up the test list, but could have appeared in sentences from the other pools.

Design and procedure. Stimuli were presented and responses were recorded by a microcomputer driven by an Apple computer. The stimuli were displayed on a CRT screen and subjects responded by pressing keys on the CRT's keyboard.

Each subject was tested with 42 study–test lists, the first 2 for practice. Each list began with an instruction to the subject to press the space bar on the CRT's keyboard when ready to begin. The study part of each list was then presented. It consisted of four sentences displayed one at a time for 6 s each. After the fourth sentence, a warning signal was displayed for 1 s, and then the test list began. The words in the test list were displayed one at a time, each one remaining on the CRT screen until the subject made a response. After the subject's response, the word ERROR was displayed for 2 s if the response was incorrect; otherwise, the next test word was presented after a 150-ms blank interval. Overall, there were 14 positive words and 11 negative words in a test list.

Subjects were instructed to respond quickly and accurately, using the "?/" key for *Old* for words from the four sentences just studied and the "Z" key for *New* for words not from the sentences just studied.

The first variable in the experiment was the condition of a target word; it either repeated a word presented earlier in the list (e.g., *freshmen* in Appendix A) or it was a different word from the same proposition of the same sentence as a word presented earlier in the list (*likeness* in Appendix A). The target words for the experimental conditions were always either the second or fourth noun of a sentence, and the priming word was always the immediately preceding noun in the sentence. The second variable was the lag in terms of number of intervening items between the earlier repetition or prime and the target. The lags used were 0, 1, 2, or 4. These two variables were crossed to form eight experimental conditions. In each test list, four of these conditions were represented, chosen randomly but so that over all 40 test lists each condition was represented 20 times.

A test list was constructed in the following way: First, the four pairs of words representing experimental conditions were placed in the test list in positions chosen randomly but with the restriction that the target word could not be in Positions 1 through 7 (this restriction was lifted in Appendix A to save space). Then, for targets in the Lag 1, 2, and 4 conditions, a positive word was placed in the immediately preceding position. Finally, the remaining positions were filled to give a total of 14 positive and 11 negative test words. With probability .2, a particular negative word was a repetition of a negative word appearing earlier in the list. Other than these negatives and the positive words in the repetition conditions, no words were repeated in the test list.

Assignment of sentences to lists and assignment of words from sentences to conditions was randomized (without replacement), a different randomization for every second subject.

Results

Means were calculated for each subject in each condition. For the target words in the experimental conditions, means included only correct responses preceded by correct responses on the immediately preceding words and on the earlier priming or repetition words. For the nontarget words, means included only correct responses preceded by correct responses on the immediately preceding words. Means of these means are shown in Tables 1 and 2. (The repeated negatives were not analyzed by lag because there were too few observations.) Standard error of response times for target words was 10 ms (computed from the mean squared error from the analysis of variance). Standard error for nontarget words was 33 ms, averaged over all types of nontarget words.

For nontargets, means are given separately in Table 2 for the first and third nouns of sentences and the second and fourth nouns. Because targets were second and fourth nouns, the nontarget second and fourth nouns provide the appropriate baseline against which primed or repeated words should be compared. Facilitation is calculated by subtracting response times for the targets from this baseline (767 ms). Amounts of facilitation for the different conditions are shown in Figure 5.

Figure 5 and analysis of variance show the effect of lag, $F(3, 60) = 49.6$, $p < .01$, and experimental condition, $F(1, 20) = 67.6$, $p < .01$, on response times. Much more facilitation was given by repetition than by priming, $F(3, 60) = 5.0$, $p < .01$. By Dunnett post hoc tests, a difference between an experimental condition and the control condition of 24.9 or more was significant at $p < .05$. Thus facilitation given by priming, though still significant at Lag 1, disappeared at longer lags, whereas the repetition effect was significant

Table 1
Reaction Time (RT: in Milliseconds) and Error Percentages (E%) for Targets in Experiment 3

