More is Better: The Effects of Multiple Repetitions on Implicit Memory Across Long Durations

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Implicit memory was measured using word fragment completion up to 18 months after being exposed to words multiple times. In all cases participants showed significant priming for multiply presented words over singly presented ones. In shorter delay conditions (up to 6 weeks), implicit memory was tested using word reading speed and fragment completion. Both measures indicated larger effects following multiple prior exposures than following a single prior exposure. This effect was greater for low- than for high-frequency words. These results are consistent with the view that implicit memory is part of the same system that produces explicit memory. They do not support claims of dissociations in the effects of repetitions on implicit and explicit memory that had been used to argue for separate memory systems.

In recent years, the distinction between implicit and explicit memories has taken a significant place among the diverse dichotomies used to partition memory into comprehensible pieces. The term "implicit memory" was first introduced by Graf and Schacter (1985) to refer to improved performance due to previous experiences that does not require conscious recollection of those experiences (Schacter, 1987), whereas the contrasting term, "explicit memory," refers to improved performance due to previous experience that does require conscious recollection.

The implicit/explicit distinction gains its primary interest to the degree that the two phenomena can be independently manipulated. For example, whereas amnesics generally demonstrate devastating loss of explicit memory, implicit memory tests show improvements due to past exposure indicating that, indeed, some memorial processes are spared (e.g., Graf & Schacter, 1985; Shimamura, 1986). Prior to the establishment of the implicit/explicit distinction, Jacoby and Dallas (1981) noted a similar dissociation in normal participants. Their research showed that whereas manipulating levels of processing affected explicit memory, implicit memory was unaffected by these manipulations.

Researchers have examined this phenomenon across the entire spectrum of memory manipulations, finding dissociations between implicit and explicit memory with some, failing to find dissociations with others, and obtaining mixed results with still others (for reviews, see Roediger & McDermott, 1993; Schacter, 1987). The effect of multiple repetitions of items during study is an example of a manipulation that has not yielded clear results. Green (1990) reported that multiple repetitions of study items under implicit test conditions yielded performance that was significantly better than single repetitions in explicit and implicit tests including word identification and fragment completion, and Grant and Logan (1993) reported that performance in a lexical decision task improved as word and non-word strings were repeated multiple times. Other researchers have reported that the consequences of multiple repetitions of study items in implicit test conditions are not clear (Jacoby & Dallas, 1981; Perruchet, 1989; Roediger & Challis, 1992), and still other researchers have reported that multiple repetitions of study items in implicit test conditions yield performance that was no better than single repetitions in either word identification or fragment completion tests (Challis & Sidhu, 1993; Parkin, Reid, & Russo, 1990).

The Source of Activation Confusion theory (SAC; Ayers & Reder 1998; Reder & Schunn, 1996; Reder et al., 1998; Schunn, Reder, Nhouyvanisvong, Richards, & Stroffolino, 1997) posits that multiple repetitions of study items should yield better performance than single items. According to SAC, implicit memory effects are based on the activation of a *concept* (word) node alone, whereas explicit memory effects are based on the activation and association strengths between

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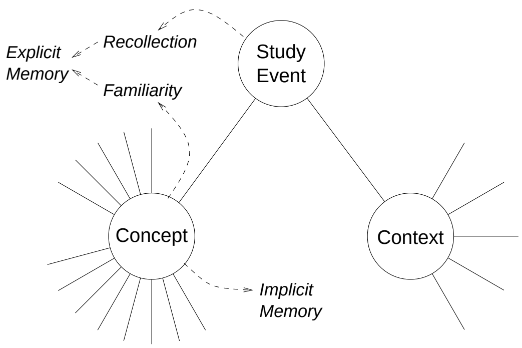

Figure 1. Implicit and explicit memory in SAC. The circles represent nodes and the lines represent linking associations. The lines emanating from the concept node indicate associations with other concepts and with the perceptual properties of the concept. The lines emanating from the context node indicate links to other events during the experiment. Explicit memories are the result of retrieving an event when a concept and context are used as probes whereas implicit memories are a function of the concept-node activation alone.

the word-node, an *event* (episodic) node that represents the event of studying a word on a particular list, and an experimental *context* node (see Figure 1). In an explicit retrieval task such as recognition, correct recognition of a word (a hit) can arise from two different processes, recollection and familiarity. A hit due to recollection is caused by activation of the event node that has been transmitted from the probed concept node and the experimental context node. A hit due to familiarity is caused by the activation of the probed concept node itself. The activation of the probed concept node, however, may be elevated for reasons unrelated to events within the experiment. For example, words with a high normative frequency tend to have elevated node activations. Thus, when probed, they seem familiar even though they have not been seen previously in the experiment. Recognition responses based on familiarity, therefore, are more susceptible to false alarms than are responses based on recollection.

In an implicit task, word-node activation alone determines responding unless explicit memories affect the process. According to SAC, repeated presentations (within a single list) should lead to better explicit and implicit memory because all the node activations increase according to the same principles with each presentation of a word, and all the node activations decrease according to the same principles as time elapses.

Given that SAC makes a straightforward prediction and the prior research is equivocal with regard to this prediction, it is worthwhile to examine the experimental procedures more closely to hypothesize how this effect might be established more robustly. First, most of these studies used relatively few repetitions. Most used only two (cf. Perruchet, 1989; Challis, & Sidhu, 1993; Grant & Logan, 1993). To verify that there is, indeed, no improvement in implicit memory performance for repeated stimuli, it seems prudent to increase the repetition manipulation (e.g., 10 repetitions). In their study, Challis and Sidhu used 16 repetitions and found no improvement in participants' implicit memory performance for the repeated stimuli. Their repeated presentations, however, were successive (i.e., massed), and hence the benefit in performance for multiple encoding trials is greatly diminished (Bahrick, 1979; Glenberg, 1976).

Second, much as in the literature for multiple repetitions and implicit memory, the relation between implicit measures of memory and normative word frequency has yet to be well established. For example, whereas MacLeod (1989a) and Roediger, Weldon, Stadler, and Riegler (1992) found more priming for low- than for high-frequency words, Tenpenny and Shoben (1991) found just the opposite. Because activations in SAC are governed by the power function, it predicts that the relative priming effect of the first exposure and each additional repetition will have a greater impact for low-frequency than for high-frequency words. According to the power function, the activation of a memory node depends on its history of prior presentations. This is expressed as

$$B_N = c_N \sum_i t_i^{-d_N}, \qquad (1)$$

where B_N is the node's base-level activation, c_N and d_N are respectively the memory growth and decay constants, and t_i is the time since the ith presentation of an item represented by that node. Therefore SAC predicts that each experimental presentation of an item increases its base-level activation, but the second increase is not as great as the first increase and so on. Similarly, the first increase in the base-level activation of a high frequency word during an experiment is not going to be as great as the first increase in the base-level activation of a low frequency word because high-frequency words are already further out on their power-function growth curves than are low-frequency words.[1] Third, we speculated that any advantage that words repeated multiple times might have over words presented just once might not be revealed immediately. That is, in some behavioral data this advantage

