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Mechanisms of Forgetting in Short-Term Memory

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This paper introduces a technique applicable to the question: Does information in short-term memory disappear with time? The technique appears to eliminate *Ss'* rehearsal in the retention interval without introducing potentially interfering material. In the experiment, *Ss* read aloud three words, then engaged in a difficult auditory signal detection task intended to keep them from rehearsing for 15 sec, and then attempted to recall the three words. The results provide no support for the principle of loss with time as an explanation of forgetting in short-term memory.

Current theories of forgetting in short-term memory (STM) include one or more of the following four basic operating principles: Displacement (Waugh & Norman, 1965, 1968), decay (Brown, 1958, 1964), associative interference (Adams, 1967; Keppel & Underwood, 1962; Postman, 1961), and acid-bath interference (Posner & Konick, 1966; Reicher, Ligon, & Conrad, 1969). The latter three have in common the notion that without rehearsal information in STM is lost in time. In the case of decay, it is straightforward. In the associative interference principle, loss in time occurs through the mechanism of unlearning; in the acid-bath principle, through the postulate that the greater the time an item is in the acid, the greater the loss. The displacement principle, on the other hand, says that it takes succeeding inputs to a limited-capacity buffer store to produce forgetting; nothing will be lost if time passes without new inputs displacing the resident items. If we are to determine which principles are in fact involved in forgetting in STM, we might first distinguish between these notions of time-loss and displacement.

Since variables other than elapsed time affect retention, the notion of

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time-loss is not sufficient explanation for all of the forgetting that takes place in STM. For example, the greater the number of items attended to immediately after the item to be retained, the greater the forgetting (Conrad & Hull, 1966; Norman, 1966; Spring, 1968), and the greater the similarity of the interpolated material to the retained items the greater the forgetting (Ligon, 1969). This does not mean, however, that information does not decay with time. Rather, time-loss may not have been evidenced in the designs employed because its effects were masked by overriding interference. Suppose for example, as in Reitman (1970), that displacement and decay both cause forgetting in STM. Items in a buffer store decay if undisturbed, but are vulnerable to being displaced by succeeding inputs. Only when the items in STM are not displaced will decay produce the forgetting evidenced.

To determine the amount of effect time-loss has, if, in fact, it does exist, we need a situation in which the factors known to produce interference of all kinds are minimized while time passes without rehearsal. This paper presents a technique intended to produce such a situation.

The technique is a variant of the Peterson and Peterson (1959) paradigm. Material is presented for the subject (S) to retain, followed by a filler task intended to prevent him from rehearsing, followed by a request for recall. In the technique introduced here, a tonal signal detection task is the filler task used to control rehearsal, minimize interference, and allow parametric variations in experimental conditions.

To insure minimal interfering use of STM, the detection task must be constructed so that the S will not retain the time of the last signal to predict when the next one will occur. Accordingly, signals are presented at points determined by a Bernoulli process, leading to a binomial distribution of events. At every point in time, the probability that a signal will occur at the next point is constant, and independent of the number of prior signals.

The best test of recall comes when no signals are presented in the retention interval. Obviously, the retention interval cannot be consistently empty if we want to assure that the S is attending the detection task and is not rehearsing. Accordingly, on every trial the S expects one or more signals to occur; but, in fact, on some of the trials, no signal occurs.

Rehearsal during the retention interval must be controlled. Define the term "rehearsal" to be conscious purposeful subvocal repetition of the items to be retained. The S can allocate his attention to rehearsal or any other cognitive activity, such as perceiving new information, coding resident items for long-term memory, and retaining useful information for the performance of an ongoing task. By increasing emphasis on the importance of an activity other than rehearsal, it should be possible for the experimenter to reduce the chance that the S rehearses. In the technique presented here, the S is instructed in the importance of accurate, speedy, signal-detection performance. He is led to believe it is highly disadvantageous for him to try to rehearse. In addition, the task is made very difficult; the signal-to-noise ratio is set so that the S can hear only about 50% of the signals.

To check on whether the S did rehearse, comparison is made between his performance in the retention interval and his control performance. A study by Johnston, Greenberg, Fisher, and Martin (1970), using a tracking filler task, found that if the S tried to rehearse while tracking, his tracking performance fell drastically below his control performance. This suggests that the signal detection task used here is, similarly, a sensitive indicator of concurrent rehearsal. Given identical performance in experimental and control conditions, it is appropriate to conclude that the S did not rehearse.

In sum, the paradigm uses a detection filler task which is highly difficult, coupled with instructions which motivate the S to attend carefully to it. A check is made on whether the S rehearsed both by comparison of the level of his filler performance with a detection control, and by asking him postexperimentally whether he did avoid rehearsal. If either of these checks indicates rehearsal, the data for the S are excluded from analysis.