	Lag			
Targets	0	1	2	4
Repeated target				
RT	588	672	719	740
E%	0.7	3.8	9.4	4.1
Primed target				
RT	695	742	764	773
E%	6.5	9.4	10.8	9.9

Table 2
Reaction Time (RT: in Milliseconds) and Error Percentages (E%) for Nontargets in Experiment 3

Nontargets	RT	%E
First and third nouns		
Preceded by positive test word	737	8.7
Preceded by negative test word	761	12.5
Second and fourth nouns		
Preceded by positive test word	767	11.1
Preceded by negative test word	773	15.7
Verbs preceded by positive test word	807	16.4
Verbs preceded by negative test word	807	22.9
Negatives on first presentation	873	9.0
Negatives on second presentation	776	23.0

at all lags. Error rates were greater for primed targets than repeated targets, but there were no significant effects with lag.

Overall, compared with Experiments 1 and 2, the results of Experiment 3 show a similar effect for repetition in recognition: facilitation declined continuously with lag. For priming, however, facilitation was significant only at Lags 0 and 1, and had disappeared by Lags 2 and 4.

Experiment 4: Lexical Decision

Experiment 4 was designed to study the relation between repetition and priming effects in lexical decision. Just as in Experiment 3, subjects were given a series of study–test lists, each consisting of four sentences to study followed immediately by 36 test items. But because the task was lexical decision, rather than recognition, subjects were to respond *Word* or *Nonword* to test items. An example study–test list is shown in Appendix B.

Repetition effects were examined by presenting a word twice in the test list, with 0, 1, 2, or 4 other items intervening between the two occurrences. Repetition effects were examined for both words that had appeared in the studied sentences and words that had not appeared in the studied sentences. Priming effects were examined by placing two different words from the same sentence in the test list, with 0, 1, 2, or 4 other items intervening. Thus, the results for lexical decision could be compared with those found for recognition in Experiment 3.

Method

Subjects. The subjects were 23 Yale undergraduates participating in the experiment for extra credit in an introductory psychology course. Each subject participated in one session lasting no more than an hour.

Materials. Sentences were chosen from those used by Ratcliff and McKoon (1978; Type 1). The sentences were made up of only one proposition, in the form "(Article) Noun Verb (Article) Noun." Shorter sentences were used in this experiment than in Experiment 3 in an attempt to ensure better learning. Nonwords were chosen randomly without replacement for each list from a set of 500 pronounceable nonwords.

Materials were assigned to conditions and lists as in Experiment 3. Sentences for each consecutive third of the test lists were drawn without replacement from different pools of sentences, and nouns and verbs were not repeated in one pool but could be repeated across pools. Only nouns and verbs were used as test words. Words to be tested in the conditions where they did not appear in the preceding study sentences were also not repeated within one pool, but could be repeated across pools. Only nouns were used in this condition.

Design and procedure. The design and procedure were much the same for Experiment 4 as for Experiment 3, so only differences are described here.

Each subject was tested with 32 lists, the first 2 for practice. The four study sentences of each list were displayed one at a time for 5 s each. The test list consisted of 36 test items, 12 words that had appeared in the four studied sentences, 10 (on average) words that had not appeared in the sentences, and 14 (on average) nonwords.

The first variable was the condition of the target word. There were three conditions: the target word repeated a word from the studied sentences that had been presented earlier in the test list, the target repeated a word not from the studied sentences but presented earlier in the test list, or the target was a word from the same studied sentence as a word presented earlier in the test list. A target was always a noun, and when from a studied sentence, always the second noun. A prime was always the first noun of a sentence. The second variable was lag, with 0, 1, 2, or 4 items intervening between repetition or prime and target word. These two variables were crossed to form 12 conditions, with 6 conditions represented in each test list; over all test lists, each condition was represented 15 times.