[1] To understand the predictions made by the power function, it is important to think of the factors that go into making the function change over time. First, consider how activation decays over time: As time elapses since the most recent presentation of a stimulus, because it is the sum of decreasing functions ($t_i > 0$), the base-level activation of a node can only decrease. The fastest decreases take place soon after the presentation of a stimulus, and over time, they become more gradual. Next, consider how the power function can increase over time: It only increases when an element is added to the list of presentation times. Both processes, however, are occurring simultaneously. Hence, as a new item is presented which increases the base-level activation of a node, the "residual" activation due to all the previous presentations is decreasing. High-frequency words have a greater residual activation due to their greater number of past presentations than low-frequency words. This means that high-frequency words have a greater base-level activation than low-frequency words, but it also means that each additional presentation of a high-frequency word is countered by a greater decrease in the residual activation (because there are more terms that are decreasing) than low-frequency words. Therefore, because a low-frequency word has a more sparse history of presentations, an experimental presentation causes a greater increase in the base-level activation than an experimental presentation of a high-frequency word.

might not appear until a substantial delay after encoding. The intuition behind this speculation is that, depending on how memory is tested, all the words presented in an experimental setting whether presented one time or many might be near the ceiling of availability (where availability is some function of activation). After some delay, however, words presented only once might drop away from that ceiling whereas words presented many times would take longer to drop away. This function that relates activation to availability is dependent upon the type of implicit test being performed. We hypothesized that whereas tests such as word identification might have an essentially linear mapping between activation and availability, we were less sure about fragment completion. Tests such as fragment completion might minimize differences between memory traces with relatively high activations because of variables intrinsic to the fragment completion process (e.g., the relative difficulty of completing various fragments). Because SAC uses thresholds to map activations to probabilities, it can account for both results. The exact prediction depends upon parameters that govern the threshold.[2] Nevertheless, we mention this because it played an important part in our experimental design.

The primary goal of this article, therefore, is to provide further support for the theory that multiple repetitions of words improves performance over single presentations in tests of implicit memory. Our ancillary goals are to evaluate the aforementioned factors such as number of repetitions, normative word frequency and delay between encoding and test to see if they do, indeed, affect the degree of improvement caused by multiple repetitions.

Experiment 1: Twelve and Eighteen Month Retention Intervals

We sought to create a study in which we could test whether high- and low-frequency words behaved differently with multiple repetitions, and we wished to use words that had been repeated many times (e.g., 10 vs. 1, not 2 vs. 1). Given our speculation that multiple repetitions might not produce large differences at short delays and given that we wished to minimize explicit recall of words, a very long delay seemed desirable. Experiment 1 emerged serendipitously from two prior experiments completed 12 and 18 months earlier. Participants in the previous studies (Reder et al., 1998, Experiments 1 and 2) had been presented with a sequence of high- and low-frequency words in a continuous recognition paradigm (see Shepard and Teghtsoonian, 1961) wherein on the first presentation of a word the correct response was to identify the word as “new,” and on subsequent presentations of the same word, the correct response was to identify it as “old.” Thus, the participants were intentionally trying to encode the words as they were presented. Each subsequent presentation of a word was separated from the previous one by at least one different word, and each of the words in these studies was repeated 1, 2, 4, 6, or 11 times.

We contacted the participants from these studies via email without revealing why they had been chosen to participate in the current experiment. Because the people with whom they had contact, the rooms in which the experiment was administered, and the format of the experiment were all different from the previous experiments in which words were encoded, we anticipated that it would be extremely unlikely that participants would relate the two studies and unlikely that they could use explicit strategies to recall words that had been presented more than a year earlier. Their task in the present experiment was to complete fragments made from words studied in the previous experiments.

Thus, by utilizing participants from these two experiments we were able to test our hypothesis that multiple presentations during study does enhance performance over single presentations in implicit memory tasks and examine the influence of repetition at five levels, at long durations, using both high- and low-frequency words.

Method

The encoding procedures described in this section are also described in Experiments 1 and 2 of Reder et al. (1998).[3]

Participants

The participants were 38 current or former Carnegie Mellon University undergraduate students. Of these, 11 had completed Experiment 1 from Reder et al. (1998) approximately 18 months earlier, and 8 had completed the Reder et al. Experiment 2 approximately 12 months earlier. These participants received $12 and were given pizza at the conclusion of the experiment. They were strongly encouraged to participate but were not told why they were being invited to do so. The remaining 19 were control participants who only participated in the fragment-completion portion of the experiment. These participants were drawn from the introductory psychology classes at Carnegie Mellon University and participated as part of a research requirement.

Design

The experiment can be viewed as a between participants design with control participants who had not been exposed to the list of words used in Reder et al. (1998) and participants who had been exposed to the words either 18 months before or 12 months before returning to perform a fragment completion test. Both groups completed fragments derived from words with high and low normative frequencies as described below. Finally, the number of times each word had been presented during encoding was nested within the experimental group such that the words from which the fragments were derived had been previously exposed 1, 2, 4, 6, or 11 times. Normative word frequency was crossed with the repetition

[2] Thresholds in SAC have two parameters that govern their behavior. The first is the level of the threshold (i.e., the amount of activation required to exceed the threshold). The second is the standard deviation, σ, of normally distributed noise, $N(0,\sigma^2)$, that is added to the activation before it is compared with the threshold.

[3] In their description, however, they limit their discussion to the first experimental session for each participant.

variable and an equal number of words of each frequency level were randomly assigned to the four repetition conditions with the constraint that there were an equal number in all cells. On the first day of the encoding experiment, 8 words were presented 10 times, 4 were presented 5 times, 4 were presented 3 times, and 80 were presented just once. On the second day, all the words were presented once. Thus, at the completion of the experiment, each participant had seen 192 words once, 160 words twice, 8 words four times, 8 words six times, and 16 words 11 times, half low- and half high-frequency words, at each level of exposure.

Materials

In the Reder et al. (1998) experiments, the words were selected from the Medical Research Council psycholinguistic database (Coltheart, 1981). Half the word were selected to have high normative frequencies, and half were selected to have low frequencies. The mean normative Kucera and Francis (1967) frequency counts were 1.6 and 142 for the 192 low- and 192 high-frequency words, respectively. All the words were between 5 and 10 letters in length.

To ensure that the duration of the fragment completion test was less than one hour, only 135 of the 384 words used by Reder et al. (1998) were selected. These 135 words were all those that had been seen three or more times by any participant in the Reder et al. experiments. Of the 135 words, 67 were high- and 68 were low-frequency words.

The fragments were constructed to minimize multiple possible completions. Because the words in the Reder et al. studies were not chosen with the requirement that they had fragments that would admit only one solution, it was not always possible to devise such fragments. The fragments were generated using our intuitions and then normed with separate groups of participants to assess the difficulty of correctly completing each fragment. In cases where there was more than one possible completion, only the instances in which the completion was the original word from the Reder et al. study were counted as correct. These norming sessions followed the same procedure described below.

The goal of the norming study was to obtain fragments that were each completed 33% of the time (as in Roediger, Weldon, Stadler & Riegler, 1992). To assess this we tested the completion rate of each word against a binomial distribution ($p = .33$) and modified the fragments with completion rates in approximately the upper and lower 5% of the distribution. If, for example, there were 10 participants, fragments that were completed 0 times or 7 or more times were modified to make them less or more difficult, respectively. After five of these norming studies, all of the fragments had been found to be within an acceptable range of completion rates. This norming involved 38 participants who were recruited from the same psychology subject pool used for recruiting control participants.

