When Forgetting Helps Memory: An Analysis of Repetition Effects

LAUREN J. CUDDY AND LARRY L. JACOBY

McMaster University

For the processing of an item to be repeated, it is argued that the memory for a prior presentation of that item must not be readily accessible when the item is repeated. Varying the spacing of repetitions corresponds to a manipulation of retention interval and is only one of several means of varying the accessibility of memory for a prior presentation. Factors such as the similarity of repetitions, the type of intervening material, and cue effectiveness are also shown to influence the processing of repetitions through their effects on accessibility. The experiments that are reported reveal interactions between each of these latter variables and the spacing of repetitions. The results are discussed with relevance to previous accounts of the effect of spacing repetitions, and a more general account of repetition effects is offered.

In a classic paper, Melton (1967) described the effect of spacing repetitions as paradoxical in that it seems to suggest that forgetting helps memory. As the spacing of repetition increases, a subject is less likely to recognize an item as being a repetition; however, when a later test of retention is given, performance is higher when repetitions of an item are spaced rather than being massed during study. Since Melton's paper, a great deal of research and theorizing have been directed toward explaining the effect of spacing repetitions (see Hintzman, 1974, for a review). Rather than focussing on the effect of spacing repetitions, however, we take Melton's paradox very seriously by investigating the effects of forgetting on the magnitude of repetition effects. It may simply be necessary for an item to be partially forgotten or not readily accessible for a repetition of that item to be maximally effective. If so, theorizing should center around the question of why repetition effects depend on forgetting rather than around the effect of spacing repetitions. Increasing the spacing of repe-

This research is based upon a MA thesis conducted by the first author, and was supported in part by Grant A0281 from NSERC to the second author. Requests for reprints should be sent to Larry L. Jacoby, Department of Psychology, University of Utah, Salt Lake City, Utah 84112. titions is not the only means of producing forgetting or decreasing the accessibility of the memory for an item; effects similar to those of spacing repetitions might be produced by manipulating other factors that influence the accessibility of the memory for a prior presentation of an item when that item is repeated.

Jacoby (1978) argued that remembering a prior presentation of an item when that item is repeated allows a subject to bypass much of the processing of the repetition that would otherwise be required. A series of experiments conducted by Jacoby demonstrated that remembering a prior presentation of an item can reduce subsequent retention performance. In a first phase of those experiments, a context word was presented along with letters and a series of blanks representing the missing letters of a word that was related to the context word (e.g., FOOT S--E). The subject's task was to solve the puzzle by reporting the related word that could be produced by restoring the missing letters. In a second phase, the context word was given as a cue for recall of the solution word. In some conditions, the task of giving a solution to the problem in the first phase was trivialized by presenting the context word with the completed solution word immediately prior to the puzzle (e.g., FOOT SHOE: FOOT S--E). In

those conditions, subjects did not have to actually solve the puzzle but could respond by simply remembering the previously read solution. In other conditions, several problems intervened between the reading of a solution and presentation of the problem requiring that solution. The memory of the previously read solution should be less accessible in these latter conditions so that more processing is necessary to obtain a solution for the presented problem; subsequent retention performance was expected to benefit from this additional processing. In line with these expectations, cued recall was found to increase with increased spacing of the reading of a solution and presentation of the problem requiring that solution. Conditions that were less favorable for remembering the previously read solution when a problem was presented led to higher subsequent recall.

In the experiments to be reported, we employed the procedure used by Jacoby (1978) but manipulated factors in addition to spacing to influence the accessibility of the memory for a prior presentation of an item when that item was repeated. Spacing of repetitions corresponds to a manipulation of the retention interval between the presentation of an item and its repetition. It is well established that the effects of increasing retention interval depend on the similarity of the material presented during the retention interval to the material that is to be remembered. In Experiment 1, the similarity of the material that intervened between the presentation of a solution and the problem requiring that solution was manipulated. The two were separated by the presentation of other word problems so that the intervening material was similar, or by addition problems so the intervening material was dissimilar to the previously presented solution. A second factor that influences the accessibility of a memory is the cues provided at the time of test. In Experiments 2 and 3, problems were repeated with a problem being either identical or altered across repetitions. An identical repetition was expected to serve as a better cue for retrieval of the prior presentation of that problem than was presentation of an altered version of the problem. In all experiments, conditions that were less favorable for remembering a prior presentation of an item when that item was repeated were expected to lead to higher subsequent cued recall. In the general discussion, we consider the relevance of the results of these experiments to accounts of the effects of spacing repetitions and other memory phenomena.

EXPERIMENT 1

Method

Design and subjects. The subjects were 18 students enrolled in an introductory psychology class who received course credit for participating in the experiment. Subjects were tested individually.

In the first phase of the experiment, subjects read pairs of related words in which the second member of the pair was presented either intact or missing letters (e.g., TREE: BR--CH). When letters were missing, the subject was to say the word that resulted from restoring the missing letters. Within the list, some pairs of words were repeated. Half of these repeated pairs were presented intact to be read on both presentations (Read-Read); the other half were intact on their first presentation but the right-hand member of the pair was missing letters on its second presentation (Read-Construct).

Repetitions of a pair were separated by either zero, four, or eight intervening items. The intervening items at four and eight spacings were either pairs of related words with letters missing from the right-hand member of the pair, similar to repeated items, or addition problems. Type of intervening item was factorially combined with the longer spacings (four vs eight intervening items) and type of repetition (Read-Read vs Read-Construct). All factors were manipulated within subjects. In the second phase of the experiment, subjects were provided with the left-hand members of repeated pairs, and asked to recall the right-hand members of those pairs.

Materials. The materials included 144 pairs of related words that were chosen from the Connecticut free-association norms (Bousfield, Cohen, Whitmarsh, & Kincaid, 1961). The right-hand member of each pair was approximately the third highest associate of the left-hand member of that pair and was from 4 to 8 letters in length. Of these pairs, 48 pairs were critical in that they were repeated within a list. Twenty-four of the pairs were presented intact to be read on each of their two presentations; the remaining 24 critical pairs were each presented intact for their first presentation but with two letters deleted from their right-hand member for their second presentation. Deleted letters were replaced by dashes. For both critical and noncritical pairs, neither the first nor the last letter of a word was ever deleted. A set of 96 addition problems completed the materials employed to construct lists. The addition problems required the addition of a single-digit number to a two-digit number; problems were selected to be nonoverlapping in two-digit numbers and to be at an approximately uniform level of difficulty.