The experiment reported here incorporates variants of this technique which allow assessment of the effects on retention of: (1) time, (2) the number of succeeding presented pieces of information, (3) interpolated verbal and nonverbal material, and (4) the S's own vocal response.

METHOD

The entire experiment was controlled through a PDP-8 computer and its auxiliary oscilloscope, teletype, and reaction-time key. The S worked by himself in an experimental room, seated at a teletype, with a reaction-time key immediately to his right. A rectangular 9 × 11-in. oscilloscope screen was positioned directly above the teletype carriage. Throughout the experiment, the S wore Koss Pro-4A earphones.

The conditions of the experiment consisted of a STM task with one of several signal-detection tasks embedded in the retention interval. In what follows, the details of the STM task and the signal-detection tasks are presented separately, followed by a description of how they were combined.

The Short-Term Memory Task

Three common English four-letter nouns of one syllable[2] appeared simultaneously on the oscilloscope for 2 sec. The S read the words aloud. The beginning and end of the 15-sec retention interval were denoted by inverted and upright Ts, respectively, each presented on the scope for ½ sec. A row of question marks appeared after the terminal upright T to signal the S to type what he could remember of the three words on the teletype in the next 15 sec. A rest interval of 7 sec preceded the beginning of the next trial. Each trial in a block of 12 trials began 40 sec after the beginning of the previous trial.

The Signal-Detection Tasks

Three different types of detection tasks were used: tonal detection, silent syllabic detection, and vocal syllabic detection. The timing characteristics of the three tasks were identical. During each 15-sec interval, a signal could occur n times, where n ranged from 0 to 14. The distribution of the number of signals in a trial was binomial, set so that the probability of no signal in a 15-sec interval was 0.14. This kept the subjective expectation of an empty interval low. Whenever the S heard the signal, he pressed the reaction-time key with his right index finger.

The tonal detection task. This task consisted of the presentation of a pure tone in a background of white noise. The tone was a 100-msec 1000-Hz square wave. A wide-band white-noise generator produced the background noise. The signal-to-noise ratio was varied for each S according to a preexperimental performance criterion.

The syllabic detection tasks. The two other detection tasks were identical in presentation but differed in the response required of the S. The tasks consisted of detecting when the spoken syllable "toh" occurred in a background series of "doh"s. For the silent syllabic task, the S was required to press the key as soon as he heard each "toh." For the vocal syllabic task, the S was to both press the key and say the syllable "toh" out loud each time he heard it.

The syllables "doh" and "toh" were artificially produced sounds made by a synthesizer at Haskins Laboratory. These syllables sounded as if they were read by a human male in a monotonous voice. The syllables occurred at 500-msec intervals and lasted 350 msec. They were presented in a background of white noise, the intensity of which was the same as in the tonal-detection task. The syllables were equally intense at a level which was varied for each S according to a preexperimental performance criterion.

[2] The words are listed in the Appendix of Reitman (1969).

Task Difficulty

These detection tasks were intended to challenge the S so that he would not rehearse. Accordingly, for each S the signal-to-noise ratios were selected prior to the experimental session to give a detection level of 50% for both the tonal and the two syllabic tasks.

Conditions

The three experimental conditions involved the retention of a triplet of words over a 15-sec period during which the S performed one of the three detection tasks. Two control conditions were included to allow comparison of each S's detection performance in the experimental conditions with his performance when he did not have to retain the words. One control condition was for tonal detection and one for silent syllabic detection. In order to make the control situation similar to the experimental situation, the S began detecting after reading the three words out loud, but was informed that he was not required to remember the words.

Each S was given 10 blocks of 12 trials each, two blocks devoted to each condition. One block of each control condition was presented first and last in the session, providing information about the change in detection performance with practice. The three experimental conditions (with the two blocks of each condition following in succession) were assigned to each set of six Ss such that all order permutations were included. The words were ordered differently for each S in a set.

In each session, the S was first "calibrated" to determine the signal-to-noise levels for the detection tasks that gave 50% detection. He was then given five trials on each of the three detection tasks (without memory tests), followed by five trials on the memory condition with the tonal detection filler task. A 90-min experimental session followed, ending with an interview of the S about his strategies and his estimate of success in following the instructions.

Instructions

The instructions emphasized the desirability of consistent high performance on the detection tasks. The S was told that the experiment concerned his ability to concentrate both after just having done something else and while having something on his mind (the words). The instructions explicitly told the S to avoid any tendency to repeat the words to himself while trying to detect the signals.

Subjects

The Ss were 18 right-handed undergraduate males from the University of Michigan pool of Ss, paid $2.00 an hour for their participation. All had some knowledge of typing.