Procedure

Encoding. The encoding procedure for the experimental participants was performed in the experiments completed either 12 or 18 months earlier (consult Reder et al., 1998 for additional details); control participants did not perform any encoding tasks. The encoding procedure employed a continuous recognition paradigm (see Shepard and Teghtsoonian, 1961) in which participants were instructed to report whether or not they had seen each word on an earlier trial. Words were presented multiple times at various (random) intervals. Thus, on the first occurrence of a word, they should have reported that the word was "new," and on subsequent occurrences, they should have reported "old." Participants were presented with the words individually in two sessions separated by 48 hours. Each session lasted about 25 minutes.

Within each session, the words were presented one at time on a Macintosh display using PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993). Participants were instructed to read each word silently and then to give the appropriate response. The participants returning after 18 months (Experiment 1 of Reder et al.) had been instructed to give one of three responses, "new," "remember," or "know." The participants returning after 12 months had been instructed to respond "new" or "old", and then to respond "remember" or "know" for those judged to be old (see Tulving, 1985).[4]

Participants were instructed to make judgments as quickly as possible while remaining accurate. After they made a judgment, the next trial would begin after an inter-trial interval of 1.5 s. This process continued until all 384 trials were completed in each session. Participants were given scheduled, self-timed breaks at 60-trial intervals.

Fragment Completion Test. The fragment completion tests were administered in small groups using a paper and pencil format. This same procedure was used for the norming studies, for the experimental participants, and for the control participants. The cover page contained instructions and an example word fragment (d_n_sa_ _; dinosaur). The 9 subsequent pages each contained 15 word fragments numbered 1–15. Although no mention was made to the participants, the first page of fragments was the same for each participant and contained practice fragments. The order of the remaining pages was randomized among participants. Participants were given masks to place over their tests so that only one fragment was visible at a time. They were given 15 s to complete each fragment, and they were told neither to go back to complete previous fragments nor to work ahead. The task was timed using an audio tape that counted off the numbers 1–15 in 15 s intervals followed by 30 s intervals for turning the page. After page 5, participants were given a break. The experimenter was present throughout the test.

Following the fragment completion test, experimental participants were asked to complete a questionnaire to ascertain the degree to which they associated this fragment-completion experiment with the encoding experiment they had completed earlier. In the instructions for the questionnaire, participants were again instructed to answer each question in

[4] Words in Session 1 were repeated up to 10 times. All the words in Session 2 were presented only once. In both cases the proportion of correct old and new responses was kept equal. (Consult Reder et al., 1998, for more details.)

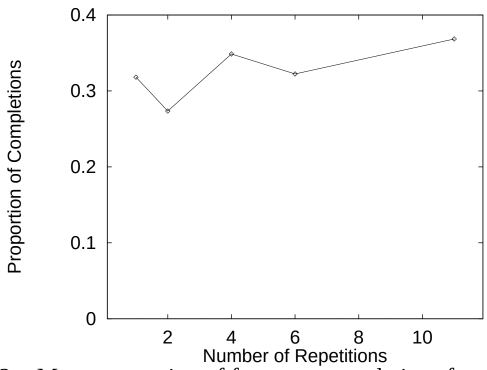

Figure 2. Mean proportion of fragment completions from Experiment 1 for each level of repetition during study.

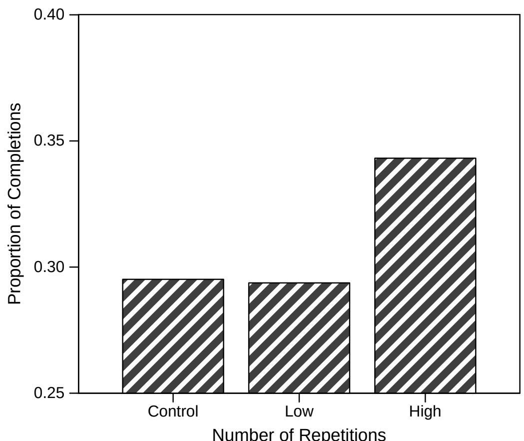

Figure 3. Mean proportion of fragment completions from Experiment 1 showing the number of repetitions during study collapsed into two groups along with the data from the control participants who had had no experimental exposure to the words prior to the fragment completion task.

order without looking ahead or going back to fill in previous questions after having read later ones. The questions became increasingly explicit over the course of the questionnaire about the relation between the present experiment and the encoding experiment 12 or 18 months earlier so that we could determine how much prompting was necessary for participants who made a connection between the two studies if they could remember it at all.

Results

First, we examined the questionnaires from the 19 participants who were called back from the encoding studies conducted 12 or 18 months earlier. Of the 19 participants, 14 completed the entire questionnaire without giving any indication that they made any connection between the encoding experiment and the fragment completion study. With substantial prompting, four reported remembering a previous experiment that may have been the encoding experiment. Only one participant, also with substantial prompting, clearly indicated that he or she remembered the encoding experiment and associated some of the words completed fragments with that experiment. Nevertheless, because no participants could remember their encoding experiment without prompting, the questionnaires strongly suggest that participants were not using explicit memories from the encoding experiment to help them with the fragment completion task.

Our first step in analyzing the fragment completion data was to do a three-way mixed ANOVA using *delay* (12 months or 18 months between encoding and the fragment completion test), normative word *frequency* (high or low), and number of *repetitions* during encoding (1, 2, 4, 6, or 11), as factors. The first factor was between-participants, and the latter two were within-participants. There was no main effect or interaction that included delay or frequency. Given that there were no reliable differences in performance between participants who had completed Reder et al.'s Experiment 1 and Experiment 2 and no effect of word frequency, we collapsed over these factors.

Figure 2 shows the proportion of fragments completed for participants who had studied these words 12 or 18 months earlier. These data are plotted as a function of the number of prior exposures to a given word but are collapsed over the non-significant factors of pre-experimental word frequency and whether the participant had been in the prior Experiment 1 or Experiment 2 from the Reder et al. (1998) study. There was no main effect of repetitions, but a first degree polynomial contrast indicated a trend toward more fragment completions for words that were repeated more often, $F(1,15) = 4.05$, $MSE = 0.04$, $p < .10$.[5]

Encouraged by this initial result, we regrouped the data to obtain more power. The design of the encoding task created a natural, qualitative difference between the words: The first group were words presented only once on Day 1 and words presented for the first time on Day 2. We calculated their respective d' scores, using as false alarms the new words from Day 2. Hits were calculated as an "old" response to any word that had been previously presented. For words presented only once on Day 1, participants' overall $d' = 0.06$ ($\beta = 1.03$). The second group were those words that were presented four or more times. For these words, d' was computed in which words were considered new on their first appearance and old on their second appearance and thereafter. Participants' responses were considered "old" if they eventually classified a repeated word as "old." For these words, $d' = 3.24$ ($\beta = 0.15$). We, therefore, divided the repetition factor into two levels such that words that had been repeated 1 or 2 times were in one level and words that had been repeated 4, 6, or 11 times were in the other level. We then per-

[5] Two of the participants (one from each delay condition) could not be included in this analysis because they had not been exposed to words in all the frequency and repetition conditions during encoding due to an experimenter error. Thus the analysis was only performed using 17 participants. Also, in the case of this statistical test and others using proportions, the tests were repeated using an arcsine transformation to correct for violations of normality. The transformation made no qualitative difference in the results reported.

formed a one-way repeated measures ANOVA using these binned repetitions as the sole factor. This grouping is shown in Figure 3 along with the data from the control participants. Words that had been repeated more were completed more often ($M = .35$, $SD = .08$) than words that had been repeated less ($M = .30$, $SD = .07$), $F(1, 17) = 5.26$, $MSE = 0.0089$, $p < .05$.

