On Interpreting the Effects of Repetition: Solving a Problem Versus Remembering a Solution

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When a problem is repeated, the later presentation of the problem sometimes results in the subject responding by remembering the solution rather than by going through the operations that would otherwise be necessary to solve the problem. The means of obtaining the solution is shown to influence subsequent retention performance; retention of the solution suffers if it has been obtained by remembering rather than by solving the problem. The distinction between solving a problem and remembering a solution is used in an account of the effect of spacing repetitions and other standard memory phenomena. The relevance of the distinction to tasks such as word perception is also discussed.

Suppose that you are asked to find the sum of $37 + 15 + 12$. After having obtained this sum your are immediately presented with the same problem. The type of processing that you do will differ drastically on the repeated presentation. On the first encounter you undoubtedly went through the process of addition to obtain the sum; on the second encounter, the sum is readily available and can be given without going back through the operations of adding the numbers. Indeed, a full repetition of the processing activity may be difficult, if not impossible, to accomplish without some delay, which is probably the rationale for the commonly prescribed routine of checking an addition by adding the numbers in reverse order rather than simply re-adding them in the same order. To make it possible to repeat the full process of addition, it is probably sufficient to separate the re-

petitions of the problem by several intervening problems of the same form.

This example of addition is the basis of the analysis of the effect of repetition on memory that is presented in this paper. The task of memorizing a list of words can be compared to the task of solving a series of problems. The presentation of a word for memory constitutes a problem; the subject must find operations that will render that word memorable after some delay. For example, the subject may image the referent of the word in order to enhance memory. As with math problems, it is unlikely that a repetition of a word results in a full repetition of the processing. If one has just imaged their own dog in order to make the word "dog" more memorable, imaging their dog a second time as a consequence of the word being repeated is unlikely to require a full repetition of the processes that were necessary for the original imaging. In general, it seems that one can retrieve the product of their prior memorizing activity without fully repeating that memorizing activity.

The means by which a solution to a problem is obtained will influence subsequent retention of the problem and its solution. This claim has been used in recommending "discovery"

learning as compared to "reception" learning (Bruner, 1966); the suggestion is that working through a problem to its solution enhances memory as compared to a situation where the solution is provided. Little is known about how these effects work. However, one possibility is that solving a problem results in a "richer" memory of that problem and its solution. In the math example, the further operations that are performed when addition is required may result in a more extensive memory of the problem by including substeps leading to its solution. This additional information could provide a further basis for subsequent recognition of the problem and increase the number of potential cues for later recall. A second explanation of the retention advantage of solving a problem as compared to reading or effortlessly remembering the solution appeals to the role of consciousness in determining subsequent retention. In the math example, adding a series of numbers to obtain a solution invloves consciousness in a way that "effortless" remembering of the solution does not. When adding the numbers, it seems necessary to monitor one's own processing while an effortless retrieval of a solution seems "automatic". The involvement of consciousness may enhance subsequent retention performance.

This analysis is relevant to the spacing effect that is well documented in the memory literature (Hintzman, 1974). The argument is that the processing of the first presentation of a word makes available an appropriate encoding and thereby trivializes the processing associated with the second presentation of the word. As the spacing of repetitions is increased, the amount of processing of the repeated word that is required to attain an appropriate encoding increases; consequently, one should expect retention to be enhanced as a function of the spacing of repetitions. As argued with reference to solving a problem, working with an item to derive an encoding produces subsequent retention that exceeds that produced when an appropriate encoding

is effortlessly retrieved.

The experiments that are to be reported provide a clear demonstration of the memory consequences of solving a problem versus remembering a solution. Much of the subsequent discussion will center around the effects of spacing repetitions. However, the contrast between solving a problem and remembering a solution is applicable over a much wider range of situations than is usually considered when discussing the memorizing of a list of words. One potential application that is of current interest involves word identification. A pronunciation for a word can be constructed by going through a series of rules that deal with letter to sound correspondences. As in the math example, however, this constructive activity is likely to be bypassed or minimized when the conditions are such as to allow the subject to easily remember a pronuniciation that he has encountered previously. Thus, the contrast with which we are dealing is relevant to many tasks in addition to those of solving math problems or memorizing word lists. Potential applications of the distinction between solving a problem and remembering a solution are described in the general discussion.

The general discussion also includes a review of several experiments that can be used to support the claim that an advantage in subsequent retention is gained by constructing rather than remembering a solution. The argument that the effect of spacing repetitions results from a change in the mode of obtaining a solution, or achieving an encoding, is expanded and contrasted with other explanations. This argument is then extended to account for various memory phenomena that have previously been discussed in much narrower contexts. The distinction between solving a problem and remembering a solution is shown to have considerable heuristic value; this distinction can be used to suggest experiments that would not arise from the more traditional explanations of the phenomena that are reviewed.

EXPERIMENT 1

Subjects engaged in a task that is similar to that of solving a crossword puzzle. A cue word was presented along with a few letters and a series of blanks representing the missing letters of a word that was related to the cue word (e.g., foot s_ _e). The subject's task was to report the word that could be produced by filling the blanks (shoe in the above example). In some instances, the task of solving the puzzle was trivialized by preceding the problem with its solution; the primary manipulation in the first experiment was to vary the spacing of the puzzle and its solution. The processing required to obtain the solution and, consequently, later memory were expected to be greater when presentation of the solution was separated from the puzzle by intervening items rather than immediately preceding the puzzle in the list. Retention performance was assessed by means of an unexpected test of cued recall; the cue word from each of the puzzles (e.g., foot) was presented as a cue for recall of the solution words.

Comparisons among conditions were designed to provide information about the processing carried out to solve the puzzle. For example, in the first experiment, cued recall after reading the solution and then solving the puzzle was compared to cued recall after having read the solution twice. When the solution word immediately preceded presentation of the puzzle, solving the puzzle was not expected to entail any more effort or produce any better recall than would result from simply reading the solution word for a second time. With greater separation of a puzzle and its solution, however, the requirement of solving the puzzle was expected to produce higher retention than would be produced by a second reading of the solution word.