Study lists were constructed by typing pairs of related words and addition problems on notecards. A study deck contained 288 cards: 24 pairs repeated intact (Read-Read), 24 pairs presented intact and then presented with letters from the right-hand member of the pair deleted (Read-Construct); 96 noncritical pairs; and 96 addition problems. Among repeated pairs, 16 pairs were presented at each of the three levels of spacing of repetitions, (zero, four, and eight). At each of the two longer spacings, half of the repeated pairs were separated by noncritical pairs and half were separated by addition problems. Twelve list formats were constructed such that across formats each pair equally often represented each of the combinations of spacing, type of intervening item, and type of repetition. Six

of these lists were presented to two subjects while the remaining six lists were presented to one subject. An attempt was made to evenly distribute items representing the different forms and spacing of repetitions throughout a study list so that no class of items would differentially benefit from any serial position effects. A cued-recall test sheet contained the left-hand member of the 48 critical repeated pairs as a cue for recall of the right-hand member of those pairs. The order of items in the test list was random.

Procedure. In the first phase of the experiment, subjects were informed that we were investigating their reaction time for solving problems of different types. They were instructed to go through the deck of cards one by one, pushing a button to allow recording of their reaction time as they announced the solution to the problem on each card. Subjects read both words aloud for the verbal problems, restoring deleted letters when necessary, and gave the sum for addition problems. A timer placed subjects through the cards by producing a tone every 6 seconds; subjects were to use the tone as a signal to turn the next card. In reality, reaction times for solving problems were not recorded.

After subjects had progressed through all of the cards, there was a brief period during which the experimenter recorded the subject's name and student number. Next, the subject was given an unexpected test of cued recall. Completion of the cued-recall test was subject paced.

The level of significance for all statistical tests was set at p < .05.

Results and Discussion

In the first phase of the experiment, only one error occurred in restoring missing letters to construct a response for pairs repeated in the Read-Construct condition. For noncritical items, more errors were made solving verbal intervening items ($\bar{X} =$ 6.67) than solving math problems that intervened between repetitions ($\overline{X} = 2.39$), t(17) = 4.27.

Of greater interest were the cued-recall results from the second phase of the experiment. For a first analysis of those results, performance was collapsed across the different types of intervening material at the two longer spacings of repetitions to produce only spacing of repetitions and repetition condition (Read-Read vs Read-Construct) as factors. This analysis revealed a significant effect of spacing repetitions, F(2,34) = 5.65, MSe = 1.24, and repetition condition, F(1,17) = 16.28, MSe = 1.60, as well as a significant interaction between these two variables, F(2,34) =64.71, MSe = .44. As shown in Figure 1, there was an effect of spacing repetitions only in the Read-Construct condition. Recall levels were identical for the Read-Construct and the Read-Read conditions at zero spacing; however, the level of recall performance increased across the longer spacings of repetition in the Read-Construct condition while remaining relatively constant in the Read-Read condition.

The above results replicate results reported earlier by Jacoby (1978), and can be interpreted as showing that the effects of spacing repetitions depend on an influence



FIG. 1. Probabilities of correct cued recall from Experiment 1 for Read-Read (RR) and Read-Construct (RC) conditions as a function of spacing interval.

of memory for a prior presentation of an item on its later processing. In agreement with others (e.g., Slamecka & Graf, 1978), we argue that retention performance shows a benefit when subjects are required to construct a response or an encoding for an item. As the spacing of presentations is increased, the previously read solution becomes less accessible in the Read-Construct condition so that more problemsolving activity is required to arrive at a solution when a problem is presented. The processing required to read a word in the Read-Read condition, in contrast, is likely to be less than that required to construct a solution, and apparently remains relatively constant across spacings of repetitions. The interaction between spacing of repetitions and repetition conditions can be interpreted in terms of differences in the effectiveness of the second presentation of an item as a cue for retrieval of the memory of its first presentation. According to this suggestion, the second presentation of an item in the Read-Read condition is nominally identical to its first presentation and so corresponds to a test of recognition memory, whereas a pair is altered prior to its repetition in the Read-Construct condition and so its second presentation corresponds to a test of cued recall for memory of its earlier presentation. Due to greater cue effectiveness, accessibility provided by a test of recognition memory is less influenced by increases in retention interval (spacing) than is that provided by a test of cued recall. The greater influence of spacing on the accessibility of the memory for a prior presentation of an item in the Read-Construct condition produces larger differences in processing and, thereby, a more pronounced spacing effect than is found in the Read-Read condition. The interaction of spacing repetitions and differences in cue effectiveness is further examined in experiments reported later in this paper.

As well as depending on the spacing of repetitions, the accessibility of a previously

read solution in the Read-Construct condition was expected to depend on the material that intervened between presentation of a problem and its solution. A second analysis included only items that had been presented at longer spacings in the Read-Construct condition so as to examine the effect of similarity of intervening material. This analysis revealed both a significant effect of intervening material, F(1,17) =5.28, MSe = .01, and a significant interaction between type of intervening material and the spacing of repetitions, F(1,17)= 6.83, MSe = .01. In general, subsequent cued recall performance was higher when verbal items rather than addition problems intervened between a puzzle and its solution; that is, when the intervening material was similar to the previously presented solution. The advantage in probability of cued recall produced by presenting verbal intervening material rather than math problems was larger at a spacing of four intervening items (.69 vs .51) than at a spacing of eight intervening items (.65 vs .58). The interaction between spacing and type of intervening material would be explained if similar intervening material produced a steeper forgetting function than did dissimilar intervening material but a relatively small difference in the asymptotic level of accessibility. Differences in acessibility as a function of type of intervening material would then be maximal at shorter retention intervals (spacing) and decrease as retention interval was lengthened to approach the asymptotic level of accessibility. Again, by this analysis, conditions that are least conducive to gaining access to a previously read solution when a problem is repeated produce higher subsequent cued recall.

