SOME TESTS OF THE DECAY THEORY OF IMMEDIATE MEMORY

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The hypothesis of decay of the memory trace as a cause of forgetting has been unpopular. The reasons for this unpopularity are criticized and a theory of the memory span, based on this hypothesis, is put forward. Three experiments which test the hypothesis are described. In each, two kinds of stimuli are presented to the subject, viz., "required" stimuli, which he attempts to remember, and "additional" stimuli, to which he merely makes responses. The first experiment will show that even when the number of required stimuli is well below the memory span, forgetting occurs if the presentation of additional stimuli delays recall for several seconds. The second shows that the effect of the additional stimuli depends only slightly on their similarity to the required stimuli; it also shows that their effect is negligible when they precede, instead of follow, the required stimuli. The third shows that the effect of additional stimuli interpolated before recall remains considerable even when there is an interval of several seconds between presentation of required and additional stimuli.

INTRODUCTION

The experiments reported below concern memory over a period of a few seconds, when only a single presentation of the material has been given. It is convenient to describe such memory as "immediate." The experiments form part of a series described in an unpublished Ph.D. dissertation (Brown, 1955): two of the series have already been published (Brown, 1954, 1956).

Immediate memory usually operates under conditions very different from those provided in conventional immediate memory tests. Typically, it is necessary to retain information while continuing to carry out other activities. In a lecture delivered in Cambridge in 1950, Sir Frederic Bartlett suggested that forgetting may be extremely rapid under these circumstances. The series of experiments began as an attempt to put this suggestion to an experimental test, with highly positive results. However, the three experiments described below, while they illustrate rapid loss of information in immediate memory when other activity intervenes before recall, were designed to test a particular theory of immediate memory. The basic hypothesis of this theory is that when something is perceived, a memory trace is established which decays rapidly during the initial phase of its career. (By memory trace is meant only the neural substrate of retention, what this may be.) Some decay of the trace is assumed to be compatible with reliable recall—just as partial fading of print may be compatible with perfect legibility But recall will cease to be reliable if decay of the trace proceeds beyond a critical level.

Two of fundamental problems of immediate memory are (l) the origin and nature of the immediate memory span, and (2) why we forget when this span is exceeded. One solution to these problems is to postulate a special mechanism for short-term retention. The memory span can then be regarded as the capacity of this special mechanism. When the span is exceeded, forgetting will occur because retention becomes dependent on a mechanism which is less efficient. The hypothesis of rapid decay of the memory trace, however, also provides a possible solution to these problems and one which has the merit of simplicity. The hypothesis leads to a theory of the memory span which in outline runs as follows: When a sequence of items is presented, the interval between the perception of each item and the attempt to recall that item will depend on the length of the sequence. If the sequence exceeds a certain length, decay of the memory traces of some of the items will proceed too far for accurate recall of the sequence to be possible. This length is the memory span. Thus the trace-decay hypothesis can explain both the origin of the span and why forgetting occurs when the span is exceeded.

The hypothesis that decay of the memory trace is an important cause of forgetting has been unpopular. However, theories of forgetting have developed almost entirely in relation to forgetting over relatively long periods. Where forgetting over very short periods has been specifically considered, there has been greater readiness to postulate a decay process. Thus the "stimulus trace" which plays an important role in Hull's explanations of serial learning phenomena (Hull, 1940) is assumed to decay rapidly. Decay of the trace has also been invoked from time to time to explain negative time errors in psychophysical judgment (e.g. Pratt, 1933). The two main reasons for the unpopularity of the decay theory are the existence of distortions in remembering and the importance of the similarity factor in P. I. and R. I. (pro- and retro-active inhibition). These facts have seemed to some to imply a more dynamic theory of forgetting than is provided by decay of a static trace (notably to Bartlett, 1932, and to Koffka, 1935). To others they have seemed to show that a competition-in-recall theory of forgetting is adequate (e.g. McGeoch, 1942, and Underwood, 1957). But it is possible to argue that distortions in remembering are due to the constructive and inferential character of recall, made necessary by decay of the memory trace (Brown 1956). In like manner, competition -in-recall may itself be a manifestation of such decay, a point which seems to have been overlooked and which merits discussion.