Methods

Design and subjects. Subjects either read or constructed the right-hand member of pairs of related words. For pairs that were to be read, the right-hand member of the pair was presented intact. For pairs that required a response to be constructed, two or more letters were deleted from the interior of the right-hand member of the pair; the subject was to say the word that could be formed by restoring the missing letters.

The experiment was designed so that each of six conditions were represented by 12 items mixed in a single 72-item list. One condition (R) consisted of the 12 items that were presented only once and in which the response had only to be *read* by the subject. A second condition (C) consisted of the 12 items that were presented only once but for which the response had to be *constructed*. In two of the remaining conditions, each pair was presented twice with the response being read both times (RR); in one of these RR conditions, the second presentation immediately followed the first, and in the other it followed with a lag of 20 items. In the final two conditions the item was to be read the first time and constructed the second (RC); again, in one of the RC conditions the repetition was immediate and in the other after 20 intervening items.

Eighteen subjects were paid $2.00/hour to participate. Testing was conducted in individual sessions.

Materials. Seventy-two pairs of related words were selected from the Connecticut free-association norms. In selecting pairs, neither the most frequent association to a cue word nor a bizarre association was selected. The intent was to select pairs such that the response word could be solved in the conditions requiring construction without the solution being too obvious. The response members of pairs varied in length from four to eight letters. When construction of a response was required, the first letter and the last letter of the response were always presented. For the longer response words, up to four letters including the first and last letter of the word were provided; two or more letters were deleted from each response word that required

construction. Deleted letters were replaced by blanks so that the number of letters in the word that was to be constructed was obvious.

Six lists were formed by rotating pairs through presentation conditions so that across lists each presentation condition was represented by the same pairs. Within a list, the order of pairs was such that each presentation condition was represented by n pairs before any presentation condition was represented by $n + 1$ pairs.

Procedure. The list of pairs was prepared as a stack of note cards with each note card containing one related pair. A timing device was used to pace subjects through this stack of note cards at a rate of 6 seconds/card. Subjects were informed that we were interested in how long it took them to solve problems of the type they might encounter in a crossword puzzle. They were to turn a note card when signaled to do so by the timing device. If the right-hand member of the pair on the note card was not intact, they were to say a word that contained the provided letters and whose remaining letters would fit in the blanks; they were further informed that the response they gave had to be related to the cue word that was provided on the card. As soon as they thought they knew the answer, they were to push a button that was in front of them and say the solution aloud. If the right-hand member of the pair on a card was intact, they were to push the button and read the response aloud. Subjects were told that their reaction times to "read" items were to serve as a baseline for their reaction time to responses that had to be construced. In reality, reaction times were not recorded; the reaction-time task was simply used to provide a cover story for subjects.

After subjects had worked their way through the deck of notecards, they were given an unexpected test of cued-recall; the left-hand member of each pair was provided, written in a random order on a sheet, as a cue for recall of the right-hand member of each pair. The cued-recall test was subject-paced.

Analyses. The test of cued-recall provided the data that are of primary interest. In analyzing the cued-recall data coming from conditions that have been required to construct a response, one has the option of conditionalizing cued-recall on successful construction of the response. The rationale for such conditionalizing is: If a subject was unable to construct a particular response during presentation of the list then he was not exposed to that response; consequently, the subject cannot be expected to recall the response on the later test of cued recall. Despite this consideration, the probability of cued-recall was not conditionalized in the analyses that are to be reported. The decision not to conditionalize the probability of cued-recall was motivated by concern for a potential confounding that could result from item selection problems. Cued-recall can obviously not be conditionalized when subjects only read the solution to a problem; conditionalizing for the problems that required construction of a solution may result in selectively dropping-out the harder pairs so that the comparison of the "read" and "construct" conditions is confounded with the difficulty of the pairs on which their performance is assessed. Although they will not be reported, analyses were also carried-out with conditionalized scores. In general, the result of conditionalizing scores was to make effects larger that were also present and significant in the analyses of unconditionalized scores. In no instance did the results of an analysis of conditionalized scores conflict with conclusions that are to be drawn from an analysis of unconditionalized scores.

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

Results and Discussion

Subjects were generally successful in constructing the appropriate response; 77% of the responses were correct in the condition in which the pairs to be constructed were presented only once. When the items had been read 20 items earlier (Read–Construct,

spaced) the rate of successful construction was 90%, significantly higher: $F(1, 17) = 13.60$, $MS_e = .011$. When the item was to be constructed immediately after having been read (Read–Construct, immediate) the rate of success was 99%, significantly higher than the delayed condition: $F(1, 17) = 23.94$, $MS_e = .003$.

The argument made earlier was that constructing a response as a solution to a problem should produce retention greater than that produced by simply reading the response. Further, the retention advantage that would result from solving a problem should depend on the processing involved in constructing the solution. Immediately preceding a problem by presentation of its solution should trivialize the problem to such an extent that the processes involved in solving the problem should not differ appreciably from those that are required to simply read the solution a second time; consequently, one should expect no advantage to result from constructing the solution as compared to a second reading of the solution. When presentation of the solution is widely separated from that of the problem, however, solving of the problem, should be nontrivial and give rise to retention that exceeds that coming from reading the solution for a second time. The cued-recall data are presented in Figure 1 and provide support for each of the above predictions.

When a pair was presented only once, construction of a solution resulted in substantially higher cued-recall than did simply reading the solution word in a pair, $F(1, 17) = 55.92$, $MS_e = .02$. For pairs that were repeated, the effect of spacing repetitions was much greater in the Read–Construct condition than in the Read–Read condition, $F(1, 17) = 22.00$, $MS_e = .01$. When reading of the solution immediately preceded presentation of the problem, cued recall in the Read–Construct condition did not exceed that in the Read–Read condition; however, with spaced presentation, the Read–Construct condition produced substantially higher cued
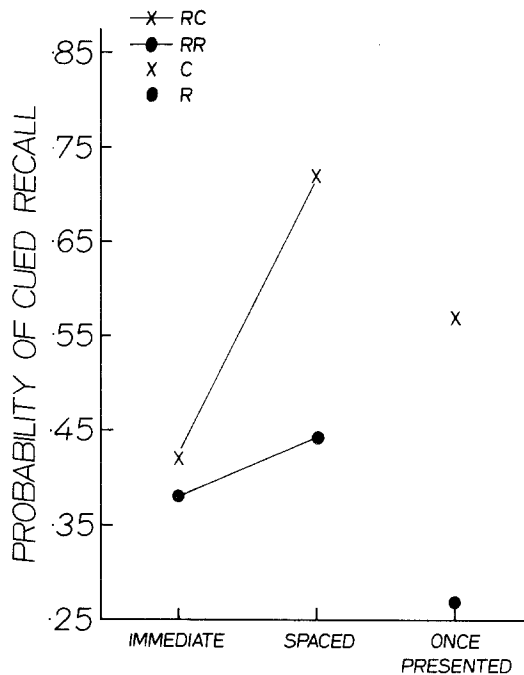