A test list was constructed by first placing the six pairs of words representing the experimental conditions in randomly assigned positions in the test list such that the target word would not occur in Positions 1 through 7. Then, for targets in the 1, 2, or 4 lag conditions, a word was placed in the immediately preceding test position (unless there was already a word in that position). Words placed in these immediately preceding positions matched the target words in whether or not they had appeared in the studied sentences (e.g., if a target had appeared in a studied sentence, then so had the immediately preceding word). Remaining positions in the test list were filled by one word that had not been in the studied sentences, three words that had been in the studied sentences (if there were three such words that had not already been used in the test list), and nonwords. A nonword was a repetition of a nonword appearing earlier in the test list with probability 0.2.

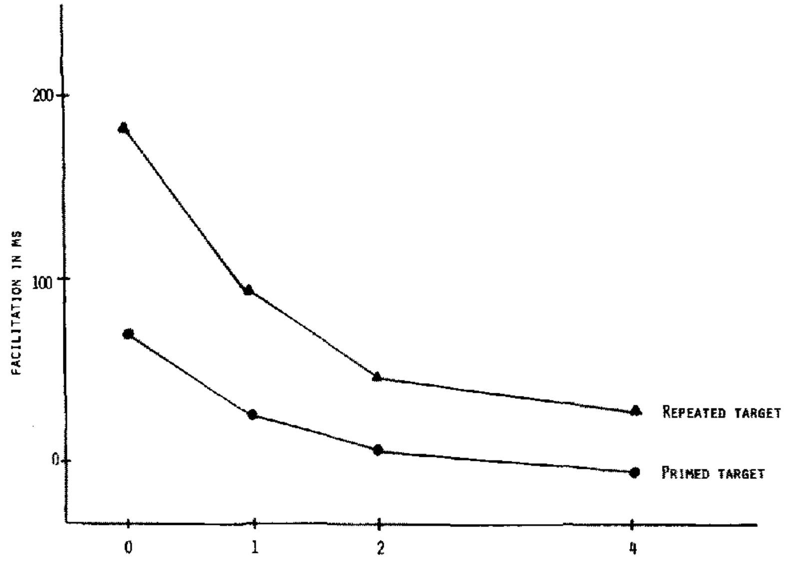

Figure 5. Experiment 3: Amount of facilitation in recognition response times as a function of target condition and lag.

Subjects were instructed to respond quickly and accurately, using the "?/" key for *Word* and the "Z" key for *Nonword.*

At the end of each test list, subjects were given a *pair* test. The instruction "From the same sentence?" appeared on the CRT screen for 2 s, and then four pairs of words were presented one at a time, each pair remaining on the screen until the subject responded *Yes* or *No.* This test was designed to ensure that subjects read the study sentences carefully.

Results

The data were analyzed as in Experiment 3 and are shown in Tables 3 and 4. Average standard error for the target words was 5.4 ms (calculated from the mean squared error in the analysis of variance), and average standard error for the nontargets was 12.5 ms. On the pair tests, accuracy was 94.5% when two words were from the same sentence, 94.4% when from a different sentence.

For response times for targets, analysis of variance showed that the main effects of target condition, $F(2, 44) = 22.3$, and lag, $F(3, 66) = 23.2$, and the interaction of these two variables, $F(6, 132) = 3.4$, were all significant at $p < .01$. There were no significant effects for error rates.

The amount of facilitation given by priming or repetition is shown in Figure 6. For words from the studied sentences, response times for target words were subtracted from 504 ms, the response time for nontarget second nouns (see Table 4). For words not from the studied sentences, times were subtracted from 550 ms. Differences between these control conditions and the experimental conditions were significant by post hoc Dunnett tests if they were larger than 14.2, $p < .05$. The figure and the statistics show, first, that repetition still gives facilitation at Lag 4, whereas priming does not; this result replicates that found in Experiment 3 with recognition. Priming effects were significant only at Lag 0, although they approached significance at Lags 1 and 2. Second, there is a short-term repetition effect at Lags 0 and 1 and a decrease to approximately constant facilitation at Lags 2 and 4. This result replicates the short-term versus long-term facilitation for lexical decision found in Experiments 1 and 2. Third, the figure shows less facilitation for repetition of words from the studied sentences than for repetition of words not from the studied sentences; this is because the studied words already enjoy an advantage (on first test, a 42 ms advantage).