Since the verbal intervening problems were more difficult in that they produced more errors than did the addition problems, as well as being closer in similarity to the critical items, it is possible that differences in task difficulty are at least partially responsible for retention differences. Other studies have found increased retention when a difficult task rather than an easy one intervened between repetitions of an item (Bjork & Allen, 1970; Proctor, 1980; Robbins & Wise, 1972; Tzeng, 1973). Bjork and Allen accounted for their results by suggesting that a more difficult intervening task increased the probability that the second encoding of an item would be different from its first encoding. The primary difference between our interpretation and that of Bjork and Allen is that we place greater emphasis on the processing of later presentations of a repeated item. The importance of this difference between interpretations will be described in the general discussion.

EXPERIMENT 2

Experiment 2 employed the same general procedure as did Experiment 1. Rather than manipulating the material intervening between presentations of a problem and its solution, however, the similarity of the presentations of repeated problems was manipulated in Experiment 2. The memory for a previously obtained solution to a problem was expected to be more accessible when the later presentation of the problem was similar rather than dissimilar to the earlier presentation of that problem. An example from each of the four repetition conditions employed in the first phase of Experiment 2 is given in Table 1. These four repetition conditions were factorially combined with two levels of spacing repetitions (0 vs 20 intervening items) to produce eight experimental conditions.

As shown in Table 1, items presented in the first phase of the experiment were divided among four repetition conditions, requiring construction of a solution for a problem on the first presentation, the second presentation, or on both presentations of a problem. In a Construct-Construct/ Different condition, different letters were deleted upon each presentation of a problem, while the same letters were deleted upon each presentation of a problem in the

Condition	First presentation	Second presentation
Read-Construct (RC)	LAWYER COURT	LAWYER CRT
Construct-Read (CR)	LAWYER CRT	LAWYER COURT
Construct-Construct/Same (CCs)	LAWYER CRT	LAWYER CRT
Construct-Construct/Different (CC _D)	LAWYER CRT	LAWYER COU

 TABLE 1

 PRESENTATION CONDITIONS AND EXAMPLES FROM EACH CONDITION FOR EXPERIMENT 2

Construct-Construct/Same condition. Changing the form of a problem between its presentations was expected to make the previously constructed solution less accessible when the problem was repeated. That is, the altered form of the problem was expected to be a poorer cue for retrieval of the previously constructed solution than would be an exact repetition of the problem. Due to this difference in accessibility, constructive processes are more likely to be involved in solving the second presentation of a problem in the Construct-Construct/ Different condition than in the Construct-Construct/Same condition, at least when repetitions of a problem are widely spaced. Even when repetitions are widely spaced, an exact repetition of a problem may be so effective as a cue for retrieval of an earlier constructed solution that responding to the problem for a second time involves little more processing than would simply reading a solution for that problem. This possibility leads to the prediction that the processing required to deal with a repetition, and consequently, subsequent retention performance will be approximately equal in the Construct-Construct/Same and the Construct-Read conditions exemplified in Table 1.

Additional comparisons between conditions in Table 1 allow assessment of the persistence of the effect of reading a solution to a problem prior to being presented with that problem. In the Read-Construct condition, subjects first read an intact version of a pair and were then presented with a fragmented version of that pair as a problem to be solved. In the Construct-Read

condition, in contrast, subjects were first presented with the fragmented version of the pair, being required to construct a solution, and then read the intact version of the pair. This second condition had the same number of exposures of the solution as did the first condition, but reading the solution came later so it could not trivialize the solving of the problem and, thereby, lower subsequent cued-recall performance. When a solution to a problem is read long before presentation of the problem requiring that solution, subsequent cued-recall performance in the Read-Construct condition might converge with that in the Construct-Read condition. This is because at longer intervals the previously read solution may no longer be easily remembered, so it will not trivialize responding to the later problem. To account for effects of the order of events, influences on processing must be considered. Any advantage in subsequent cued-recall performance of the Construct-Read condition over the Read-Construct condition must be due to an influence of memory for a prior presentation of an item on its later processing.

Method

Design and subjects. Experiment 2 employed the same crossword puzzle task as did Experiment 1. The four repetition conditions illustrated in Table 1 were factorially combined with two levels of spacing of repetitions (0 vs 20 intervening items). Both factors were manipulated within subjects so that each subject served in each of the eight experimental conditions.

The subjects were 16 students enrolled in

an introductory psychology course who served in the experiment for course credit.

Materials and procedure. The 96 pairs of words that served as critical items were drawn from the same word pool as items in Experiment 1. Each of the eight experimental conditions resulting from the combination of repetition condition and spacing of repetitions was represented by 12 pairs within a list. To produce word problems, two letters were deleted from the right-hand member of a pair; the first letter of a word was never among the deleted letters. To produce problems for the Construct-Construct/Different condition, pairs were used to produce two problems that differed only in the letters that were deleted. The construction of lists employed 96 additional pairs of words that were noncritical in that their recall was not tested; they appeared in a study list intervening between repetitions of a critical item. The left-hand member of each of these noncritical pairs was repeated and repetitions were made to appear similar to those in the Construct-Construct/Different condition. For noncritical pairs, however, each presentation of a pair containing a particular context word required a different solution word. For example, intervening pairs might be "RIGID ST--F" followed by "RIGID ST--CT"; solution words for these pairs are STIFF and STRICT, respectively. The similarity of noncritical pairs to critical pairs was expected to encourage subjects to attend to the letters of a solution word that were provided when a problem was repeated. Eight list formats were produced such that across formats each pair of critical items equally often represented each of the combinations of spacing and form of repetitions. The noncritical items intervening between repetitions of critical items were held constant across formats.

The procedure followed was the same as that in Experiment 1. Subjects were paced through the 288 cards, with one pair of items presented on each card, at a rate of 6 seconds per card. In the second phase of the experiment, subjects were given a cued-recall test which contained the context words from the 96 critical items as cues for recall of the solution words from those items.