Competition-in-recall may mean one of two things. It may mean that a competing response inhibits recall of the required response. In this case, the competition theory is a genuine theory of forgetting and belongs to that class of theories according to which, for some reason, not dependent on the state of the trace itself, the trace fails to lead to effective recall. Alternatively, it may mean that both responses tend to be elicited and that the organism is unable to distinguish which of the two responses is correct. It is important to recognize that such failure of discrimination, i.e. confusion between responses, cannot be regarded as a primary cause of forgetting. Failure of discrimination presupposes forgetting of that which determines which of the responses is correct. It is thus a possible *effect* of forgetting, however caused, but is not itself a primary cause of forgetting. Now experiments which have demonstrated the importance of the similarity factor on R.I. and P.I. have invariably used an interfering material which could be confused with the required material; very often, for example, both materials have consisted of nonsense syllables. Properly considered, therefore, the results of such experiments do *not* constitute evidence against the decay of the trace of forgetting,

EXPEPRIMENT I

On the hypothesis of decay of the memory trace, recall will become unreliable if decay proceeds too far, i.e. if the retention interval exceeds a certain length. This will apply whether or not the amount the subject attempts to retain lies within the memory span. One way to test the hypothesis of decay of the trace, therefore, is to see whether if recall is delayed for several seconds forgetting occurs even when the amount of material is well within the memory span. However, if the subject is left free to rehearse the material during the delay, no forgetting is to be expected. For rehearsal is itself a form of recall, albeit implicit, and is likely to counteract the effect of decay, either directly, or through the establishment of a new trace. Thus, in order to test the hypothesis, it is necessary to require the subject to perform an additional activity during the delay period so that rehearsal is prevented. And it must be arranged that this activity involves a high information rate, if prevention of rehearsal is to be really effective. In the following experiment, between 1 and 4 pairs of stimuli were presented for the subject to remember and there was an interval of just under 5 sec. before recall. Under one condition, the subject was required to make immediate responses to 5 pairs of additional stimuli during this interval in order to prevent rehearsal; under a second condition, the interval was empty.

METHOD

Condition I: On each trial two sets of stimuli were presented in immediate succession. The subject was instructed to read out the stimuli of both sets during presentation and to attempt to remember the stimuli of the first set. The first set will therefore be called the required or "M" stimuli and the second set the additional or "X" stimuli. The required stimuli consisted of between 1 and 4 pairs of consonants (excluding the consonant Y), which were randomly selected except that no consonant was repeated in the stimuli for any one trial. The additional stimuli consisted of 5 pairs of number digits copied directly from tables of random numbers. Both sets of stimuli were recorded on a paper strip, the required stimuli in black and the additional stimuli in red. This strip was passed behind a screen in which there was a viewing window so that the stimuli appeared pair by pair (for details of apparatus, see Brown, 1954). The sequence of events on each trial was as follows. The experiment said "ready" and a warning line appeared in the window. Then, after 0.5 sec., the pairs of stimuli followed at intervals of 0.78 sec., (all the M pairs ware presented before the X pairs). As soon as presentation was over, the subject attempted to write down the required stimuli. Each consonant was scored correct if, and only if, it was reproduced in the correct position in the sequence.

Condition II: This was the control condition and differed in that the additional stimuli were omitted, i.e. there was still an interval (4. 7 sec.) before recall, but it was unfilled.

Six Stimulus strips were prepared, three for each condition. Each strip carried stimuli for 3 trials with 1 pair of M stimuli, followed by 3 trials with 2 pairs, 3 with 3 pairs and 4 with 4 pairs (but trials with only 1 pair were omitted under Condition II). Ten university students were tested and each was first given a practice strip. Condition I and Condition II strips were given alternately. Half the subjects started with Condition I and half with Condition II.

Two of the original 10 subjects made an acceptable number of errors in reading out the stimuli during presentation. Accordingly, two substitutes were tested instead. With the other subjects reading errors were rare. Reading errors were also rare in the other two experiments.

RESULTS

Table I shows the scores for the subjects as a group under the two conditions.