Table 3
Reaction Time (RT; in Milliseconds) and Error Percentages (E%) for Targets in Experiment 4

Targets	Lag 0	Lag 1	Lag 2	Lag 4
Repeated target from studied sentences				
RT	442	462	489	483
E%	0.0	0.6	0.9	1.1
Repeated target not from studied sentences				
RT	475	477	510	514
E%	0.0	0.3	1.5	0.6
Primed target				
RT	485	494	492	504
E%	0.9	0.3	1.2	1.8

Table 4
Reaction Time (RT; in Milliseconds) and Error Percentages (E%) for Nontargets in Experiment 4

Nontargets and nonwords	RT	E%
Nontargets from studied sentences		
First nouns preceded by word	508	1.0
First nouns preceded by nonword	551	1.9
Second nouns preceded by word	504	0.7
Second nouns preceded by nonword	545	2.4
Verbs preceded by word	510	1.4
Verbs preceded by nonword	554	1.4
Nontargets not from studied sentences		
Preceded by word	550	3.8
Preceded by nonword	589	8.7
Nonwords on first presentation	605	4.9
Nonwords on second presentation	598	4.9

General Discussion

The experiments reported in this article serve two purposes. First, they allow a comparison of repetition effects in lexical decision with repetition effects in recognition and, second, they allow a comparison of repetition effects with priming effects.

The shape of the repetition function across lag for lexical decision differed in two respects from that for recognition. First, the lexical decision function showed a very short-term

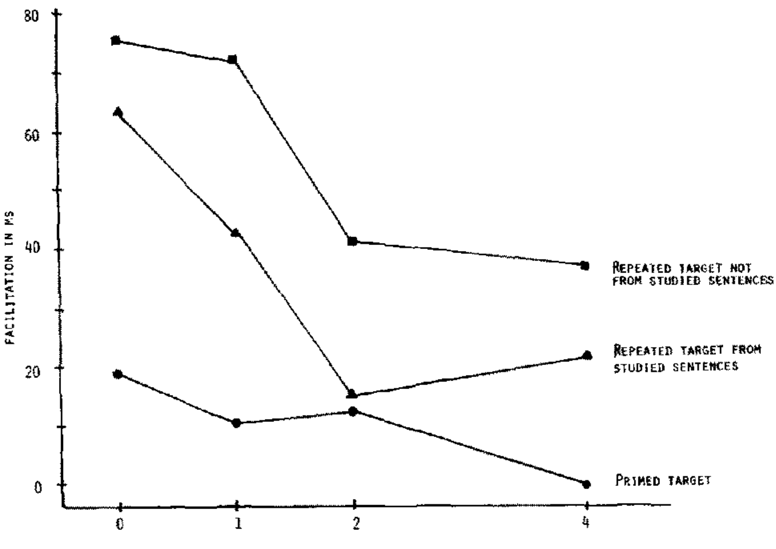

Figure 6. Experiment 4: Amount of facilitation in lexical decision response times as a function of target condition and lag.

component of facilitation (replicating Monsell, 1983). This short-term component was observed at Lag 0 in all three experiments that included lexical decision (Experiments 1, 2, and 4) and can be seen in Figures 1, 3, and 6. Second, the lexical decision functions showed a second component of facilitation that was smaller than the short-term component but constant across all lags after Lag 0. This constant long-term component was also observed in all three experiments that included lexical decision and also can be seen in Figures 1, 3, and 6. There is, however, one qualification about this component and that is that it may depend on the compatibility of the decisions on first and second tests. In Experiment 2, there was a long-term facilitation effect only when both tests of the repeated item were lexical decision. However, the long-term component does not arise only from response repetition. In Experiment 4, repeated test words that had appeared in studied sentences led to faster responses than repeated test words that had not appeared in studied sentences. Apparently, encoding an item during study can contribute to long-term facilitation.