Analyses. The manipulation of repetition conditions in the first phase of the experiment would be expected to influence the probability of a subject correctly solving a presented problem. For example, when the solution to a problem is presented prior to that problem as in the Read-Construct condition, subjects should be more likely to give the correct solution for the problem than when the solution has not been previously presented. Consequently, differences in cued recall may reflect differential exposure to solution words produced by differences in the probability of correctly solving problems. At the extreme, subjects cannot be expected to recall a word that they failed to generate and, therefore, never encountered in the first phase of the experiment. To counter this difficulty, the cued-recall data that are reported were conditionalized on correct responding in phase 1 of the experiment. Unconditionalized data were also analyzed but are not reported since both the direction of results and conclusions drawn are the same for conditionalized and unconditionalized data.

Results and Discussion

There were very few errors in solving problems in the first phase of the experiment. Differences in the probability of an error, however, did provide some evidence of an effect of memory for a previously presented solution. The probability of an error in the Construct–Read condition was .09 while that in the Read–Construct condition was .01, so previously reading a solution to a problem did decrease the probability of an error when the problem was later presented. The probability of an error on the second presentation of a problem in the Construct–Construct/Same and the Construct–Construct/Different condition were .06 and .02, respectively. Contrary to expectations, reducing the similarity of repetitions apparently did not reduce access to memory for a prior presentation of an item and, thereby, produce more errors when that item was repeated.

The cued-recall results from the second phase of the experiment are plotted in Figure 2. Analysis of these results revealed a significant effect of repetition condition, F(3,45) = 23.04, MSe = .02, and an effect of spacing repetitions, F(1,14) = 111.38, MSe = .01, as well as a significant interaction between repetition condition and the spacing of repetitions, F(3,45) = 7.02, MSe = .01.

Consistent with predictions made earlier, the effect of spacing repetitions was more pronounced in the Read-Construct condition than in the other repetition conditions. As in Experiment 1, the spacing effect in the Read-Construct condition can be interpreted as being due to the previously read solution becoming less accessible due to increases in spacing. Further processing is required to solve a problem as spacing is increased and retention benefits from this further processing. If memory for the pre-



FIG. 2. Probability of correct cued recall for conditionalized data of Experiment 2 for Read-Construct (RC), Construct-Read (CR), Construct-Construct/ Same (CC_s), and Construct-Construct/Different (CC_p) conditions as a function of spacing interval.

viously read solution were to become totally inaccessible, the processing required to solve a problem in the Read-Construct condition should not differ from that required to solve a problem in the Construct-Read condition, and, consequently, cued-recall performance in the two conditions should be equal. Even the longer spacing of presentations employed in the experiment, however, was insufficient to produce equality of these two conditions in cued-recall performance. The effect of previously reading a solution can apparently persist over a relatively long period of time to influence the processing required to solve a later problem, and reduce subsequent retention performance.

It was earlier suggested that an exact repetition of a problem can be a very effective cue for retrieval of a previously constructed solution so that little processing may be required to allow responding to a second presentation of a problem. In line with this suggestion, cued-recall performance in the Construct-Construct/Same condition did not differ substantially from that in the Construct-Read condition. Even when repetitions were spaced, a previously constructed solution was apparently so readily accessible that the processing required to respond to an identical repetition of a problem differed little from that required to simply read the solution to that problem. Varying the form of a problem between its repetitions, in contrast, was expected to reduce the effectiveness of the second presentation of the problem as a cue for retrieval of the solution constructed on its first presentation, particularly when repetitions were widely spaced. This reduced accessibility was expected to necessitate further processing at the time of the second presentation of a problem to arrive at a solution, and, consequently, enhance subsequent retention performance. Performance in the Construct-Construct/Different condition was marginally superior but not significantly different from that in the Construct-Construct/Same condition. The effect of similarity of repetitions of a problem was further investigated in Experiment 3 in an attempt to magnify the effects observed in Experiment 2.

EXPERIMENT 3

Experiment 3 was identical to Experiment 2 with the exception that problems repeated in the Construct-Construct/ Different condition were altered to make their repetitions even more dissimilar. This change in materials was expected to increase cued recall of items presented in the Construct-Construct/Different condition while having little influence on recall from the other conditions.

Method

Design and subjects. The design of Experiment 3 was identical to that of Experiment 2. The subjects were 16 students enrolled in an introductory psychology class who served in the experiment for course credit.

Materials and procedure. Stimuli were identical to those employed in Experiment 2 with the following exceptions: First, the second presentation of an item in the Construct-Construct/Different condition was altered to appear as different as possible from the first presentation of that item. In contrast to Experiment 2, the first letter of the solution word was always present in the first presentation of a problem and deleted from the second presentation of a problem in Experiment 3 (i.e., Experiment 2: "LAWYER C--RT" and "LAWYER COU--; Experiment 3: "LAWYER C--RT" and "LAWYER -OUR-"). Second, items that appeared in the study list intervening between repetitions were altered to make them appear similar to items repeated in the Construct-Construct/Different condition. This change between experiments corresponded with the change in critical items. The second presentation of a noncritical context word was paired with a new solution word as in Experiment 2 but the pattern of deleted letters was changed to correspond with that of repetitions in the Construct-Construct/Different condition of Experiment 3 (i.e., Experiment 2: "JOSTLE SH-K-" and JOSTLE SH-V-"; Experiment 3: "JOSTLE SH-K-" and "JOSTLE --OVE").

The procedure, instructions, and cuedrecall test were identical for Experiments 2 and 3. As in Experiment 2, cued-recall performance was conditionalized on correctly responding to a problem in the first phase of the experiment. Unconditionalized scores were also analyzed but since the direction of differences and conclusions drawn were the same only conditionalized data are reported.

Results and Discussion

As in Experiment 2, the probability of an error in solving a problem during the first phase of the experiment reflected memory for a previously encountered solution. The probability of an error was higher in the Construct-Read condition (.086) than in the Read-Construct condition (.005). The probability of an error on the second presentation of a problem in the Construct-Construct/Same and Construct-Construct/ Different conditions were .062 and .10. The probability of an error in these latter two conditions was conditionalized on correct responding to a problem on its first presentation for further analyses. An analysis of those conditionalized probabilities of an error revealed both an effect of spacing repetitions, F(1,15) = 8.93, MSe = .003 and an effect of repetition condition, F(1,15) =5.36, MSe = .001. Given that a problem was solved correctly on its first presentation, changing the problem prior to its repetition served to increase the probability of an error as did increasing the spacing of repetitions. The conditionalized probability of an error at 0 and at 20 spacing in the Construct-Construct/Same condition were .004 and .022; the corresponding probabilities in the Construct-Construct/ Different condition were .047 and .069.