Planned comparisons between the fragment completion rates of the participants in the control condition and the participants from Reder et al. (1998) failed to show a significant advantage for the returning participants either for words presented 1 or 2 times ($F < 1$, $MSE = 0.009$) or for words presented 4, 6, or 11 times ($F = 2.31$, $MSE = 0.009$, $p = .13$). This failure to show a difference between the experimental and control conditions is best attributed to the increased noise inherent in between-participants analyses inasmuch as the within-participant analysis described previously showed a significant effect of levels of repetition.

Discussion

The results of Experiment 1 show that exposure to multiple repetitions of a word can improve performance over single presentations of a word in implicit memory tasks for up to 18 months. This finding is novel and it conforms to predictions derived from SAC.

We made two additional predictions, however, that were not confirmed by the data. SAC predicted that the number of times a word was repeated would have a greater influence on the completion rate of low- than on high-frequency words. The failure to find interactions that would confirm these predictions, however, should only be considered suggestive for two reasons. First, the delay between participants' exposure to these words and their subsequent tests is among the longest delays in the implicit memory literature. With such extreme delays, SAC predicts only subtle distinctions between high- and low-frequency words. Second, previous researchers (e.g., Sloman, Hayman, Ohta, Law, & Tulving, 1988) have found that performance measured at similar delays, especially with relatively few participants, is highly variable. This variability may thus eclipse any slight differences in completion rates between high- and low-frequency words.

Our second prediction that was not confirmed by this experiment was that it might be possible to detect more priming due to multiple repetitions over single repetitions at longer delays. As described in the introduction, however, SAC predicts that the greatest changes in memory activation will happen soon after encoding, and this is confirmed in the study performed by Sloman et al. (1988) in which they found that performance declined very slowly at long delays Hence, if such an interaction were to occur, its detection would be difficult after delays as long as 12 and 18 months.

Nevertheless, the finding that many (4–11) repetitions provided an advantage in fragment completion performance above that attained by few (1–2) repetitions at 12- and 18-month delays is significant and in accord with the predictions made by SAC.

Experiment 1 demonstrated that multiple presentations of words can produce implicit memory task improvements more than one year later. There was a significant difference in word fragment completion between words presented multiple times and those words that were presented only once on Day 2 of the encoding experiments (i.e., 1 time total) or only once on Days 1 and 2 (2 times total).[6] This provides support for the idea that multiple repetitions affect implicit memory just as they affect explicit memory.

Although we were pleased to find these results, we had also hoped to find support for the idea that the impact of multiple presentations would be greater for low frequency words than high frequency words. We also would have preferred to be able to compare zero presentations with one presentation, and with multiple presentations. Because we had brought back participants from another study, we had not designed the experiment to make this within-participant comparison possible.

Experiment 2 was designed to accomplish several goals. First, we wanted to replicate the results of Experiment 1 but with a within-participant manipulation of 0 vs. 1 vs. many repetitions during encoding. Although it was gratifying to find our results 12 and 18 months later, such long delays were neither practical nor deemed necessary. We were still interested in establishing whether delay was also a critical variable in demonstrating effects of multiple repetitions. For this reason, we choose to vary delay between encoding and test.

It occurred to us that one reason we did not obtain the predictions of greater impact of multiple presentations for low frequency words may have been because we used fragment completion as the task. With fragment completion, we needed to first norm the items so that earlier in the study, low and high frequency words would be equally likely to be completed. Because the difficulty of completing a word fragment may interact with prior availability (i.e., normative word frequency, cf., Hintzman & Hartry, 1990), we elected to use an additional task that did not require norming. Word reading time is a task that presumably should show some priming benefit and that we predicted would show greater benefit with multiple presentations.

An additional rationale for including word reading time is that we did not need to be concerned with explicit memory influencing performance. One might argue that with these shorter delays and given that we were calling back our participants there was the potential for explicit memory attempts to contaminate the fragment completion results in this new experiment. Therefore, it seemed important to replicate the results of multiple presentations being better than a single repetition with a task impervious to explicit memory efforts.

[6] Recall that those presented only one time on Day 1 had a d' of close to 0, indicating that they could not distinguish these words that were new on Day 2; in contrast those presented multiple times had a d' greater than 3, suggesting that these words were indeed well recognized as old.

Experiment 2: Word-fragment Completion and Reading Times at Short Delays

In Experiment 2, we made four substantial changes from Experiment 1: (a) the delays were reduced so that the maximum was six weeks; (b) whereas the previous study task was intentional, the one in this experiment was incidental to reduce the chances of interference from explicit encoding strategies; (c) in this experiment, implicit memory was measured in a word-reading task, in which words were presented for 100 ms and reading times were measured, as well as a fragment-completion task; and (d) words not presented during study were tested to provide a baseline against which implicit memory effects could be compared within individual participants.

The word reading task was used in addition to fragment completion for several reasons. First, it provides evidence of the generality of the results found in Experiment 1. Second, because fragment completion tasks operate on a fairly long time scale, there is a possibility that participants can utilize different strategies, including explicit strategies, that could corrupt the measurement of implicit memory (cf. Roediger et al., 1992). The word reading task, in which responses are made on the order of 500 ms seems less likely to admit that possibility. Third, although implicit memory clearly plays a role in the rate of fragment completions, a substantial portion of the variability in the task appears to be due to factors such as the intrinsic difficulty of particular fragments, which are unrelated to memory (Hintzman & Hartry, 1990). Thus, the word reading task may prove to be a more direct measure of the strength of implicit memories. Fourth, because fragments derived from high- and low-frequency words are normed to the same completion rate, the intrinsic difficulty of completing those fragments has been systematically manipulated between the two frequency levels. The word reading task may therefore better reflect the strength of people's memories for high- and low-frequency words.

In sum, the goals of this experiment went beyond those of Experiment 1. We desired to replicate the finding that multiple repetitions of a word yield better performance in tests of implicit memory than single presentations. We hope to find a greater benefit of multiple repetitions for low- than for high-frequency words and to show these effects in a second task, namely a word reading task.

In this experiment, participants were presented with a list of words and were instructed to rate the commonness of each. Some of the words on the list were repeated up to eight times. Participants were not told that there would be any kind of memory test. At the end of the study session, the experimenters explained to the participants the cover story that some of the words in the list were repeated to test the hypothesis that participants' ratings of commonness would increase for repeated words due to their heightened availability in memory.

Some participants were given implicit memory tests immediately after the study sessions, some were tested after two weeks, and some were tested after six weeks. Returning participants were tested individually either with a paper and pencil test like that used in Experiment 1 or with a word reading test presented on a computer. In the word reading test, words were presented on a screen for 100 ms before being masked, and reading times were measured using a voice key.