The repetition functions for recognition showed a continuously decreasing amount of facilitation across all lags, in all three experiments (Experiments 1, 2, and 3; see Figures 2, 4, and 5). These functions do not show the very short-term component of facilitation that was found with lexical decision, but it may be that such a component does exist and is impossible to isolate from the gradual decrease in facilitation across intermediate lags in the current experiments. Ratcliff and Hockley (1980), with somewhat different experimental procedures, found increased facilitation at Lag 0 relative to longer lags, so a short-term component in repetition in recognition has received some empirical support.

The recognition functions in Figures 2, 4, and 5 also do not show the other effect found in lexical decision, the constant amount of facilitation across longer lags. However, this may be because experimental conditions were not appropriate. In Experiments 1 and 2, the correct response to the first test for recognition was different from the correct response to the second test (*new* versus *old*). Hockley (1982) has shown that when the responses are the same, both *old* on second and third tests, then there is a constant 70 ms facilitation for third tests over second tests, across lags ranging from 0 to 40. Similar results have been found by Ratcliff and Hockley (1980) and by Ratcliff and Murdock (1976, Experiment 4). Thus, the suggestion is that constant long-term facilitation from repetition is not restricted to lexical decision. Of course, this is not to say conclusively that such long-term components in recognition and lexical decision are the same; that is a question for further research.

In sum, taking into account previous experiments as well as the experiments in this article, the most compelling difference between repetition effects in lexical decision and repetition effects in recognition lies in the intermediate range, where facilitation for recognition is only gradually decreasing while facilitation for lexical decision has dropped to its constant long-range value. The conclusion that this is the only difference would call into question the use of differences between lexical decision and recognition in, for example, research on amnesia. Amnesics show normal long-term facilitation effects in lexical decision even after recognition performance has dropped to chance (Moscovitch, 1982), and it has been argued that this demonstrates that a procedural system is intact even while there is a deficit in declarative memory (Cohen, 1983; Nelson, 1978). The presence of a long-term component to facilitation in recognition would raise difficulties for this line of argument, because the two memory systems could no longer be clearly separated by experimental tasks.

Facilitation due to priming between different words from the same sentence was observed with both lexical decision and recognition (Experiments 3 and 4, Figures 5 and 6). With both procedures, facilitation was limited to very short lags, possibly only to Lag 0. The result that facilitation due to priming disappears quickly as a function of number of intervening items or time has been observed previously. For example, Ratcliff and McKoon (1978), in a post hoc analysis, found decay functions similar to those obtained here in Experiment 3. Dell, McKoon, and Ratcliff (1983) found that facilitation of a nontopic word from a sentence decayed in about 1,200 ms (2 to 4 intervening words). In these examples, the priming words were related because they were studied together in textual material. Using a cross-modal lexical decision task, Swinney (1979) found that during auditory presentation of a two-sentence paragraph, the inappropriate meaning of a word was activated immediately after presentation of the word. By three intervening syllables (750–1,000 ms), this activation had decayed. All of these short-term decay functions are consistent with the decay rates found in Experiments 3 and 4.