Fig. 1. Probability of cued-recall as a function of reading (R) vs construction (C) in Experiment 1.

recall than did the Read–Read condition. Comparisons with once-presented items reveal that reading the solution immediately prior to being required to construct the solution produces *lower* performance than results from constructing the solution without having previously read it, $F(1, 17) = 15.91$, $MS_e = .01$. With spaced presentations, the retention advantage conferred by a prior reading of the solution in the Read–Construct condition is approximately equal to that gained in the Read–Read condition. That is, the difference between Read and Read–Read is approximately equal to that between Construct and Read–Construct; the prior reading of the response enhances recall in both instances.

It was once generally believed that the important condition for learning was to lead the subject, by whatever means, to make a correct response. This belief in the importance of making the correct response has motivated

educational practice. It is not unusual for a teacher to present a problem along with its solution and then require the class to "parrot" that solution. Within the Skinnerian tradition, programmed instruction was designed to ensure that a correct response was made. An inserted question often occurs almost immediately after the text that provides the answer to that question; in addition, prompts such as rhyming cues or a portion of the letters comprising the response are provided to further ensure that the correct response will be given. One point to be made by the present study is that the processes involved in solving a problem determine retention of the solution. If the problem is trivialized by presenting the solution immediately prior to the problem or by simpy requiring the person to read the solution, retention performance will suffer.

It might be argued that the retention advantage gained by constructing rather than reading or remembering a solution is due to differences in study time; it takes longer to construct a solution than to read one, and this difference in effective study time is responsible for effects in subsequent retention. First, it probably did not take twice as long to construct a solution as to read a solution. However, reading the solution twice produced substantially lower recall than did constructing a solution only once; recall of once-presented items that required construction was higher than that in the Read–Read condition. Further, arguments about differences in *effective* study time are meaningless unless we have some idea of what constitutes effective study, and of the variations in processing that are responsible for differences in the effectiveness of study. Other data (e.g., Craik & Tulving, 1975) can be used to suggest that differences in time per se are irrelevant to differences in retention that are produced by manipulating orienting tasks.

EXPERIMENT 2

The results of the first experiment could be summarized by the statement that increas-ing the effort required to solve a problem enhances later retention performance. The second experiment provides further evidence on the role of effort by directly varying the difficulty of the problems themselves. In one condition, the crossword puzzle problems were extremely easy to solve. Puzzles for that condition were constructed by deleting a single interior letter from the solution word (e.g., check m-ney); the result for most pairs was to make the problem so easy that it seems possible to just read the solution word. Puzzles for a second condition were made more difficult by deleting two interior letters from the solution word (e.g., lance sp—r). As can be seen from the examples, deleting a second letter appears to produce a substantial increase in the difficulty of the problem. The more difficult problems were expected to yield higher retention performance.

The second experiment also differed from the first in that the effect of intermediate levels of spacing were investigated in the second experiment. In the current memory literature there is some disagreement whether there is a dichotomous effect of immediate vs spaced repetitions or a true continuous effect of spacing repetitions; that is, some studies find differences only between massed and nonzero levels of spacing while other studies find differences among nonzero levels of spacing (see Hintzman, 1974, for a review). In the present situation, this observation can be translated into a speculation about the role of short-term memory. A prior presentation of the solution to a problem might reduce later retention only if that solution is still in short-term memory when the problem is encountered. If so, one would expect a difference between immediate and widely spaced repetitions but would not expect increases in spacing outside the range of short-term to influence later retention.

The interaction of spacing with problem difficulty is also of interest. With massed presentation of the solution and problem, the two levels of problem difficulty should yield

equivalent levels of later recall; for both types of problems, the task of providing a solution should be trivial. At greater levels of spacing, however, the more difficult problems should produce higher retention than the easier ones.

Method

Design and subjects. The second experiment employed the same crossword puzzle task as did the first experiment. However, all repetition conditions in the second experiment involved first reading the response member of a pair and then later encountering that pair as a problem that required the previously read response as a solution (the Read–Construct arrangement in Experiment 1). Eight repetition conditions were produced by factorially combining two levels of solution difficulty (Easy vs Hard) with four levels of spacing of presentations (0, 10, 20, or 40 intervening pairs). In four additional conditions, a pair was presented only once. To produce these four conditions, the two levels of problem difficulty were combined with the solution to the problem being either read or constructed. Problem difficulty was a pseudovariable, inserted for purposes of analyses, when the solutions to the once-presented problems were read. All conditions were represented within-subjects.

The subjects were 18 students enrolled at McMaster University who were paid \$2.00/hr to participate in the experiment.

Materials and procedure. The materials comprised 120 pairs of related words selected from the Connecticut free-association norms using the same criteria as in Experiment 1. Solution words varied from four to six letters in length. Easy problems were produced by replacing one interior letter of the solution word with a blank; difficult problems were produced by replacing two interior letters of the solution word with blanks.

To construct a list, 10 pairs were assigned to each of the 12 conditions described in the design and subjects section. Since eight of these 12 conditions required repetitions of a pair, a list was 200 pairs long. For the repetition conditions, presentations of a pair were separated by 0, 10, 20 or 40 intervening pairs. Twelve lists were constructed by rotating pairs through conditions so that across lists each condition was represented by the same pairs; six of these lists were presented to two subjects while the remaining six lists were presented to only one subject.

A final cued-recall test was constructed in the same manner as described for Experiment 1. The procedure was also identical to that described for the first experiment.

Analysis. As in Experiment 1, the cued-recall data that will be reported were not conditionalized on the subject correctly solving the corresponding crossword puzzle problem. Again, conditionalized data were also analyzed, but the results of those analyses do not alter any conclusions drawn on the basis of the unconditionalized data.