Method

Participants

The participants were 80 Carnegie Mellon University undergraduate students, and were divided into three groups: The first group ($n = 13$) completed the encoding task and returned after two weeks for a single implicit memory test, the second group ($n = 17$) returned after six weeks to complete a single implicit memory test, and the third group ($n = 50$) completed two implicit memory tests on non-overlapping subsets of the words either immediately after the encoding or after a two-week delay or both. The 30 participants in the first two groups received partial credit toward the completion of a research requirement in their introductory psychology classes and $6. Of the 50 participants in the third group, 4 received only credit for their introductory psychology courses, 2 received credit for their introductory psychology courses and $10, and the remainder were paid $10–20 depending upon the duration of the experiment.

Design and Materials

The words used in this experiment were a subset of the words used in Experiment 1,[7] and the fragments were the same as those used in Experiment 1. Three factors were manipulated in this experiment: the number of times each word was presented to each participant during encoding, the normative word frequency of the stimuli as described in Experiment 1, and the delay between encoding and test. During encoding, 20 words were repeated 8 times, 20 were repeated 4 times, and 40 were presented only 1 time yielding 280 encoding trials. This factor was crossed with normative word frequency, so that half of the words in each level were high and half were low frequency.

For participants in the first two groups, 25 words were retained for use in the implicit memory test without being presented during encoding. These participants, therefore, were tested with 52 low- and 53 high-frequency words. For the participants in the third group, 40 words were not presented during study because each participant this group was tested twice. They, therefore, saw half of the words (60 words; 30 low- and 30 high-frequency) on each test.

[7] Words from Experiment 1 were retained or excluded based upon the quality of their fragments with the constraint that the number of high- and low-frequency words in the final set should be the same. Thus it is almost certain that the normative Kucera and Francis (1967) frequency counts differed from those listed previously. Nevertheless, the original frequency counts were so widely separated that the qualitative difference between the two groups of words certainly remained.

The words for each participant were randomly assigned to the four repetition conditions and were randomly permuted with the constraint that at least three words intervened between repetitions of a word.

The fragment completion tests were administered in a paper and pencil format. The word reading tests were administered on Macintosh computers using PsyScope (Cohen et al., 1993). Response times were measured using a voice-key, which yielded millisecond precision.

Procedure

Encoding. For encoding, the participants each received a packet with identical instructions followed by 20 pages with 14 words per page, yielding 280 words. Participants were instructed to rate how common each of the words in the packet was on a scale of 1–10. They were given 4 s to rate each word and were instructed not to work ahead nor to go back. Participants were instructed to use a mask over the pages in their packet so that only one word was visible at a time. The task was timed using an audio tape that counted off the numbers 1–14 in 4 s intervals followed by 15 s intervals for turning the page. After page 10, participants were given a break. The encoding portion of the experiment lasted approximately 40 minutes. In the first two groups, participants completed the encoding task with as many as nine other participants, whereas in the third group, encoding was performed either individually or in pairs.

Implicit Memory Tests. The implicit memory tests were administered individually. The procedure for administering the fragment completion tests was the same as for Experiment 1 with the exception that the tests were shorter (eight pages of fragments for the first two groups and five pages of fragments for the third, including the first page of practice fragments), and the order of the fragments (rather than of the pages) was permuted among participants. In the first two groups, participants were given a self-timed break after page 4. The third group did not receive a break.

In the word reading tests, participants were told that words would be shown briefly on the computer screen, and that their job was to read them aloud as quickly and accurately as possible. Participants wore a lapel microphone connected to a button box that registered word onset. All the stimuli were presented in black on a white background. Each trial began with the presentation of a fixation cross in the center of the screen. After 750 ms, the cross was replaced by the word to be read, which remained on the screen for 100 ms. The word was then replaced by a mask consisting of 11 ampersands (i.e., "&&&&&&&&&&&") until the voice key detected the initiation of the word, at which point the mask disappeared. After 500 ms more, the word reappeared so that the experimenter and participant could determine if the participant read the word correctly. The experimenter then indicated, using a button box, if the word was read correctly, was read erroneously, or if there appeared to be a computer malfunction (e.g., the voice-key failed to detect the participant's voice). This was followed by a 1000 ms inter-trial interval, and then the procedure repeated.

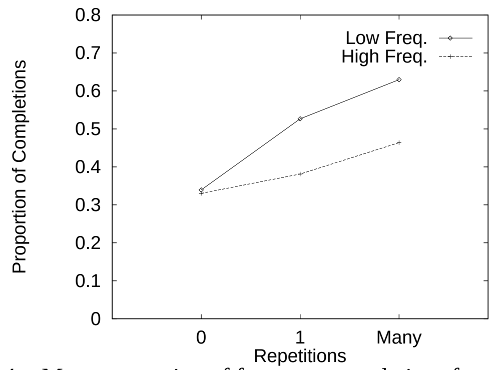

Figure 4. Mean proportion of fragment completions from Experiment 2 for three levels of repetition during encoding.

The first 15 trials were practice trials using words not presented during encoding. Participants were not told at any time about the practice trials, and they were indistinguishable from the remaining trials. The first two groups completed 120 trials including the practice trials, and the third group completed 70 trials including the practice trials.

Results

The data from one participant were discarded because he or she succeeded in reading only 61% of the words correctly. (The remaining participants were able to read 92% of the words correctly, $SD = 6\%$.)

Fragment Completion Tests

Although there were differences between the design of Experiments 1 and 2, the fragment completion test in Experiment 2 also affords an opportunity to replicate Experiment 1. First, it is useful to review the differences between the two experiments: The encoding procedure in Experiment 2 was incidental whereas it was intentional in Experiment 1; participants were likely aware of some degree of connection between encoding and test in Experiment 2; participants were tested on words not presented during encoding in Experiment 2; the number of times that words were repeated was different between the two experiments; and the delay between encoding and test was different between the two experiments.

Figure 4 displays the fragment completion data for each level of normative word frequency as a function of the number of repetitions during encoding. Despite the differences between Experiments 1 and 2, Experiment 2 shows the same basic result: Words presented multiple times (4 or 8) during encoding ($M = .55$, $SD = .20$) yielded more fragment completions than words presented just once ($M = .45$, $SD = .22$) as indicated by a planned contrast, $F(1,59) = 20.72$, $MSE = 0.08$, $p < .001$ (see Figure 4).

Furthermore, this experiment also allowed a within-participants comparison between words not presented during encoding, words presented once, and words presented multiple times. These three levels were crossed with two levels of

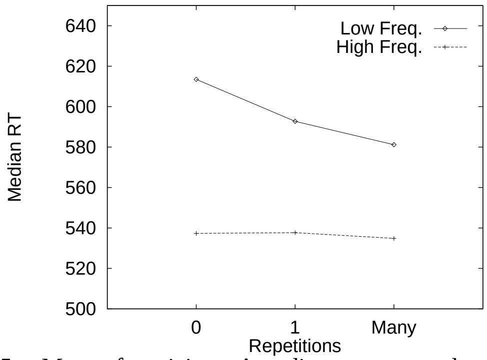

Figure 5. Mean of participants' median correct word reading response times from Experiment 2 for three levels of repetition during encoding.

normative word frequency yielding a 3x2 repeated measures ANOVA. This indicated that as the number of repetitions seen during study increased, participants successfully completed more fragments, $F(2,118) = 44.43$, $MSE = 0.024$, $p < .001$. This was confirmed by the linear component of a planned polynomial contrast, $F(1,59) = 67.29$, $MSE = 0.064$, $p < .001$.