The results from Experiments 3 and 4 invite comparison between priming effects and the short-term component of facilitation observed in repetition effects in both lexical decision (Experiments 1, 2, and 4, and previous research) and recognition (Ratcliff & Hockley, 1980). The suggestion is that short-term activation is common to both priming and repetition and to both lexical decision and recognition. The main problem with attributing these effects to a single source of activation is the lack of converging evidence. For example, it should be possible to find variables that affect priming and short-term repetition in lexical decision in the same way, although finding them may be difficult because the effects in lexical decision are so small. Nevertheless, evidence that both effects appear to be automatic (as opposed to strategic, Posner, 1978) seems to relate them. Priming effects in recognition (Ratcliff & McKoon, 1981b) and in lexical decision (McKoon & Ratcliff, in press) for newly learned associates have rapid onset and a significant component unaffected by probability manipulations, and repetition effects have rapid onset in letter matching tasks (Posner, 1978, Chap. 4). If priming and the short-term repetition effect can be assigned to a common process, then this process might be identified with the theoretical notion of activation (of concepts or nodes) used in current models of cognition (e.g., Anderson, 1976; 1983; Collins & Loftus, 1975; Grossberg, 1981; Wickelgren, 1976). The characteristics of the activation process suggested here are those required by the models, specifically a rapid onset combined with a reasonably rapid decay that allows the system to perform other tasks without being overwhelmed by activation left from earlier processes.

It is important to point out that this activation cannot be responsible for the long-term facilitation observed in repetition in lexical decision (Experiments 1 and 2, and previous research) and in recognition (Hockley, 1982). In other words, the long-term facilitation is not due to the kind of activation of the meaning of a concept that can come from another related concept in priming. Instead, the long-term effect must be located in encoding processes or other operations performed when the repeated word was originally encoded, or in the products of encoding associated with repetition not found in priming from another concept (e.g., facilitation of graphemic or phonemic traces). The long-term facilitation effect occurs only when the encoding of the item is repeated.

Forster and Davis (1984) make a similar argument for two different components of facilitation in repetition effects in lexical decision. They found evidence for a short-term component that is not sensitive to word frequency and a long-term component that is sensitive to word frequency and requires more than passive study, for example, that a response be made to the first presentation (see also Morton, 1979; Scarborough, Gerard, & Cortese, 1979). Forster and Davis argue that the long-term effect is mediated by episodic factors not lexical in nature, whereas the short-term component is an automatic consequence of repeated access to the same lexical entry. However, Forster and Davis's view would require modification given the current results. The short-term lexical component, as well as the long-term component, would have to be subject to episodic factors. For example, the similarity between the short-term priming effect in lexical decision (a lexical task) and recognition (an episodic task) implicates a common mechanism. In addition, the fact that one word can provide activation to another word that is its newly learned associate suggests that short-term activation can proceed through episodic connections.

In conclusion, the separability of effects in lexical decision and recognition tasks has provided one of the bases for separating either modes of processing (Jacoby & Brooks, 1984) or memory systems (Cohen, 1983). The examination of the components of facilitation in this article adds one level of complexity to the use of such tasks in arguing for separability; it is necessary to deal with situations in which there are components of activation common to both lexical decision and recognition tasks (and possibly other tasks), and so a perfect empirical separation based on tasks is not possible. Instead, the components involved in tasks must be considered, and then individually related to modes of processing or to memory systems.

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Appendix A

An Example of a List From Experiment 3

PRESS SPACE BAR

The mirror reflected a likeness but the image horrified the villager.
The registrar alphabetized the list while the copyist enrolled freshmen.
The satellite relayed the videotape and the station explained the event.
The Indian brushed the palomino while the squaw erected a tepee.
*****

relayed
ruler
mirror
satellite
likeness priming; Lag 1
freshmen
fern
list
freshmen repetition; Lag 2
⋮

Appendix B

An Example of a List From Experiment 4

PRESS SPACE BAR

A freighter transported the cargo.
The debutante pampered the poodle.
The edict forbade dancing.
The merchant foreclosed the deal.
*****
edict
rab
debutante
poodle priming; Lag 0
cargo
nart
forbade
cargo repetition of word from sentence; Lag 2
pern
horoscope
horoscope repetition of new word; Lag 0
⋮

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