Significance level for all tests was set at $p < .05$.

Results and Discussion

Differences in the probability of an unsuccessful attempt at solving the crossword problems verified that the "hard" problems were indeed more difficult than were the "easy" problems; the probability of being unable to solve a problem in the once-presented conditions was .12 for hard problems and .02 for easy problems. Prior reading of the solution facilitated solving of the problems when reading of the solution immediately preceded presentation of the problem (0-spacing); the probability of being unable to solve a problem under those circumstances was quite low (.005) for both the easy and the difficult problems. When 40 items intervened between reading the solution and presentation of the problem, the probability of being unable to solve a difficult problem (.04) was still lower than that in the once-presented condition where the solution was not read
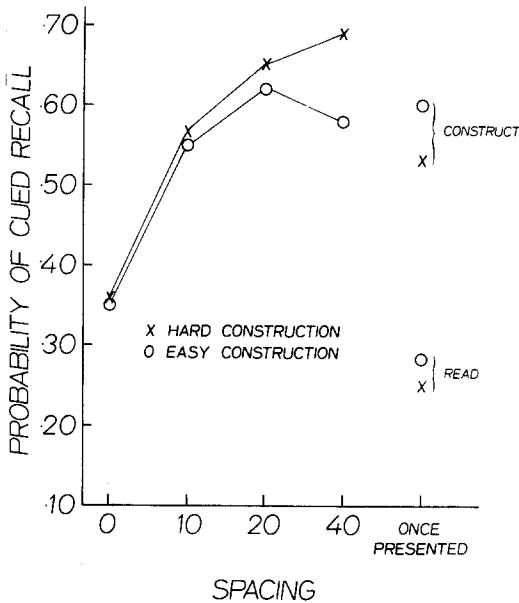
FIG. 2. Probability of cued-recall as a function of construction difficulty and spacing.

prior to presentation of the problem (.12). With the easy problems, in contrast, the probability of being unable to solve a problem when 40 items intervened between reading the solution and presentation of the problem (.02) was equal to that in the corresponding once-presented condition.

The cued-recall results from the second experiment are displayed in Figure 2. A portion of those results simply replicate effects found in the first experiment. Among the once-presented items, being required to construct a solution produced substantially higher cued-recall than did reading the solution, $F(1, 17) = 80.76$, $MS_e = .02$. Within the conditions that required construction, reading the solution immediately prior to solving a problem that required that solution (0-spacing) lowered later cued-recall as compared to the corresponding once-presented conditions that solved the problem without previously reading the solution, $F(1, 17) = 32.64$, $MS_e = .02$.

It was earlier suggested that the results of the first experiment reflect the influence of short-term memory. The suggestion was that prior reading of the solution will depress later cued-recall only if the solution resides in short-term memory after the problem requiring that solution is presented. This position leads to the prediction that increases in spacing beyond the range of short-term memory should have no effect on later cued recall; that is, one should find an immediate vs spaced effect but should find no differences among greater levels of spacing. The results of the second experiment revealed a quite large effect of spacing presentations, $F(3, 51) = 33.98$, $MS_e = 02$. Contrary to expectations, however, the effect of spacing presentations remained significant when the 0-spacing conditions were dropped from the analysis, $F(2, 34) = 3.93$, $MS_e = .02$. It does not seem reasonable to argue that the effects of spacing within the range of 10–40 intervening items are due to differences in the probability of the solution residing in short-term memory during the presentation of the problem; the levels of spacing involved are all outside of what is usually considered to be the range of short-term memory. Some factor that operates over a greater range than does short-term memory is apparently responsible for the spacing effect observed in the present experiments.

Although the more difficult problems were expected to produce higher retention than were the easy problems, results from the once-presented items reveal no effect of problem difficulty on later cued-recall. However, effects of problem difficulty are observed when one examines the repeated items. Among the repeated items, the more difficult problems produced higher cued-recall than did the easy problems, $F(1, 17) = 9.76$ $MS_e = .007$. Examination of the data presented in Figure 2 suggests that problem difficulty interacts with the spacing of presentations. At 0-spacing, the two levels of problem difficulty produced essentially equivalent levels of cued-recall

while the more difficult problems produced higher performance than did the easy problems at the greater levels of spacing. The interaction of spacing and problem difficulty, however, was not statistically significant, $F < 1$.

A significant interaction was found when an analysis was carried out on the two levels of problem difficulty at 40-spacing and the two once presented item conditions that required construction of a response, $F(1, 17) = 5.58$, $MS_e = .028$. Examination of this interaction shows that problem difficulty had an effect with the repeated items but not with once presented items. Further, prior reading of the solution enhanced recall relative to the once-presented items only for the difficult problems; at the longest-spacing, the level of cued recall produced by easy items is approximately equal to that produced by the corresponding once-presented items.

These results can easily be interpreted in the same terms as was Experiment 1. Presenting the solution of a problem prior to the presentation of that problem provides the subject with two means of generating a response: The subject can either remember the solution that he was given previously or he can use the information provided by the problem to construct a solution (mixes of the two means of generating a response are, of course, also possible). When a presentation of the solution immediately precedes a presentation of the problem, the subject almost certainly remembers rather than constructs the solution, and later retention performance suffers. The effect of spacing of presentations for both levels of problem difficulty can be interpreted as being due to a corresponding increase in the likelihood that a solution to the problem must be constructed rather than remembered.

When a solution was not presented prior to the presentation of a problem as was the case with once-presented pairs, the subject had no option but to construct a solution. It appears that the only important factor for later retention was that construction be required; the

difficulty of the problem did not influence later cued-recall performance. This lack of an effect of problem difficulty may simply result from problem difficulty having been manipulated over too narrow of a range; however, the manipulation was sufficient to produce substantially more unsuccessful attempts to solve the difficult problems as compared to the easier ones. Perhaps the most surprising result is the large advantage in cued-recall produced by an easy construction as compared to reading the solution to a problem. As shown by the example provided earlier, the deletion of a single letter appears to make the problems so easy that one can just read the solution; however, solving problems that were even this easy produced subsequent recall that was double that produced by actually reading the solution. Additional research is required to determine whether or not a continuous effect of problem difficulty can be obtained. If the effects prove to be dichotomous, as is suggested by the results of the present experiment, it may be necessary to invoke the concept of consciousness to explain the effect of problem difficulty. To enhance later retention, it may only be necessary to disrupt the flow of processing so that some minimal amount of conscious construction is required.