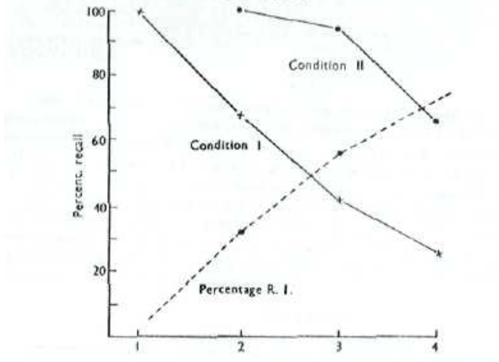
Table 1

Pooled Recall Scores

	Number of pairs of required stimuli			
	1	2	3	4
Condition I	176	244	221	181
Condition II	—	358	505	471
Maximum possible ..	180	360	540	720

In Figure 1, these scores are shown as percentages. The most striking features of the results is that only single pair of stimuli were retained without error when the additional stimuli intervened before recall. The dotted line in Figure I represents the effect of this activity as percentage R.I. It will be seen that the effect increases with the number of pairs of required stimuli. Table I I shows that percentage recall for the last pair of required stimuli was much higher when there was only one pair of required stimuli than when there were four pairs: the difference is significant for each subject individually on a x^2 test ($p < 0.05$).

FIGURE I



Number of pairs of required stimuli

DISCUSSION

The results confirm what was expected on the hypothesis of decay of the memory trace: a delay of several seconds before recall could produce considerable forgetting, if rehearsal was prevented, even when the number of stimuli was within the memory span, as shown by a control condition.

TABLE II

RECALL OF LAST PAIR

Number of pairs	1	2	3	4	5	6	7	8	9	10
1 ..	18	18	18	18	15	18	18	18	17	18
4 ..	11	10	14	4	0	10	7	9	9	12

Figure I shows that the effect of preventing rehearsal varied with the number of required stimuli. This can be partly attributed to the increase in the mean interval between presentation of stimuli and the start of the recall period which occurs as their number increases (since the stimuli are presented successively). But this is not the whole explanation. Table I I shows that recall of the last pair of required stimuli, for which the interval was constant, was not independent of whether there were previous pairs. Several factors may contribute to this result. Firstly, since the subject attempts recall of the stimuli in the order of their presentation, recall of the last pair is delayed by recall of earlier pairs. And as one might expect on the trace decay theory, this can lead to further forgetting (Brown, 1954). Secondly, prevention of rehearsal may not be fully effective when there is only a single pair of stimuli to rehearse.

EXPERIMENT II

This experiment tests two further deductions from the decay of the trace hypothesis about the effect of additional stimuli to which the subject is asked merely to make responses, on the recall of required stimuli. The first concerns the effect of similarity between required and additional stimuli. The second concerns the effect of additional stimuli presented immediately before the required stimuli.

(1)On the trace-decay hypothesis, the similarity factor should be important only in so far as it leads to confusion in recall. This has already been argued in the Introduction. On certain other theories of forgetting, the similarity factor can be a crucial one. For example, according to Koffka (Koffka, 1935), similarity determines the extent to which perceptions interfere with pre-existing traces and to which traces interfere with one another.

(2)Stimuli presented immediately before the required stimuli should have little effect on recall on the trace decay hypothesis, since they cannot prevent rehearsal of the required stimuli during retention. Again on other theories of forgetting, inter--ference is possible or even likely. For if incidental learning of the additional stimuli occurs, the traces so established may interact with the traces subsequently established by the required stimuli or may lead to blocking of recall. Even on the decay hypothesis however, such incidental learning may have a slight effect. For it may lead to confusion of the additional and required stimuli in recall. Accordingly, in the experiment, the effect of additional stimuli which precede the required stimuli is studied, both where such confusion is possible (i.e. both sets of stimuli belong to the same class) and where it is not possible (i.e. one set consists of digits and the other of consonants).