This experiment also showed a reliable difference in the effect of additional repetitions as a function of normative word frequency, $F(2,118) = 9.09$, $MSE = 0.021$, $p < .001$. Overall, repetition had a greater effect on low- than on high-frequency words as indicated by a planned polynomial contrast, $F(1,59) = 15.81$, $MSE = 0.041$, $p < .001$, confirming our theoretical prediction.

Planned contrasts between participants' completion rates for singly and multiply presented words, however, showed significant effects for both low- ($F(1,59) = 12.72$, $MSE = 0.041$, $p < .001$) and for high-frequency ($F(1,59) = 8.51$, $MSE = 0.039$, $p < .01$) words. Thus, as can be see in Figure 4, the overall interaction depends largely on the differential change in completion rates for low- and high-frequency words between zero and one encoding presentations.

Word Reading Tests

The word reading tests provided a second dependent measure to ascertain the effect of multiple repetitions in implicit memory, and the analyses performed are analogous to those performed for the fragment completion tests. We used means of participants' median correct response times to avoid distortions due to outliers.

A 3×2 repeated measures ANOVA, with three levels of encoding presentations (0, 1, many) and two levels of normative word frequency (low and high), indicated that as the number of repetitions during study increased, participants did respond more rapidly, $F(2,130) = 5.62$, $MSE = 1,506$, $p < .01$ (see Figure 5). This is confirmed by the linear component of a planned polynomial contrast, $F(1,65) = 11.09$, $MSE = 3,046$, $p < .01$. Further, the degree to which response times decreased with increased repetitions depended on whether the word had a high or low normative frequency, $F(2,130) = 6.14$, $MSE = 955$, $p < .01$. Repetition had a greater effect on low- than on high-frequency words as indicated by a planned polynomial contrast, $F(1,65) = 10.93$, $MSE = 1703$, $p < .01$, as indicated by the steeper slope for the low- as opposed to the high-frequency words in Figure 5.

Consistent with the polynomial contrast, a contrast between response times for low-frequency words presented only once ($M = 593$ ms, $SD = 84$) and ones presented multiple times ($M = 581$ ms, $SD = 76$) indicates that participants were faster in the latter case, $F(1,65) = 13.62$, $MSE = 4,138$, $p < .001$. The same contrast for the high-frequency words, however, indicated no significant difference between words presented once ($M = 538$ ms, $SD = 70$) and words presented multiple times ($M = 535$ ms, $SD = 71$), $F < 1$. Thus, in this experiment, whereas multiple repetitions provided additional priming for low-frequency words, no such benefit was found for high-frequency words.

Effects of Delay

One of the purposes of Experiment 2 was to afford a more detailed analysis of the effect of delay between encoding and test across three delay intervals. An initial analysis yielded the same qualitative results as the comparison between Experiments 1 and 2. As the delay between encoding and test increased, the advantage in the proportion of completions for multiply over singly presented words decreased (.123 at immediate test, .069 at 2 weeks, .070 at 6 weeks), but not significantly $F(2,59) = 1.08$, $MSE = 0.02$, $p \gg .10$. An examination of the experimental procedure, however, suggested that experimental fatigue or duration covaried with delay. For example, in the immediate test condition, participants might have already been participating in the experiment for nearly an hour before the fragment completion test was administered, whereas in the six-week delay condition, the fragment completion test was always given immediately at the beginning of the experimental session. Therefore, it cannot be stated with certainty that the effect attributed to delay between encoding and test is either strictly due to delay or is the entire effect of delay. Nevertheless, this analysis of delay yields the same qualitative results as the comparison between Experiments 1 and 2: As delay between encoding and test increases, the effect of multiple over single repetitions decreases. Again, this finding conflicts with our intuitions described in the introduction.

An analysis of how word reading response times changed as a function of delay encounters the same difficulty as the analysis of word fragment completion. For the word reading tests, the advantage in response times for multiply over singly presented words had no systematic trend (19 ms at immediate test, -4 ms at 2 weeks, 9 ms at 6 weeks), $F(2,65) = 2.82$, $MSE = 1,185$, $p < .10$. (These differences did not reliably interact with normative word frequency, $F < 1$.) Because this variation may be a combination of the effect of experimental fatigue or duration combined with delay, we made no interpretation of these results.

Discussion

The results of Experiment 2 replicate and extend the results of Experiment 1, namely that multiple repetitions of a word can improve performance beyond that of a single presentation in implicit memory tasks. This effect was shown in tests completed immediately after study and up to six weeks later. Additionally we found that SAC's prediction that low-frequency words should be more strongly influenced by multiple repetitions than high-frequency words was also confirmed. By showing these effects using two different implicit tasks, we provide converging evidence that implicit memories are indeed strengthened beyond the first repetition.

SAC's prediction that the number of experimental presentations will have a greater influence on low- than on high-frequency words relies on the power function shown in Equation 1. The power function predicts that each repeated presentation will yield diminishing returns, and it does not distinguish between pre-experimental and experimental presentations. Hence, each presentation of a high-frequency word tends to have a smaller impact in memory than a presentation of a low-frequency word, all else being equal.

Experiments 1 and 2 both showed that implicit memory is affected by repeated presentations beyond the first presentation. This was shown in tasks that measured word fragment completion and that measured word reading times. Experiment 1 showed that these effects can endure for up to 18 months after encoding one or more presentations. Experiment 2 showed that low-frequency words yield greater implicit memory effects than do high-frequency words.

Because the results of these experiments show that implicit memory is qualitatively affected by multiple repetitions of a word in the same way as explicit memory, it is important to verify that participants were not using explicit strategies. In Experiment 1 it is clear that participants could not have been relying on explicit memories inasmuch as none of them associated the fragment completion task with the encoding task while they were performing the fragment completions. The first item on the questionnaire asked if completing the experiment had given the participants had any idea why they were invited to take part in the study, and not one of them responded affirmatively. Had they been explicitly scanning memory for words from the encoding task, it seems likely that they would have been able to state the association between the two experimental sessions. Given the long delay and the complete change of context (i.e., new room, procedure, and experimenter), this lack of connection is not surprising.

In Experiment 2, because the participants were told that the experiment consisted of two sessions, the association between the two tasks was more obvious. Nevertheless, two factors argue against accounting for the results with explicit memory. The first is that the same results were obtained using word reading as well as fragment completion procedures. Whereas it is conceivable that participants could have been using an explicit strategy during the fragment completion task, an explicit strategy would have only slowed responses in the word reading task. The second is that even using a fragment completion procedure similar to ours, dissociations between implicit and explicit memories have been found (Roediger et al., 1992). Hence, it cannot be the case that fragment completion procedures are inherently corrupted by intrusions from explicit memory.