The effect of problem difficulty found with repeated items remains to be explained. In these cases, problem difficulty may have had its effect by influencing the ease of *remembering* the solution. Even at the longer spacings, subjects may have sometimes remembered rather than constructed the solution. This remembering of the solution is more likely with the easy problems where only one letter of the solution word is deleted than with the hard problems where two letters of the solution are deleted. That is, because there are more letters and therefore a more restrictive context, the easy problems provide a better cue for recall of the previously given solution than do the hard problems; consequently, constructon of the solution is required more often for the hard problems with resulting

better retention. Evidence that the prior reading of the solution does influence solving the problem even at the longest spacing is provided by both experiments. In both experiments, the probability of being unable to solve a problem was lower when the solution had been read previously. This reduction in the probability of being unable to solve a problem is presumably due to the solution being at least partially remembered in some instances rather than being solely constructed.

The possibility of remembering rather than constructing a solution, even when the solution does not immediately precede presentation of the problem, casts a new light on the role of short-term memory in producing the effect of spacing repetitions. Greeno (1967) has emphasized the role of short-term memory in producing the spacing effect by arguing that a subject might learn nothing from the presentation of an item if that item currently resides in short-term memory. This is said to be because the subject will not select a new "code" for an item that resides in short-term memory during its repetition; memory over the long term is described as requiring the selection of an appropriate code. Similarly, in the present paper, it was suggested that presentation of a problem may have little effect on subsequent retention if the solution to that problem currently resides in short-term memory so that solving the problem is trivialized. On the basis of the results of the present experiment, however, it appears that effortless remembering rather than residence in short-term memory is the important factor for subsequent retention. Discussions of short-term memory have usually emphasized limited-capacity notions so that it is the number of intervening items that is seen as determining whether or not a particular item will still reside in short-term memory when it is repeated. Implicating ease of remembering, in contrast, emphasizes the importance of the cues provided for retrieval of an earlier presented solution as well as the number of items intervening between presentation of the solu-

tion and that of the problem. An implication of emphasizing retrieval is that when remembering of the solution is enhanced by providing more effective cues, as in the easy construction as compared to the hard construction conditions, subsequent retention performance will suffer even when presentation of the solution does not immediately precede that of the problem. The presentation of less effective cues for retrieval makes it more likely that the subject will have to solve the problem rather than remember the solution, and subsequent retention benefits.

The above account of the results claims that remembering a solution always leads to poorer later remembering of that solution than does construction of the solution. Such a position is too extreme in that remembering sometimes involves construction. As one example, Lindsay and Norman (1977) argue convincingly that construction or reconstruction is involved when we answer a question about where we were on some specified data in the distant past. Perhaps a distinction needs to be drawn between effortful and effortless retrieval (e.g., Gotz & Jacoby, 1974). Effortful retrieval involves many of the same processes as does construction and acts the same way as construction to enhance later retention. In contrast, effortless remembering of a solution, regardless of the spacing of the solution and problem, is much like reading the solution and does relatively little to enhance later retention performance. Further theorizing at this point is by necessity speculative. However, one advantage offered by the procedures employed in the present experiments is that the task is one that can be further analyzed to yield information about the processes in which subjects engage to deal with a problem.

The main questions left unanswered in the above account are: What is involved in the[r] construction of a solution and why does engaging in construction enhance later retention performance? These questions will be considered in the general discussion. Before considering those questions, however, the

spacing effect obtained here will be compared with that obtained in more typical memory experiments, and the applicability of current theories of the spacing effect to the results of the present experiments will be discussed.

GENERAL DISCUSSION

Whereas it is possible that the spacing effect found here has a totally different basis than does the spacing effect found in more typical memory experiments (e.g., Melton, 1967), it seems more likely that the two are closely related. In order to memorize a word, a subject must engage in some series of operations; for example, finding relations among words or imaging the words. As with the math problems considered earlier and the crossword puzzle problems used in the present experiments, it seems unlikely that these memorizing operations are fully repeated when the second presentation of a word immediately follows its first presentation. In the remainder of this paper, I proceed as if the spacing effect found here and the spacing effect found in more typical memory experiments have a common basis. If this common basis is accepted, it is of interest to see how various theories of the spacing effect fare in attempting to account for the results of the present experiments.

One explanation of the spacing effect has appealed to differences in the frequency of rehearsal as a function of the spacing of repetitions. The claim is that an item is rehearsed during the interval intervening between its presentations; consequently, spaced repetitions of an item result in more rehearsal of the repeated item than do massed repetitions (Rundus, 1971). This greater number of rehearsals is used to explain the retention advantage of spaced repetitions by assuming that long-term memory of an item is a direct function of the number of rehearsals that item has received. Although it may apply in other situations, the frequency of rehearsal explanation cannot account for the spacing effect obtained in the present experiments.

First, the incidental learning procedure employed here made it unlikely that subjects would rehearse an item during intervals outside of its presentation. More importantly, the differential rehearsal explanation cannot account for the debilitating effect of reading the solution to a problem immediately prior to solving the problem. It is not reasonable to claim that the prior reading of the solution resulted in the solution being rehearsed less than it would have been had the solution not been read prior to presentation of the problem.

The encoding variability hypothesis has provided a second explanation of the effect of spacing repetitions. By this hypothesis, there are several different ways a to-be-remembered word can be encoded; the more different ways a word is encoded the better will be retention since each different encoding provides an additional access route to the word in memory. It is further assumed that an increase in spacing makes it more likely that repetitions of an item will be encoded differently. Thus, the effect of spacing of repetitions is attributed to an increase in the number of encodings of the repeated item (Melton, 1967; Madigan, 1969). A variant of the encoding variability hypothesis assumes that an item becomes conditioned to contextual elements that are active during the presentation of the item. The spacing effect is then explained on the basis of differences in the similarity of these contextual elements as a function of spacing (Anderson & Bower, 1972; Glenberg, 1977).