Previous work: Several experiments have concerned the similarity factor in immediate memory. Robinson (1927) found, as one might expect, that recall increased with the degree of percentage identity between the two halves of a list. Harden (1929) and Young & Supa (1940 found that, if one half of the list consisted of consonants and the other of digits, recall was higher than when the whole list. consisted of items of the same kind. This result is held to show that intra-serial R.I. and P. I in immediate memory are a function of the similarity factor. But it is a result which seems readily explicable in terms of reduced intra-serial confusion when the two halves differ. Thus 8 consonants, for example, can be arranged in 40,320 ways: whereas 4 consonants followed by 4 digits can be arranged in only 576 ways. It is therefore quite compatible with the trace-decay hypothesis. An experiment by Pillsbury & Sylvester (1940)- to which little attention has been paid—makes ques- tionable any assumption that R.I. in immediate memory is a function of similarity to a marked extent. They studied the effect of different activities interpolated during a 10-sec. retention interval. Comparison between the effects of these activities is a little difficult, since there was no control of the rates at which they were performed.

Nevertheless, it is noteworthy that all activities produced considerable R.I., irrespective of whether there was much similarity between original and interpolated materials.

METHOD

Only differences from the method of Experiment I will be described. The required, M, stimuli consisted of four pairs of consonants. The additional, X, stimuli consisted of either three pairs of consonants or of three pairs of digits: these two types of X wilt be referred to as Xs and Xd respectively (i.e. similar to or different from M). No consonant or digit was repeated in the stimuli for any one trial. The additional stimuli were presented either immediately before or immediately after the required stimuli. Thus there were four experimental conditions which will be labelled Xs (before), Xd (before), Xs (after), Xd (after). In addition there was a control condition under which no additional stimuli were presented. The pairs of stimuli were presented at intervals of 1.33 sec. This relatively slow rate was chosen so that subjects would not have any tendency to make mistakes in reading out M stimuli when they had been immediately preceded by X stimuli. The interval between the start of each trial and the presentation of M and the interval between the presentation of M and the start of the recall period were both 5.33 sec. under all conditions. Five paper strips were prepared: each carried eight trials under one of the five conditions. After a practice strip, with samples of all conditions, each subject was given the Strips in a different order. Each strip was taken equally often at each stage of the experiment. The 15 subjects were university students.

RESULTS

Table III shows percentage recall of the required stimuli by the subjects as a group under the various conditions. An analysis of variance of individual scores was performed, after transforming each score, s, to $\sin^{-1}{}_{s}$ in order to improve the stability of the error variance. The variance attributable to conditions was highly significant ($p < 0.001$). The residual variance of this analysis was then used to calculate " *t*" for each of the comparisons (in transformed scores) shown in Table IV. From Tables III and IV it will be seen that (i) bulb Xs (after) and Xd (after) produced very large amounts of interference, (ii) Xs (after) produced slightly but significantly *(p* < 0.05) more interference than Xd (after), (iii) Xs (before) produced slight interference *(p* (*0.01)* but Xd (before) did not.

TABLE III

PERCENTAGE OF RECALL SCORES

PERCENTAGE I

Control	*Xs (before)*	*Xs (after)*	*Xd (before)*	*Xd (after)*
67·3	58·6	25·6	65·5	30·6

TABLE IV

Comparison	*t* *(*with 56 d.f.*)	*Significance*
1. Control with Xs (before) ..	3·39	$p < 0·01$
2. Control with Xd (before) ..	< 1·0	not significant
3. Xd (after) with Xs (after) ..	2·03	$p < 0·05$

* Derived from analysis of variance: *see* text.

*

The extent to which subjects inadvertently gave additional stimuli in their recall attempts, when both sets of stimuli consisted of consonants, is of interest. No consonant was repeated in the stimuli for each trial and the letter Y was not used. On each trial, of the 20 possible consonants, 8 were used for M stimuli, 6 for X stimuli and 6 were not used on each trial. Thus on a chance basis, intrusions from Xs should form about half the total number of intrusions. With Xs (after), 122 out of a total of 234 intrusions, i.e. a little over one half, were Xs stimuli. This is not significantly more than chance expectation on a X^2 test, which provides an approximate test of significance. But with Xs (before), 76 out of a total of 194 intrusions, i.e. less than one half, were Xs stimuli. This is significantly less than chance expectation on a X^2 test ($p < 0.01$).

DISCUSSION

Both deductions from the trace-decay hypothesis appear to be confirmed. When the additional stimuli intervened before recall, their similarity to the required stimuli was of minor importance in determining the amount of interference produced. When they preceded the required stimuli, the interference was slight, and occurred only when the two sets of stimuli could be confused in recall. Several points require discussion, however.