Mean probabilities of cued recall are dis-

played in Figure 3. The results of Experiment 3 generally support the findings of Experiments 2. Analysis of the cued-recall data revealed significant effects of repetition condition, F(3,45) = 28.43, MSe = .02, and the spacing of repetitions, F(1,15) =97.76, MSe = .01, as well as a significant interaction between those two variables, F(3,45) = 3.12, MSe = .02. As in Experiment 2, cued-recall performance in the Read-Construct condition was lower than that in the Construct-Read condition even at the longer level of spacing of repetitions. Although the previously read solution apparently became less accessible in the Read-Construct condition as the spacing of repetitions was increased, memory for the solution was still having some influence on processing of the later presented problem even at the longer spacing of repetitions. Of greater concern, the further reduction of the similarity of repetitions in the Construct-Construct/Different conditions had the predicted effect. At the longer spacing of repetitions, the Construct-Construct/Different condition produced substantially higher cued-recall performance than did the Construct-Construct/Same



FIG. 3. Probability of correct cued recall for conditionalized data of Experiment 3 for Read-Construct (RC), Construct-Read (CR), Construct-Construct/ Same (CC_s), and Construct-Construct/Different (CC_p) conditions as a function of spacing interval.

condition, F(1,15) = 9.47, MSe = .01. This difference between the Same and Different repetition conditions was also significant in the analysis of unconditionalized cued recall. As in Experiment 2, the Construct-Construct/Same and the Construct-Read conditions produced approximately equal levels of cued-recall performance.

The important comparison to make in Experiment 3 is of conditions that allow a solution to a problem to be easily retrieved or read (Construct-Construct/Same and Construct-Read) with conditions that require more extensive processing of the second presentation of an item when repetitions are spaced (Construct-Construct/ Different and Read-Construct). It appears that when exactly the same problem is encountered twice, the second presentation is treated essentially like items that are presented to be read. Processing of the second presentation is minimal in these conditions and that presentation does relatively little to enhance subsequent retention. On the other hand, the results of solving different forms of the same problem are much the same as those of constructing a solution that has been previously read. The effect of spacing repetitions was similar in the Construct-Construct/Different and the Read-Construct conditions although the Construct-Construct/Different condition held a large overall advantage due to the subjects having solved problems on their first presentation as well as their second. In both conditions, increasing the spacing of repetitions is seen as having the effect of making a previously encountered solution less accessible so that more processing is necessary to deal with a repetition of a problem; this additional processing enhances retention performance.

It should be noted that repetition condition was confounded with problem difficulty in the present experiment. For the second presentation of a problem in the Construct-Construct/Different condition, terminal letters were deleted while it was always interior letters that were deleted from the solution word to form problems in the Construct-Construct/Same condition. It might be argued that the deletion of terminal letters produced more difficult problems, and that the difference in problem difficulty rather than a difference in similarity of repetitions was responsible for the observed effects. Indeed, the error data from the first phase of the experiment provide evidence that the second presentation of a problem in the Different repetition condition was more difficult than that in the Same repetition condition. To account for the cued recall results in terms of differences in problem difficulty, however, it must be claimed that differences in difficulty were effective only when repetitions were widely spaced. It was only at the wider spacing that cued recall produced by the Construct-Construct/Different condition was superior to that produced by the Construct-Construct/Same condition. Any differences in problem difficulty as a function of the spacing of repetitions is likely to be attributable to differential accessibility to memory for a previously constructed solution to a problem when that problem is repeated. That is, when one has just constructed a solution to a problem prior to its being repeated, the solution to the problem is likely to be readily accessible so deleting initial letters from the solution word to produce a second version of the problem will not effectively increase problem difficulty. At the wider spacing of repetitions, memory for the previously constructed solution may be less accessible so the same manipulation does produce an effective increase in problem difficulty. When expanded in this fashion to account for the interaction of repetition condition and spacing, the account of results in terms of problem difficulty is similar to an account in terms of differential cue effectiveness. For both accounts, the lack of a significant interaction between repetition condition and spacing in the error data from the problem-solving phase of the experiment poses a difficulty. The increase in number of errors as a function of spacing should have been larger in the Different than in the Same repetition condition. The probability of an error in solving problems was low in all conditions so that measures may have simply been to insensitive to detect an interaction between spacing and repetition conditions.

By the cue effectiveness account, the second presentation of a problem serves as a cue for memory of its first presentation and the similarity of repetitions influences cue effectiveness. By the problem difficulty account, in contrast, it might be claimed that at the wider spacing of repetitions a problem is solved without reference to its prior presentation, and it is the difficulty of the problem, solved in isolation, that is important for later retention. Results reported by Jacoby (1978, Expt. 2) are useful for choosing between these two alternative accounts. That experiment employed procedures similar to those employed in the present experiment but deleted either one or two interior letters from target words to vary problem difficulty. Problems were presented only once to be solved or were preceded by a presentation of an intact version of the pair that was to be read prior to the problem being presented to be solved, as in the Read-Construct condition of the present experiment. In the Read-Construct conditions, the spacing of repetitions was also varied. The manipulation of problem difficulty was successful in that deleting two interior letters produced more errors than did deleting one interior letter when pairs were presented only as a problem to be solved. Despite this effect on errors, subsequent cued recall of those once presented items was not influenced by the manipulation of problem difficulty. In the Read-Construct conditions, memory of a prior presentation influenced the later solving of the more difficult problems as shown by a reduction in errors in solving those problems as compared to the corresponding once-presented condition in which a pair was not previously read. In contrast to the results obtained for oncepresented items, the manipulation of problem difficulty did influence subsequent cued recall in the Read-Construct conditions. At the wider spacing of repetitions, the more difficult problems produced substantially higher subsequent cued recall than did the easier problems. That the effect of problem difficulty in subsequent cued recall was confined to the repetition conditions and was then only substantial at wider spacings, implies that cue effectiveness played a critical role in producing those results, and supports the argument that it was cue effectiveness rather than problem difficulty without reference to a prior presentation of a problem that was important for producing the results of the present experiment.