There seems to be no way that anything like encoding variability could have operated to produce the spacing effect observed in the present experiments. The encoding variability hypothesis appears irrelevant when one abandons the procedure of presenting a list of words to be memorized and instead presents a series of problems that are to be solved. Notions discussed earlier, however, do provide a means of reinterpreting data that have been presented as supporting the encoding variability explanation of the spacing effect.

Several investigators (e.g., Madigan, 1969) have demonstrated that the effect of spacing repetitions can be reduced by varying the context in which the repeated word is presented. If the context biases a different interpretation for each presentation of the repeated word (e.g., fever–CHILL, snow–CHILL) the spacing effect is flatter than it is when the context biases the same meaning for each presentation. This biasing of different interpretations by manipulating context is assumed to mimic what happens in ordinary circumstances when repetitions of an item are widely spaced; it is claimed that both manipulations increase the number of access routes to the repeated item. An alternative interpretation, however, is that the change in context essentially produces different problems that are to be solved. Changing context is analogous to first asking a person to add 37 and 15 and then asking them to multiply 37 and 15. Although the numbers remain the same in the two problems, the answer to the first problem cannot be carried over to trivialize the solving of the second problem. Similarly, operations carried out to encode an item in one context may not provide an encoding that is appropriate to the item repeated in a different context. The manipulation of context results in more full processing of later presentations of the repeated item, and consequently, enhances retention.

A third explanation of the spacing effect is similar to the account offered here. By a habituation hypothesis (Hintzman, 1974), the spacing effect is due to the deficient registration of later presentations when repetitions of an item are massed; Hintzman, Block, and Summers (1973) provide evidence that the encoding of later presentations is deficient. This deficient registration is described as being due to habituation and is considered to be outside of the subject's voluntary control. In outline, the habituation hypothesis agrees with the notions described in the introduction to explain the spacing effect. There it was suggested that a massed repetition results in

the subject remembering the solution to a problem rather than constructing that solution. This remembering of the solution produces poorer retention so the locus of the spacing effect is in the registration of the second presentation. The conclusion that the registration of the later presentation is deficient is compelled by the finding in the present experiments of an *absolute* debilitating effect of repetition when reading the solution immediately preceded presentation of a problem. Further, the influence of having read the solution is not seen as being optional; it is nearly impossible to be uninfluenced by having just read the solution when one is solving a problem.

Although I agree with claims of the habituation hypothesis, what is habituation? That is, what processes are involved in habituation? It may be possible to describe habituation by appealing to notions that have been used here to explain the effect of spacing repetitions. Perhaps a habituated stimulus is one for which an encoding can be remembered rather than constructed. This view of habituation contrasts with a view recently proposed by Wagner (1976). Wagner claims that when an event is already represented in short-term memory, further occurrences of that event are rendered less effective than they would otherwise be. A similar hypothesis about the importance of short-term memory was tested in Experiment 2 of the present investigation. There it was concluded that the solution to a problem did not have to reside in short-term memory to influence the solving of the problem; all that appeared necessary was that the solution to the problem could be "effortlessly" retrieved. Similarly for habituation, it may only be important that a prior encoding of an event is retrieved so an encoding need not be constructed. This assumes that it is the necessity of construction that gives rise to the orienting response observed in studies of habituation.

A series of experiments by Waugh and Norman (1968) may be relevant to under-

standing the effects of spacing repetitions and the processes underlying habituation. Waugh and Norman were interested in specifying the nature of an event that would displace an earlier event from short-term memory. The results of their experiments revealed that a new and unpredictable event would displace an earlier event; however, a repetition of a recently presented event would not. If we identify short-term memory with consciousness, it appears that the processing of a massed repetition is automatic in that it does not heavily involve consciousness. Combining this piece with arguments made earlier we arrive at the following picture: Presentation of an event whose solution or encoding can be easily remembered does not give rise to an orienting response or heavily involve consciousness; presentation of such an event will also have little impact on later retention. The necessity of construction, in contrast, gives rise to an orienting response, involves consciousness to a greater degree, and produces a substantial effect on later retention performance. The spacing of repetitions has its effect by determining whether a solution or encoding can be remembered or must be contructed.

The Generality of Effects of Construction

Effects can be found using manipulations in addition to those employed in the present experiment and, therefore, the speculation about different modes of solving a problem or responding becomes more interesting. Before going on to deal with some negative effects of remembering a solution or encoding, one positive effect will be cited. A consistent finding reported in many reaction-time studies is that the response to an event that is repeated is quicker than the response to an event that occurred earlier but was not the last one to occur. Bertelson (1963) has proposed that when a stimulus is presented a subject first checks memory to see if the presented stimulus is the same as the one that immediately preceded it. If the stimulus is the same, the subject makes the same response as he did

previously; if it is not the same, the subject has to retrieve a response that is appropriate to the presented stimulus. The retrieval of a response takes additional time so responding is more rapid when the retrieval is not necessary; that is, when the subject can simply give the same response as was given to the immediately preceding stimulus. Bertelson's distinction between repeating a response vs retrieving a response is essentially the same as the distinction that has been drawn here between remembering a solution vs constructing a solution. Repeating a solution is more efficient than is constructing one in that repetition of a solution can be done faster and, perhaps, with less involvement of consciousness. Further, there is some evidence (Keele, 1969) that can be interpreted as showing that the repetition effect found in reaction-time studies, like the effects found in Experiment 2, are not limited to short-term memory.

Slamecka (Note 1) has reported results that are similar to those found here with the once-presented items. Slamecka found that generating a response to an item (e.g., a rhyme or an associate of the presented item) produced better later retention than did reading the same response. One factor that differentiates reading a response from contructing a response is that the task of constructing a response is a more difficult one. Several experiments have shown that a difficult inital task is associated with high levels of retention. Illustrations of the relation between the difficulty of an initial *retrieval* and subsequent retention level have been provided by Gotz and Jacoby (1974) and Whitten and Bjork (1977) among others. A parallel series of demonstrations has related the difficulty of an initial decision to subsequent retention level. For example, in one experiment by Jacoby, Craik, and Begg (in preparation) subjects were required to specify which word in a pair referred to the larger object; later retention was higher when members of a pair were close in size (flea–ant) rather than highly discrepant in size (flea–elephant). Aubel and Franks

(1978) have demonstrated that the difficulty of comprehension influences later retention. It was found that requiring additional effort toward comprehension of a sentence enhanced recall so long as the sentence was eventually understood.