The effects of consonants and digits as additional stimuli may differ intrinsically, irrespective of their similarity to the required stimuli. This could distort the apparent importance of the similarity factor. Another experiment of the series (Brown, 1955)—which is primarily concerned with a different problem—shows, in conjunction with the results of the present experiment, that there is in fact little difference in the intrinsic effects of the two kinds of stimuli. It is therefore safe to accept the conclusion that the similarity factor is of minor importance (at any rate for the type of similarity studied).

On the trace-decay hypothesis, it was expected that any effect of similarity would be attributable to confusion in recall. In conformity with this expectation, intrusions from these stimuli were a little higher than would be expected on a chance basis, when similar stimuli intervened before recall. But when similar stimuli preceded the required stimuli, intrusions were significantly less than would be expected on a chance basis, although slight interference was produced by these stimuli. This is certainly puzzling. A possible explanation is that, if the unwanted stimuli intrude in the process of recall, this will tend to delay recall of required stimuli, even when the subject recognizes them as intrusions and does not include them in his overt recall attempts. This would impair recall, on the trace-decay hypothesis, and yet lead to fewer intrusions than would be expected on a chance basis, since no consonant was used twice in the stimuli for any one trial.

EXPERIMENT III

If an interval is introduced between the required stimuli and the additional stimuli which intervene before recall, the subject is likely to rehearse the stimuli during this interval. Everyday experience—of trying to remember telephone numbers, for example —suggests that the effect of such rehearsal may be to counteract decay of the trace rather than to strengthen it much, since continuing rehearsal tends to be necessary to prevent forgetting. If this is so, an interval between the required and additional stimuli should not drastically reduce the interference produced by the latter on the trace-decay hypothesis. On a theory which ascribes the effect of intervening stimuli to interference with the traces of the required stimuli, however, this interval might prove to be very critical, for there is much evidence to suggest that the lability of the memory trace- at least to gross cerebral disturbance—is highest immediately alter learning and declines rapidly with its age. Thus a blow on the head often produces short-term retrograde amnesia and the various forms of shock therapy have the same effect. Some of the most interesting evidence comes from experiments on the effect of electro-convulsive shock on learning; Duncan (1949), for example, studied the effect of different time intervals between learning trials and the administration of shock for rats learning a simple, avoidance response. There was little evidence of learning if the interval was under 20 sec. and little interference with learning if it exceeded 60 sec.

It is of interest that Muller & Pilzecker (1900), who introduced the misleading expression "retroactive inhibition" (ruckwirkende Hemmung), believed that an activity interpolated during retention interferes with a process of consolidation in the memory trace. Consolidation was believed to depend on a sort of after-discharge of the neural elements involved in learning (it is not, therefore, to be identified with rehearsal, which consists of successive voluntary recall). The idea of a perseverating neural activity following learning, which consolidates a (presumably) structural trace, is not unlike the dual trace mechanism of Hebb (1949) and others.

METHOD

Again only differences from the method of Experiment I will be described. The required, M, stimuli consisted of three pairs of consonants and the additional, X, stimuli of three pain of digits. The pairs were presented at interval of 0.78 sec. However, the interval between the last M pair and the first X pair was varied and was either 0.78, 2.34 or 4.68 sec.: these will be referred to as Intervals I_1, I_2, and I_3, respectively. The total length of the retention interval was held constant at 7 sec. A practice strip was prepared and THREE test strips. Each test strip carried Stimuli for three I1, three I2, and three I3 trials. The orders of I_1, I_2, and I_3, in the different strips formed a Latin square. After the practice Strip, different subjects took the different strips in different orders. At the start of each trial, the subject was told the position of the X stimuli. Twelve university Students were tested.

TABLE V

INTERVAL IN SECONDS

0·78 (I_1)	2·34 (I_2)	4·68 (I_3)
41	54	59

(percentage recall scores).