Regardless of whether the cue effectiveness or problem difficulty account of the results is favored, it is clear that memory for a prior presentation of an item did play some role in producing the results. By both accounts, it is the accessibility of memory for a prior presentation that was responsible for eliminating the difference between the Same and Different conditions when repetitions were massed. A useful direction for future research may be to further investigate the effect of problem difficulty and the sequencing of problems. In an investigation of the effects of spacing repetitions, Landauer and Bjork (1978) found that a sequence that involved successively increasing the spacing of repetition produced higher subsequent retention performance than did a sequence in which the spacing of repetition was initially larger and then successively reduced across presentations. Similarly, successively increasing the difficulty of a problem as recommended by the "fading" procedure employed by operant psychologists may enhance retention performance. Results of the present experiment and those reported by Jacoby (1978) can be used to suggest that variations in cue effectiveness play a central role so that both the spacing of repetitions and differences in problem difficulty will be important.

GENERAL DISCUSSION

Melton (1967) described the effect of spacing repetitions as presenting a paradox in that it seemed to show that forgetting is beneficial for memory. Results of the present studies provided support for Melton's contention that the effect of repetition is greater when memory for an earlier presentation of the repeated item is less accessible. Experiment 1 led to the conclusion that similar material intervening between item presentations results in higher recall at a later test. Experiments 2 and 3 led to two main conclusions: First, memory for a prior presentation of an item can act over at least a few minutes to influence the processing involved in solving a problem. That it was processing of the problem that was involved was shown by the differential effects of reading the solution to a problem prior to rather than after solving the problem. Second, varying the form of a problem between its presentations renders memory for a prior presentation of the problem less accessible when that problem is repeated so that repetition of the problem engenders greater processing and, consequently, subsequent retention performance is enhanced.

Emphasizing the role of forgetting in producing the effect of spacing repetitions has the advantage of relating the spacing effect to other memory phenomena. One effect of forgetting a prior presentation of an item is to make the processing of a later presentation of that item more difficult, and several experiments have demonstrated that task difficulty influences subsequent retention performance. Jacoby, Craik, and Begg (1979) reported three new experiments and reviewed other experiments to show that increasing the difficulty of judgments can enhance subsequent retention of items involved in those judgments. Similarly, Slamecka and Graf (1978) showed that the more difficult task of generating a response to an item produces higher subsequent retention performance than does reading a response to an item. Effects of task difficulty

are also found when the effects of a prior test on subsequent retention performance are considered. Similar to the effects of spacing repetitions, increasing the spacing of the presentation and test of an item enhances subsequent retention performance. A prior test of an item does more to enhance later retention if that test is delayed by the presentation of intervening material rather than being directly preceded by presentation of the item that is to be tested (e.g., Landauer & Eldridge, 1967; Gotz & Jacoby, 1974; Whitten & Bjork, 1977). Further, later retention performance shows a greater benefit if an earlier test of retention is made more difficult by giving a recall rather than a recognition test of memory (e.g., Bjork & Whitten, 1974). This latter effect of test difficulty can be seen as paralleling the effects of similarity of repetitions investigated in Experiments 2 and 3 reported earlier; increasing the cues for retrieval provided either at an earlier test or by the repetition of an item reduces subsequent retention performance.

The ineffectiveness of maintenance rehearsal for improving long-term retention can also be interpreted as being due to an influence of memory for a prior encounter on the processing of an item when it is repeated. Manipulations of maintenance vs elaborative rehearsal are similar to manipulations of spacing of repetitions except that in the former paradigm it is the spacing of rehearsals rather than the spacing of experimenter-provided repetitions that is varied. To show the ineffectiveness of maintenance rehearsal, it has been demonstrated that rehearsing a small set of items in order to maintain those items in primary memory does not enhance performance on a delayed recall test (e.g., Craik & Watkins, 1973; Jacoby & Bartz, 1972). This maintenance rehearsal involves massed rehearsal of items and is likely to reflect influences on processing that are similar to those produced by the presentation of massed repetitions. It is unlikely that the processing required to initially encode an item must be

repeated each time that item is rehearsed as a member of a small set of items. Similar to experimenter-provided repetitions, the ease of the accessibility to memory for a prior rehearsal of an item is likely to reduce the processing that is necessary to produce a later rehearsal of that item. That is, the ineffectiveness of maintenance rehearsal may reflect a drastic reduction in processing between the original encoding of an item and subsequent rehearsals of that item.

The question remains as to why forgetting between repetitions or increasing task difficulty by other means should enhance memory performance. The most popular account of the effect of spacing repetitions attributes that effect to an influence of spacing on encoding variability. Theories of this form hold that repetition enhances retention performance only to the extent that the encoding of a later presentation of an item does not repeat that of an earlier presentation. The spacing effect is attributed to spaced repetition producing greater dissimilarity among the encoded versions of a repeated item. This greater variability in encoding is said to increase the number of retrieval routes to memory of a repeated item, and to increase the probability of overlap between information provided by a retrieval cue and that contained in a memory trace of repeated item. The most sophisticated account of the spacing effect in terms of encoding variability has been put forward by Glenberg (1979). The account of the ineffectiveness of maintenance rehearsal for long-term retention offered by Craik and Lockhart (1972) is similar to the encoding variability theory used by others to account for the effect of spacing repetitions. According to Craik and Lockhart, repeatedly processing an item at the "same level" serves to maintain that item in primary memory but will not benefit subsequent memory performance. To benefit secondary memory, it is said that further study of an item must involve deeper processing or serve to elaborate the memory trace of the item. As claimed by encoding

variability theory, then, Craik and Lockhart see rehearsal as being effective only to the extent that later processing or encoding of an item does not repeat that of earlier presentations or rehearsals. The two views are made even more similar by the suggestion that maintenance and elaborative rehearsal are better seen as end points on a continuum rather than as discrete categories (Craik & Jacoby, 1975; Glenberg & Adams, 1978). Elaboration and variability in encoding are similar notions in that both are described as having their effect by increasing the number of access routes to the memory for an item. The effects of decision difficulty can also be attributed to an influence of decision difficulty on elaboration of the memory for a presented item. A more difficult decision requires further processing and, consequently, a more elaborate or distinctive memory trace results (Jacoby et al., 1979). The notion of distinctiveness differs from that of elaboration only in that distinctiveness requires that conditions of test as well as those of study be taken into account.