There are some reasons to suggest that repeating an item a large number of times has effects that parallel those of massing repetitions of an item. Dependent upon the similarity of problems and other factors that contribute to interference, it is possible to remember the solution to a problem that has been solved rather than it being necessary to construct the solution when the problem is again encountered. That interference is important can be illustrated by asking the reader to find the sum of $37 + 15 + 12$, the math problem that was presented in the introduction of this paper. It is likely that the solution to that problem was easily remembered rather than it being necessary to again go through the operations of addition to solve the problem. This is true even though the presentations of the problem are widely separated. If interference had been increased by requiring the reader to solve a number of other math problems prior to repeating the one problem, however, it would be necessary to again go through the operations of addition to obtain the solution for the second presentation of the problem. Interference can apparently be offset by increasing the number of presentations of the repeated problem.

Many of the characteristics that have been used to describe "automatic" responding that results from repetition (e.g., Norman, 1976; Shiffrin & Schneider, 1977) are the same as those used here to describe responding to massed repetitions. An item that has been presented a large number of times is responded to more rapidly, and does not appear to tax the limited capacity processor that can be identified with consciousness. Effects on memory of presenting a well-learned item or a problem for which the solution can be effortlessly remembered might be expected to parallel those effects that are obtained when massed repetitions of an item are presented. A commonplace example is the difficulty in remembering whether or not we turned off a light switch. By the argument given here, memory for turning off the switch is poor due to the automatization of that activity through a large number of repetitions.

The experiments in the present investigation were concerned only with the effects of repeating an item or a problem. However, similar effects may be obtained as a result of extended practice with a *task*. Through practice, performance of a task usually becomes more efficient; the task is accomplished smoothly, rapidly, and with less effort. This greater efficiency may be gained at the expense of memory for the individual encounters with the task. Perception of words and other events can be considered as skilled tasks, and thus amenable to this analysis. Kolers (1975) has described the results of his experiments on reading transformed text in these terms. Kolers found that students that are unpracticed in reading inverted text remember sentences read in inverted text better than sentences read in normal text. However, after extended practice in reading inverted text, the memory advantage for *inverted* sentences largely disappears. That is, increased skill is associated with poorer retention. One finding that is particularly relevant to the present investigation has to do with manipulation of the transformation performed on the text. In one experiment (Kolers, 1973) transformations varied in the amount of difficulty they produced for reading. This difference in difficulty, however, was not mirrored in later retention performance; the effect of reading transformed text appeared to be all-or-none in that reading transformed text produced better memory than did reading normal text but there were no differences among the various transformations. This lack of a difference among transformations parallels the lack of an effect of problem difficulty found in Experiment 2 of the present investigation.

Proactive inhibition observed in studies of verbal learning may result from subjects becoming more skilled at the task of memorizing lists of words. As a function of paractice, fewer trials are required to reach a performance criterion on a list. That is, learning-to-learn occurs; coinciding with this increase in learning-to-learn is poorer retention for later lists in the series. In contrast to the interference theory of forgetting usually employed to interpret this proactive inhibition (e.g., Postman & Underwood, 1973), the present position emphasizes the influence of prior practice on the encoding of events at input. A similar argument regarding proactive inhibition has been made by Warr (1964).

The discussion here has obviously gone rather far afield in pointing out effects that may be related to those obtained in the present experiment. However, it does seem clear that requiring construction of a response influences the subsequent level of retention in a variety of situations. The mapping-out of similarities among those situations is likely to be useful. For example, it may be reasonable to talk about remembering vs constructing a procedure to deal with a particular task in much the same terms as are used for talking about remembering vs constructing a solution to a specific problem.

Why Should Construction Enhance Retention?

One interpretation of the effects discussed here assumes that a task is made easier or supports "automatic" processing by deleting some operations. Retention suffers since deleting these operations detracts from the distinctiveness of the encoding of the event and reduces the number of potential bases of retrieval. That is, there is less learned about the event to individualize it; there are fewer operations to be recognized and consequently, retrieval suffers (Lockhart, Craik, & Jacoby, 1976; Jacoby & Craik, 1978). In the case of the crossword puzzle problems employed in the present experiments, remembering rather

than constructing the solution may have made it unnecessary for the subject to deal with semantic relationships between the cue and solution word. Construction, in contrast, requires more processing of meaning and this more meaningful processing produces a higher level of retention (Craik & Lockhart, 1972).

One factor that is ignored by the level-of-processing and distinctiveness notions is the affective consequences of repetition. Generally, we do not enjoy sitting through the same movie twice, a joke heard for the second time is less funny, repeatedly producing the solution for the same problem is boring. The idea is that the necessity of construction involves consciousness and engenders arousal in a way that effortless remembering does not; it is this involvement of consciousness and heightened arousal that is responsible for difference in subsequent levels of retention. The consequences of repetition for arousal and consciousness were briefly described earlier in conjuction with the discussion of habituation. There is also evidence to suggest that arousal influences retention. One illustration of the effects of arousal is the memory of hearing about President Kennedy's assassination; people can typically recall in great detail the circumstances in which they heard the news. Brown and Kulick (1977) have described these vivid memories as "flashbulb memories" and go on to speculate that there may be some biological value associated with keeping an exact record of the circumstances surrounding a significant event. In this vein, it seems quite reasonable to argue that remembering the solution to a problem has biological value; a great deal of efficiency is gained if the solution to a difficult problem can be remembered rather than the problem being solved anew each time it is encountered.

A second example of the effects of heightened arousal comes from studies of animal learning. There it is found that the occurrence of a "surprising" stimulus is remembered longer and produces more learning than does

an expected stimulus (e.g., Kamin, 1969; Wagner, 1976); these effects may be due to heightened arousal. Until recently, a more commonplace effect that might be attributed to differences in arousal was supported by only anecdotal evidence; however, Kintsch and Bates (1977) have provided more traditional evidence by showing that students have excellent retention for jokes inserted in a lecture; indeed, memory of jokes often surpasses that of content material. The superior memory of jokes may be due to the greater success of jokes in capturing the interest of students. Variables such as interest or arousal are likely to have effects in a large number of situations including memory for prose, discussions (Keenan, MacWhinney, & Mayhew, 1977), and so forth; however, little has been done to incorporate these effects into theories of memory.