Using two different tasks to measure implicit memory within Experiment 2 was also important to allow for comparison. The results found using fragment completion mirrored those found using word reading time with one exception: Whereas fragment completion indicated that participants' performance improved with many presentations of a word compared to just a single presentation for both high- and low-frequency words, the word reading task only indicated improvement for low-frequency words. Two principle explanations of this finding should be considered. The more interesting explanation is that the word reading task is more sensitive to the relative differences in memory strength than is fragment completion. This might be because the fragments used in the fragment completion task are normalized to yield approximately equal baseline levels of completion for both high- and low-frequency words. Thus, the result might be due to the normalization process that systematically changes the relation between the availability of a memory and the probability of correctly completing a word fragment for high- and low-frequency words. The less interesting explanation is that no improvement was found for high-frequency words in the word reading task because of a ceiling effect. Because the words were so familiar and so easy to read, prior presentations had no discernable effect on performance. This can be resolved in future studies by limiting the input process, for example, by decreasing the duration of the word presentation or reducing the contrast of the words against the background.

Whereas many dissociations have been shown between implicit and explicit memory, the experiments presented in this article demonstrate a similarity between the two: Implicit and explicit memory tasks are both strengthened by multiple presentations of a word beyond the level to which they are strengthened by single presentations. Moreover, Experiment 2 showed that the degree to which this strengthening occurs depends upon the normative frequency of the word.

Theoretical Implications

Although the experiments presented in this article were motivated by the theoretical predictions of SAC, the purpose of this article is principally empirical. Nevertheless, the findings of this study do have theoretical consequences that should be discussed. First, the results of the foregoing experiments accord with the predictions of SAC as outlined in the introduction, and they do not support theories that claim that either multiple repetitions or normative word frequency affect only explicit memories, not implicit memories. To review, SAC posits that performance differences between implicit and explicit tasks are due to the reliance on episodic traces, such that tasks that tap explicit memory generally rely on retrieval of episodic information. Implicit tasks rely on availability of conceptual and perceptual information assumed to be associated with the word node (see Figure 1).

SAC predicts that memories in both implicit and explicit tasks should be strengthened by multiple repetitions because it assumes that the principles of strengthening and decay that govern the two types of memories are the same. It also predicts that low-frequency words should be primed more than high-frequency words on each presentation because low-frequency words are not as far out on their power-function growth curves (see Equation 1).

Using the remember–know paradigm, Gardiner and Java (1990) found no effect of normative word frequency on “know” responses (recognition responses that indicate “old” because of familiarity) but they did find an effect of word frequency on “remember responses (“old” responses attributed to recollection of the event of perceiving the word). They inferred from this finding that “know” responses are generated by a separate memory system. They concluded that this memory system must be separate from the explicit memory system, that it must be one that bears no trace of encoding events such as the implicit memory system proposed by Hayman and Tulving (1989). The finding in Experiment 2 that word frequency did affect performance in implicit memory tasks the same way as in explicit tasks places Gardiner and Java’s contention into question.

The success of any empirical result providing support for a theory of implicit verses explicit performance that posits only a single memory system cannot disprove a multiple memory systems account. A multiple systems account simply has more flexibility (i.e., more degrees of freedom) with which it can account for empirical facts. Nevertheless, as studies continue to be published showing qualitatively similar behaviors in implicit and explicit memory tasks, parsimony argues for a common memory system. Among the studies that find substantial similarities between explicit and implicit behavior are: McBride and Dosher’s (1997) finding that the functional form and the rate of forgetting were the same for implicit and explicit tasks, Green’s (1990) finding that people show spacing effects in implicit memory tasks, MacLeod’s (1989b) finding that directing participants to forget influences performance in both implicit and explicit tasks, and Jacoby’s (1983) finding that reinstatement of the study context enhances implicit and explicit memory.

Although no theory of implicit memory has been successfully extended to provide complete accounts of all the implicit memory phenomena, the representational and procedural assumptions of single memory system theories establish a promising foundation for further inquiries.

References

Ayers , M. S, & Reder, L. M. (1998). A theoretical review of the misinformation effect: Predictions from and activation-based memory model. *Psychonomic Bulletin and Review, 5,* 1–21.

Bahrick, H. P. (1979). Maintenance of knowledge: Questions about memory we forget to ask. *Journal of Experimental Psychology: General, 108,* 296–308.

Challis, B. H., & Sidhu, R. (1993). Dissociative effect of massed repetition on implicit and explicit measures of memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 115–127.

Cohen, J. D., MacWhinney, B., Flatt, M., & Provost, J. (1993). PsyScope: A new graphic interactive environment for designing psychology experiments. *Behavioral Research Methods, Instruments & Computers, 25,* 257-271.

Coltheart, M. (1981). The MRC Psycholinguistic Database. *Quarterly Journal of Experimental Psychology Human Experimental Psychology, 33A* (4), 497-505.

Gardiner, J. M., & Java, R. I. (1990). Recollective experience in word and nonword recognition. *Memory and Cognition, 18,* 23–30.

Glenberg, A. M. (1976). Monotonic and nonmonotonic lag effects in paired-associate and recognition memory paradigms. *Journal of Verbal Learning and Verbal Behavior, 15,* 1–16.

Graf, P., & Schacter, D. L. (1985). Implicit and explicit memory for new associations in normal and amnesic subjects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 11,* 501–518.

Grant, S. C. & Logan, G. D. (1993). The loss of repetition priming and automaticity over time as a function of degree of initial learning. *Memory and Cognition, 21,* 611–618.

Hayman, C. G., & Tulving, E. (1989). Is priming in fragment completion based on a “traceless” memory system? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 941–956.

Hintzman, D. L., & Hartry, A. L. (1990). Item effects in recognition and fragment completion: Contingency relations vary for different subsets of words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 955–969.

Jacoby, L. L. (1983). Perceptual enhancement: Persistent effects of an experience. Journal of Experimental Psychology: Learning, Memory, and Cognition, 9, 21–38.

Jacoby, L. L., & Dallas, M. (1991). On the relationship between autobiographical memory and perceptual learning. *Journal of Experimental Psychology: General, 110,* 306–340.

Jacoby, L. L., Witherspoon, D. (1982). Remembering without awareness. *Canadian Journal of Psychology, 36,* 300–324.

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

MacLeod, C. M. (1989a). Word context during initial exposure influences degree of priming in word fragment completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 398–406.

MacLeod, C. M. (1989b). Directed forgetting affects both direct and indirect tests of memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 13–21.

McBride, D. M., & Dosher, B. A. (1997). A comparison of forgetting in an implicit and explicit memory task. *Journal of Experimental Psychology: General, 126,* 371–392.

Parkin, A. J., Reid, T. K., & Russo, R. (1990). On the differential nature of implicit and explicit memory. *Memory and Cognition, 18,* 507–514.

Perruchet, P. (1989). The effect of spaced practice on explicit and implicit memory. *British Journal of Psychology, 80,*113–130.

Reder, L. M., Nhouyvansivong, A., Schunn, C. D., Ayers, M. S., Angstadt, P. & Hiraki, K. (1997). Modeling the mirror effect in a continuous remember/know paradigm. *Proceedings of the Nineteenth Annual Meeting of the Cognitive Science Society* (pp. 644–649). Mahwah, NJ: Erlbaum.