We agree that learning more about an item as a result of encoding variability or elaboration can enhance memory performance. However, we would also like to entertain the possibility that repetition can produce a "strength-like" effect on memory. By an encoding variability theory, the effect of repeating an item should be maximal when there is no overlap between the encodings of a repeated item so that independent traces are formed. However, the effect of repeating an item has been found to be larger than could be produced by independent traces (Jacoby, Bartz, & Evans, 1978; Ross & Landauer, 1978). One way to account for this too-large effect of repetition is to assume that traces of an item can sometimes act in concert to have a strength-like effect (Jacoby et al., 1978). Further, we suggest that neither elaboration nor a strength-like effect will occur if memory for a prior presentation is too readily accessible when that item is repeated. Others have

suggested that the effect of repetition is diminished if an item is represented in short-term memory when it is repeated (e.g., Greeno, 1967; Whitten & Bjork, 1977). Rather than employing the distinction between short-term and long-term memory, we emphasize differences in accessibility, and the influence of memory for a prior presentation of an item on the processing of a later presentation. We believe that repeated processing of an item can enhance memory performance but that processing will only be repeated if memory for a prior presentation of an item is not readily accessible. Maintenance rehearsal and massed repetition are seen as being similar in that relatively few of the operations originally required to encode an item are likely to be repeated. Any strengthening effect will be limited to those operations that are actually repeated. By our view, then, it is not that repeated processing does nothing to enhance memory but rather that much of the processing of an item is not repeated when repetitions are massed.

An implication of the emphasis on forgetting between presentations is that it is the encoding of later presentations of an item that is influenced by the spacing of repetitions. Hintzman, Black, and Summers (1973) demonstrate effects of spacing on the encoding of later presentations and suggest a habituation account of the spacing effect that is compatible with the view that we propose. By our view, accessibility of memory for a prior presentation can result in the "dropping out" of some encoding operations and, thereby, a more impoverished trace. If the processing of later presentations is abbreviated, one would expect a corresponding reduction in the amount of effort invested in the processing of those later presentations. In line with this possibility, Johnston and Uhl (1976) have reported a positive correlation between processing effort indexed by performance on a subsidiary task and subsequent retention performance. Massed repetitions required less effort to process and produced poorer retention performance than did spaced repetitions.

The effect of changing modifiers between repetitions has been interpreted as evidence for the encoding variability account of the spacing effect (e.g., Madigan, 1969) but is, perhaps, better interpreted in terms of its influence on the accessibility of memory for a prior presentation when an item is repeated. It is sometimes found that the spacing effect is attenuated when a change in modifiers is used to bias a different meaning of a repeated word upon each of its presentations (Madigan, 1969). In Experiment 3, however, changing an item between its repetitions produced a more pronounced spacing effect rather than attenuating the spacing effect as would be predicted by an encoding variability theory. This exaggeration of the spacing effect is understandable as an interaction between the cues for retrieval provided by a repetition and length of the retention interval (spacing). At zero spacing, memory for the prior presentation of an item is readily accessible so the reduction in cues for retrieval produced by changing an item prior to its repetitions was ineffectual. A change in cues, however, did have an effect at the longer retention interval produced by wider spacing, presumably because memory for the prior presentation was less accessible by other means so the cues for retrieval provided by the presented version of the repeated item were more important. To eliminate the effect of spacing repetitions by changing modifiers, our view suggests that the change in an item between its repetitions must be so drastic that the second presentation of an item will not provide access to memory for its first presentation even when the two presentations are contiguous in the list. It seems reasonable that a change in modifiers can sometimes have such profound effects. When homographs are employed as stimuli a change in modifiers between repetitions of an item of the sort employed in some experiments may have so large an effect on encoding as to produce traces of the repeated item that

are no more similar than would be produced by the presentation of two unrelated words.

The emphasis on forgetting between repetitions has substantial heuristic value. For the spacing effect, the implication is that the details of that effect should change across other manipulations that influence the accessibility of memory for a prior presentation of an item when that item is repeated. In the experiments reported earlier, we found interactions of spacing with type of intervening material and the similarity of repetitions. The manipulation of type of intervening material corresponds to a manipulation of retroactive inhibition. Spacing would also be expected to interact with manipulations of proactive inhibition. Other factors that would be expected to be important are factors such as modality of presentation and the level-of-processing of prior presentations. In sum, the manipulation of spacing repetitions corresponds to a manipulation of retention interval and the effect of that manipulation should be moderated by other factors that also influence acessibility to memory for a repeated item's prior presentation.

Glenberg and Smith (1981) criticized an earlier paper by Jacoby (1978) as attributing the spacing effect totally to differences in encoding and as ignoring the importance of retrieval. The encoding variability view advanced by Glenberg, in contrast, was described as taking both differences in encoding and differences in retrieval into account. Rather than ignoring retrieval, we see the emphasis on forgetting between repetitions as saying that retreival is important during study as well as at the time of test. During study, retrieval is seen as operating to influence the processing of later presentations of a repeated item. If the trace of a prior presentation is too readily accessible when an item is repeated, few of the operations originally required to encode that item will be repeated and the result will be an impoverished trace of the later presentation. A more telling criticism might be that our approach allows so many

factors to operate that it predicts that almost anything can happen. What is needed is some measure of forgetting between repetitions that is independent of subsequent retention performance. In this regard, incidental learning procedures of the sort employed in the present experiments are likely to be particularly useful. It may be possible to use effects on the probability of correctly solving a problem and effects on reaction time to analyze the processing of later presentations of a problem so as to arrive at an independent measure of forgetting between repetitions that can then be related to subsequent retention performance.