The notions of distinctiveness and arousal differ from one another in much the same way as do the notions of organization and strength (cf. Jacoby, Bartz, & Evans, 1978). An account in terms of distinctiveness or level-of processing attributes effects to differences in the extent to which an item is elaborated for encoding. Like the organization theories, the claim is that enhancement of retention requires that more aspects of an event be appreciated; particularly useful for retention is finding relationships among items in a list. The notion of arousal, in contrast, gives rise to what is essentially a strength theory of memory. In this instance, however, differences in strength are seen as being due to differences in arousal rather than to differences in number of repetitions as is usually assumed. If one is to argue in terms of biological value, a strengthening effect that results from arousal or surprise seems at least as valid as one that arises from an event being repeated.

The notions of level-of-processing and distinctiveness have been criticized for being vague (e.g., Baddeley, 1978). The idea of arousal is obviously at least as vague as that of level of processing . To further compound the

problem, it seems quite likely that both level-of-processing and arousal are involved in determining retention so that the task is not to choose between them but is rather to determine what contribution is made by each. Despite its difficulty, I feel that the task is not an impossible one; we are currently carrying out experiments that we hope will separate the effects of arousal from those that have been attributed to differences in level-of-processing or distinctiveness.

SUMMARY AND CONCLUSIONS

The present experiments clearly demonstrate that solving a problem enhances subsequent retention as compared to remembering a solution. Why solving a problem should yield this retention advantage is an important question for future research. However, application of the distinction between solving a problem and remembering a solution need not wait on an explanation of the retention differences. Even without such an explanation, the distinction has considerable heuristic value. By emphasizing the effects of remembering a solution, the distinction encourages the application of a large literature concerned with the conditions that foster memory. That literature can be used to suggest manipulations that will aid in the analysis of standard memory phenomena. The interpretation of the effect of spacing repetitions offered here provides one example. That interpretation claims that the poor retention after massed repetitions results from the encoding of later presentations of an item being remembered rather than constructed. The memory literature can be used to generate situations other than massed repetition that will foster easy remembering of a prior encoding or solution. For example, when repetitions of a word are separated in a list that is to be learned, remembering of the prior encoding for a repeated word should be more likely when repetitions are separated by some unrelated activity (e.g., adding numbers) rather

than by the learning of other words. Consequently, the effect of spacing repetitions should interact with the nature of the activity intervening between repetitions; the effects of spacing should be less pronounced when the intervening material is distinct from the items that are to be remembered. Similar lines of argument can be used to propose manipulations that will amplify or reduce proactive inhibition. As suggested earlier, proactive inhibition may in part result from a subject remembering rather than constructing a procedure for dealing with a particular task or class of situations. If so, manipulations that interfere with this remembering of procedures should reduce proactive inhibition.

The distinction between solving a problem and remembering a solution may also help to clarify the notion of automaticity. Previous authors have emphasized extended practice as a necessary precondition for automaticity (e.g., Norman, 1976; Shiffrin & Schneider, 1977). Similarly, in discussing language processing, Schank (1976) has suggested that repeated encounters with a given class of situation are instrumental in the evolution of a "script" that will guide the processing of further situations of the same kind. The view taken here, in contrast, equates automaticity with the remembering of a solution or encoding; the remembering of a solution eliminates the necessity of carrying out the computations that would otherwise be required to arrive at the solution, so performance appears automatic. This emphasis on remembering a solution can be used to suggest that factors in addition to extended practice determine automaticity. Remembering of the solution and, consequently, automaticity will also be influenced by the length of the delay since the last encounter with the task or event, the nature of the activity intervening since that prior encounter, the similarity of the current situation to the previous one, and so forth. The implication is that automaticity is situation-specific; a response that is automatic in one situation will not be automatic in a situation

that is less favorable to remembering. Further, the number of repetitions required to produce automaticity will depend on the values of other variables that influence remembering.

Another potential application of the distinction between solving a problem and remembering a solution involves reading. Programs of reading instructions have vacillated between employing "look-say" and "phonics" methods of instruction. The phonics method is designed to provide a set of rules so that one is able to construct a pronunciation by dealing with parts of a word while the look-say method instructs the learner to remember the pronunciation for the word as a whole. A question of continuing concern relates to the skilled reader: Does the skilled reader remember or construct a pronunciation for a word? By the view taken here, both remembering and construction are likely to be involved. When a word is presented in an unfamiliar context, for example, construction of a pronunciation may be necessary. However, if that word is then repeated after a short duration, it seems unlikely that it is necessary to fully repeat the prior construction to arrive at a pronunication; rather, the pronunciation can be remembered. Mixing of these modes of word indentification is also possible. The reader may engage in some construction with the effect that the construction yields a sufficient number of additional cues to allow remembering of the pronunciation; rendering further construction unnecessary. In connected discourse, repetitions occur with substantial frequency. Further understanding of the effects of these repetitions on processing appears essential for a realistic theory of word identification. Similar arguments can be applied to other aspects of reading. For example, when an argument is first encountered in a paper, comprehension of the argument may require a great deal of construction; however, depending on the conditions for memory, the argument may be remembered rather than constructed when it is encountered again later in the paper.

In conclusion, to understand the effects of repetition we must specify how the processing of the repeated event is altered by its prior presentation. It is incorrect to conclude that because an event is repeated the processing of that event is also repeated. Rather, repetition of an event can result in the solution being remembered without the necessity of engaging in the activities that would otherwise be required to obtain that solution. The means by which a solution is obtained influences subsequent retention performance; subsequent retention suffers when the solution is remembered rather than being constructed. The reason for this retention advantage of construction is not clear; however, arousal and the necessary involvement of consciousness in construction may play some role. The distinction between solving a problem and remembering a solution is potentially useful for understanding several phenomena including the effects of spacing repetitions, proactive inhibition, and automaticity. The distinction also appears important for an analysis of tasks such as word identification.

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