Reder, L. M., Nhouyvansivong, A., Schunn, C. D., Ayers, M. S., Angstadt, P. & Hiraki, K. (1998). A mechanistic account of the mirror effect for word frequency: A computational model of Remember/Know judgments in a continuous recognition paradigm. Manuscript submitted for publication.

Reder, L. M., & Schunn, C. D. (1996). Metacognition does not imply awareness: Strategy choice is governed by implicit learning and memory. In L. M. Reder (Ed.), *Implicit memory and metacognition* (pp. 45–77). Hillsdale, NJ: Erlbaum.

Roediger, H. L., & Challis, B. H. (1992). Effects of exact repetition and conceptual repetition on free recall and primed word-fragment completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 3–14.

Roediger, H. L., Weldon, M. S., Stadler, M. L., Riegler, G. L. (1992). Direct comparison of two implicit memory tests: Word fragment and word stem completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 1251–1269.

Schacter, D. L. (1987). Implicit memory: History and current status. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13,* 501–518.

Schunn, C.D., Reder, L.M., Nhouyvanisvong, A., Richards, D.R & Stroffolino, P. J. (1997). To calculate or not to calculate: A source activation confusion model of problem familiarity's role in strategy selection. *Journal of Experimental Psychology: Learning, Memory, Cognition, 23(1),* 3–29.

Shepard, R. N., & Teghtsoonian, M. (1961). Retention of information under conditions approaching a steady state. *Journal of Experimental Psychology, 62,* 302–309.

Shimamura, A. P. (1986). Priming effects in amnesia: Evidence for a dissociable memory function. *Quarterly Journal of Psychology, 38A,* 619–644.

Sloman, S. A., Hayman, C. A. G., Ohta, N., Law, J., & Tulving E. (1988). Forgetting in primed fragment completion. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 223–239.

Tenpenny, P., & Shoben, E. J. (1991). Component processes and the utility of the conceptually-driven/data-driven distinction. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 25–42.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychologist, 26,* 1-22.

Tulving, E., Hayman, C. A. G., & Macdonald, C. A. (1991). Long-lasting perceptual priming and semantic learning in amnesia: A case experiment. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 595–617.

Tulving, E., Schacter, D. L., & Stark, H. A. (1982). Priming effects in word-fragment completion are independent of recognition memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 8,* 336–342.

Appendix

Words and Fragments Used in Experiments 1 and 2. H and L represent high- or low-frequency words, respectively.

Item	Freq.	Fragment
abscissa	L	ab _ci _ _a
analysis	H	_ _al _ _is
answer	H	a _ _we _
asbestos	L	a _ _est _s
asphalt	L	_s _h _lt
astringent	L	_str _ _gen _
attention	H	a _te _t _o _
attitude	H	_t _ _tu _e
authority	H	_u _h _ri _y
basis	H	b _ _is
bassinet	L	b _ _s _n _t
bridge	H	b _ _dg _
broom	L	_r _om
butterfly	L	_u _t _ _f _y
casino	L	c _s _ _o
century	H	_en _u _y
chance	H	_h _nc _
chaperon	L	_h _per _n
child	H	_h _ld
childbirth	L	_h _ _db _r _h
chorale	L	ch _ral _
chute	L	_hu _e
colossus	L	c _l _ _s _s
commando	L	_omm _n _o
concentric	L	c _nc _ _t _ _c
conjecture	L	c _ _j _c _u _e
connection	L	_o _n _c _io _
council	H	_o _nci _
crater	L	c _at _r
creamery	L	cr _am _ _y
creeper	L	c _ _ep _r
crocodile	L	c _ _c _ _il _
cruise	L	c _ui _ _
decision	H	_ec _ _i _n
defense	L	_ef _n _e
deltoid	L	de _toi _
department	H	_ep _ _t _ _nt
dilatation	L	dil _tat _o _
director	H	_ir _c _ _r
discussion	H	_ _scu _s _ _n
distance	H	_is _a _c _
district	H	d _s _ric _
division	H	_iv _s _ _n
dodger	L	d _dg _ _
dragon	L	d _ _g _n
effort	H	_ _f _rt
embryo	L	e _br _ _
enervation	L	en _rv _t _ _n
equipment	H	_qu _ _m _ _t
eraser	L	_r _s _r
evidence	H	_v _ _enc _
existence	H	_xi _t _ _c _
figure	H	_ig _re
freedom	H	f _ _e _om
gayety	L	g _yet _
glass	H	_las _
grievance	L	g _ _ _v _nc _
health	H	h _a _th
image	H	_ma _e
importance	H	i _ _ort _ _c _
income	H	_nc _m _
indolence	L	i _d _l _nc _
inferno	L	i _fe _n _
influence	H	_n _lu _ _c _
infusion	L	i _f _s _ _n
inmate	L	_nm _t _
inside	H	i _ _id _
irrigation	L	i _ _iga _ _o _
island	H	_sl _ _d
justice	H	_us _ic _
kinship	L	_in _h _p
kitchen	H	ki _c _e _
language	H	_a _ _u _ge
length	H	_e _gt _
letter	H	le _t _ _
lumbar	L	lu _ba _
luxuriance	L	l _xu _ _a _c _
market	H	m _r _ _t
mascara	L	m _sc _ _a
member	H	_e _b _r
modern	H	_od _r _
mother	H	_o _he _
movement	H	m _ _e _ _nt
mushroom	L	_us _r _om
nation	H	n _ _i _n
nature	H	na _u _ _
nocturne	L	n _ct _ _n _
objective	H	ob _ec _i _e
oracle	L	o _ac _ _
palsy	L	p _l _y
parsimony	L	p _rsi _o _y
party	H	pa _t _
plane	H	_l _ne
planner	L	pl _ _ne _

Item	Freq.	Fragment
policy	H	_ol _cy
process	H	_ _oc _ _s
property	H	_ro _e _ty
proton	L	_r _to _
quality	H	qu _ _ _ty
radiation	H	_ad _at _o _
rafter	L	r _f _ _r
recurrence	L	r _c _ _r _nc _
respect	H	r _s _ec _
scavenger	L	_c _ve _g _r
science	H	_ _ie _c _
scoundrel	L	s _o _ _dr _l
security	H	s _cu _i _y
septic	L	s _p _ _c
skewer	L	ske _ _r
sojourner	L	so _o _rn _r
solicitude	L	s _lic _tu _e
sorrel	L	s _rr _l
source	H	so _ _c _
spirit	H	s _ir _t
staff	H	_ta _f
statement	H	_ta _ _m _ _t
student	H	_tu _ _nt
subject	H	_ub _ec _
sublime	L	_ _b _im _
suburbia	L	s _ _u _b _a
syllable	L	_yl _a _l _
table	H	ta _l _
thesaurus	L	t _es _u _ _s
trench	L	t _ _n _h
trouble	H	_ro _bl _
union	H	u _ _ _n
value	H	_a _ue
vegetation	L	_eg _ta _ _o _
vernal	L	v _rn _ _
viscount	L	v _sc _ _nt
volition	L	v _li _ _o _
volume	H	vo _ _m _
wager	L	_ag _r
weight	H	we _ _h _
yeast	L	y _a _t