RESULTS

Table V shows mean percentage recall scores for the group for_different sizes of the interval between the required and additional stimuli. As in the previous experiment, individual scores were subjected to analysis of variance. The variance attributable to variation of the interval was highly significant (*p<0.001*). The analysis also showed that the effect of increasing the size of the interval was non-linear ($p < 0.05$). It will be seen from Table V that as the Interval increased from 0.78 to 4.68 sec. recall rose from 41 to 59 per cent. It will also be seen that the increase in the interval from 0.78 to 2.34 sec. was relatively more important than the increase from 2.34to 4.68. Another experiment of the series under comparable conditions gave similar results. Nearly all subjects spontaneously reported "going over" the letters during the longer two intervals. Some subjects also reported searching for interpretations of the letters such as "National Debt" for ND.

DISCUSSION

Recall was 59 per cent, when the interval between the required and additional stimuli was about 4 sec. and about 41 per cent, when the interval was less than 1 sec. With similar subjects, recall was 94 per cent, in Experiment I when there were no additional stimuli, but conditions were otherwise almost identical. Thus even when the interval was about 4 sec., the additional stimuli must still have produced considerable interference to keep recall as low as 59 per cent. The conclusion is that increase in the interval from less than 1 sec. to about 4 sec. only moderately reduces the interference produced by the additional stimuli. This reduction ran plausibly be attributed to the effect of rehearsal during the interval, without postulating any additional effect such as diminished interference with traces. A rough cheek—based on asking subjects to rehearse aloud suggests that two or three complete rehearsals of the required stimuli are possible during an interval of 4 sec. It is not impossible that the moderate strengthening of learning which did occur was due, not to rehearsal as such, but to finding interpretations of the letters, in the manner spontaneously reported by some subjects (e.g. "National Debt" for ND). If so, this raises the interesting problem of why immediate rehearsal has no permanent effect on learning.

GENERAL DISCUSSION

The results of the individual experiments have already been discussed. They fit well with the hypothesis of rapid decay of the memory trace when it is first established.

It is not claimed that they are incompatible with alternative theories of forgetting. The merit of the decay hypothesis lies in its simplicity and its ability to explain the results without arbitrary auxiliary hypotheses. Results of other recent experiments can also be readily explained on the hypothesis. Brown (1954) found that the delay produced by recalling earlier members of a sequence impairs recall of later members. Conrad (1957) has reported that, if the rate of recall of the sequence as a whole is reduced, recall is likewise impaired. Broadbent (1956, 1957) presents results on a two-channel intake of information which can be interpreted, as he points out, as an effect of trace-decay, although in this case a subsidiary hypothesis is also required (1957, p. 6).

Any theory about forgetting in immediate memory, if it is to be acceptable, must take account of the memory span. A theory of the memory span, based on the hypothesis of trace-decay, was outlined in the Introduction. However, the main problem is not the mere existence of a limit to the amount which can be fully recalled following a single presentation: it is the fact that this limit is on a number of disconnected items or "chunks" (Miller, 1956) rather than on information content. Can the trace-decay hypothesis provide a solution to this problem? This will now be considered.

Partial decay of the memory trace of an item is assumed to be compatible with reliable recall because the trace may adequately specify the item, even when it has lost some of its initial features—in other words, because of initial "redundancy" in the trace. The extent of this redundancy should be inversely related to the information content of the item (c.f. a chalk mark remains legible, after more smudging if it can only be "A" or "B" than if it can be "A" or "B" or "C" or "D"). This means that the critical interval, after which recall becomes unreliable, will be longer for items of low information content than for items of high information content. Consequently one might expect the span to vary directly with the information content of the items. But this does not take account of the fact that the items have to be recalled in a sequence. If the redundancy of those aspects of the traces which mediate retention of the order of the items is low, it is primarily the information content of the order which will determine the size of the span. This could explain why the span is a relatively fixed number of items irrespective of the information content of the items, since the order information depends only on the number of items, provided the items are all different and the order is random, (the order information in such a sequence of n items is $\log_2$nl "bits"). One way to test this hypothesis would be to see whether the size of the span becomes much larger if the subject is not required to recall the order of the items. But unless he recalls the items in order of presentation, the retention interval will be disproportionately long for some items. Moreover, recall in the order of presentation may well aid recall of what the items are. A better test, therefore, would be to see whether the span is greatly increased if the order information is reduced or eliminated. It is significant and probably not just accidental that the span is high for words in a meaningful passage, since here the constraints of language partly predetermine the order of the words and hence greatly reduce the order information.

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