The message of a considerable body of recent research has been that it is not words per se that are remembered but rather what is remembered in some product of a presented word and the processing activities of the learner (e.g., Craik & Lockhart, 1972; Jenkins, 1974) or perhaps the operations performed on a presented word (Kolers, 1976). The approach to analyzing repetition effects that we propose continues in the above vein. To specify the effect of repetitions, it must be determined which, if any, processing is repeated across presentations of an item, and then plot performance against that which is truly repeated. One factor that likely influences the probability of processing being repeated is the accessibility of the memory for a prior presentation of an item when that item is repeated.

References

- BJORK, R. A., & ALLEN, T. W. The spacing effect: Consolidation or differential encoding? Journal of Verbal Learning and Verbal Behavior, 1970, 9, 567-572.
- BJORK, R. A., & WHITTEN, W. B. Recency sensitive retrieval processes in long term free recall. *Cognitive Psychology*, 1974, **6**, 173–189.
- BOUSFIELD, W. A., Cohen, B. H., WHITMARSH, G. A., & KINCAID, W. D. The Connecticut free association norms. Studies on the mediation of verbal behavior. Technical report No. 35, University of Connecticut, November 1961.
- CRAIK, F. I. M., & JACOBY, L. L. A process view of short-term retention. In F. Restle, R. N. Shiffrin, H. J. Castellan, M. R. Lindman, & D. B. Pisoni

(Eds.), *Cognitive Theory*, Vol. I. Potomac, Md.: Erlbaum, 1975.

- CRAIK, F. I. M., & LOCKHART, R. S. Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, 1972, 11, 671-684.
- CRAIK, F. I. M., & WATKINS, M. J. The role of rehearsal in short term memory. Journal of Verbal Learning and Verbal Behavior, 1973, 12, 599-607.
- GLENBERG, A. M. Component-levels theory of the effects of spacing of repetitions and recall and recognition. *Memory and Cognition*, 1979, 7, 95-112.
- GLENBERG, A. M., & ADAMS, F. Type 1 Rehearsal and recognition. Journal of Verbal Learning and Verbal Behavior, 1978, 17, 455-463.
- GLENBERG, A. M., & SMITH, S. M. Spacing repetition, and solving problems are not the same. *Journal of Verbal Learning and Verbal Behavior*, 1981, 20, 110-119.
- GOTZ, A., & JACOBY, L. L. Encoding and retrieval processes in long-term retention. *Journal of Experimental Psychology*, 1974, 102, 291–297.
- GREENO, J. G. Paired-associate learning with shortterm retention: Mathematical model and data regarding identification of parameters. *Journal of Mathematical Psychology*, 1967, 4, 430-472.
- HINTZMAN, D. L. Theoretical implications of the spacing effect. In R. L. Solso (Ed.), *Theories of* cognitive psychology: The Loyola Symposium. New York: Erlbaum, 1974.
- HINTZMAN, D. L., BLACK, R. A., & SUMMERS, J. J. Modality tags and memory for repetitions: Locus of the spacing effect. *Journal of Verbal Learning* and Verbal Behavior, 1973, 12, 229-238.
- JACOBY, L. L. On interpreting the effects of repetition: Solving a problem versus remembering a solution. Journal of Verbal Learning and Verbal Behavior, 1978, 17, 649-667.
- JACOBY, L. L., & BARTZ, W. H. Rehearsal and transfer to LTM. Journal of Verbal Learning and Verbal Behavior, 1972, 11, 561-565.
- JACOBY, L. L., BARTZ, W. H., & EVANS, J. D. A functional approach to levels of processing. Journal of Experimental Psychology: Human Learning and Memory, 1978, 4, 331-346.
- JACOBY, L. L., CRAIK, F. I. M., & BEGG, I. Effects of decision difficulty on recognition and recall. *Journal of Verbal Learning and Verbal Behavior*, 1979, 18, 585-600.
- JENKINS, J. J. Remember that old theory of memory? Well forget it. American Psychologist, 1974, 29, 785-795.
- JOHNSTON, W. A., & UHL, C. N. The contributions of encoding effort and variability to the spacing effect and free recall. *Journal of Experimental Psychology: Human Learning & Memory*, 1976, 2, 123-160.

- KOLERS, P. A. Reading a year later. Journal of Experimental Psychology: Human Learning and Memory, 1976, 2, 554–565.
- LANDAUER, T. K., & ELDRIDGE, L. Effects of tests without feedback and presentation-test interval in paired-associated learning. *Journal of Experimental Psychology*, 1967, 75, 290-298.
- MADIGAN, S. A. Intraserial repetition and coding processes in free recall. *Journal of Verbal Learning* and Verbal Behavior, 1969, 8, 828-835.
- MELTON, A. W. Repetition and retrieval from memory. *Science*, 1967, **158**, 532.
- PROCTOR, R. W. The influence of intervening tasks on the spacing effect for frequency judgments. Journal of Experimental Psychology: Human Learning and Memory, 1980, 6, 254-266.
- ROBBINS, D., & WISE, P. S. Encoding variability and imagery: Evidence for a spacing-type effect without spacing. *Journal of Experimental Psychology*, 1972, **95**, 229–230.
- Ross, B. H., & LANDAUER, T. K. Memory for at least one of two items: Test and failure of several theo-

ries of spacing effects. Journal of Verbal Learning and Verbal Behavior, 1978, 17, 669-680.

- SLAMECKA, N. J., & GRAF, P. The generation effect: Delineation of a phenomenon. Journal of Experimental Psychology: Human Learning & Memory, 1978, 4, 592-604.
- TZENG, O. J. L. Stimulus meaningfulness, encoding variability, and the spacing effect. Journal of Experimental Psychology, 1973, 99, 162-166.
- WHITTEN, W. B., & BJORK, R. A. Learning from tests: Effects of spacing. Journal of Verbal Learning and Verbal Behavior, 1977, 16, 465-478.

Reference Note

 LANDAUER, T. K., & BJORK, R. A. Optimum rehearsal patterns and name learning. Paper presented at the International Symposium on Practical Aspects of Memory, Cardiff, Wales, 1978.

(Received March 10, 1981)