RESULTS

Did the Subjects Rehearse?

To the question: "Could you avoid repeating the words to yourself while trying to concentrate on detecting the signals?", all 18 of the Ss in this study reported success. The experimental procedure provided checks of the accuracy of the Ss' reports. Each S's performance on the signal-detection task when he was to remember the words could be compared with his performance when he had no need to retain the words.

The difference between performance in the control and experimental conditions, first in terms of *d′* [3] (Swets, 1964), was calculated for each S. For the group as a whole, these differences were not significantly distinct from zero for all three tasks. On the average, the Ss detected as well in the experimental conditions as in the control conditions (see Table 1).

The group performance is not, however, as important as individual performance if one intends to detect a single S's rehearsal. Accordingly, an "outlyer" test (Kendall & Stuart, 1961; David, Hartley, & Pearson, 1954) was applied to each S's *d′* measures. This test is a method of determining whether a single S's experimental *d′* is significantly below his control *d′*. According to this test, there were no outlyer scores in the sample of 18 Ss.

TABLE 1
Detection Performance

Condition/Task	Signal detection (*d′*)			Reaction time (msec)		
	Tonal	Silent syllabic	Vocal syllabic	Tonal	Silent syllabic	Vocal syllabic
Experimental	3.10	2.70	2.68	457	425	465
Control	2.87	2.78	2.78	449	428	428

[3] To compute the *d′* measure for the tonal task, we assumed that the 15-sec detection period was broken up into 15 single-second intervals. If a response occurred later than 100 msec and before 1100 msec after an event (signal or no signal), it was considered a reaction to that event. Responses falling outside this range were considered reactions to the appropriate preceding or succeeding event.

Another indicator of a S's rehearsal strategy is the reaction time (RT). If the S is covertly repeating the words to himself while trying to detect the signals, his RTs to the signals should be slower than if he were not rehearsing. For the group as a whole, the experimental and control RTs were equivalent in the tonal and silent syllabic detection tasks. The experimental RTs in the vocal syllabic task were significantly longer ($t = 3.95$, $p < .01$). Since, for this condition, comparison is made with a silent rather than vocal syllabic control, this result merely demonstrates that RTs are longer when the S must accompany his key press with the pronunciation of the syllable "toh." To test each individual S instead of the group as a whole, an "outlyer" test was applied to these RTs. According to this test, there were no outlyer scores in the sample of 18 Ss.

In conclusion, unless rehearsal can be carried out without detriment to the performance of the detection task, these Ss did not rehearse.

Are the Words Forgotten During an Empty Retention Interval?

The primary purpose of this experiment was to look at the forgetting that takes place when a S's attention is diverted from rehearsal and no succeeding information is presented to him. This situation appears in the trials of the tonal detection condition in which no signal was presented and for which no response was elicited (no false alarms).

Mean retention was 93%. Thirteen of the 18 Ss had scores of 100%,[4] giving a median score of 100% recall. For most of the Ss, then, retention of three words was perfect for 15 sec in which attention was diverted from rehearsal and information subsequently presented to the S was minimized.

What Causes Forgetting?

Type of filler task. An overview of the forgetting that did occur is shown in Table 2. Data from all trials within each of the three experimental conditions were summed, regardless of the number of signals

TABLE 2
Memory Performance

Measures of memory (% correct)	Detection task		
	Tonal	Silent syllabic	Vocal syllabic
Mean	92	77	70
Median	100	74	61

[4] Scores for the other five Ss ranged from 67 to 89% and show consistently low memory and detection performance in all conditions.

presented or responses made. A within-S test of the decrease in performance across the filler tasks showed both the tonal–silent and the silent–vocal differences to be significantly distinct from zero ($t = 3.82$; $t = 3.07$; $p < .01$).

Difficulty of filler tasks. The d' measure is a good indicator of the difficulty of the detection filler tasks. Comparison of d's within Ss across tasks shows that the tasks were not significantly different. Differences in retention as a function of different filler tasks were the result of a variable other than difficulty.

Number of responses made. Table 3 illustrates the effect on retention

TABLE 3
Retention (% Recall) as a Function of the Number of Responses Made in the Retention Interval

Number of responses	Detection task		
	Tonal	Silent syllabic	Vocal syllabic
0	92	74	71
1–2	92	76	66
3–4	90	80	74

of an increasing number of responses made in the retention interval. Retention with the tonal detection filler task showed no increase or decrease as a function of the number of responses made. Both the silent and vocal syllabic task conditions seemed to show a slight increase in performance with an increasing number of responses.

The tests of significance were complicated because of the variable number of observations per point and per S. The procedure adopted here was to compute a within-S linear trend component in a one-way analysis of variance, and to assign it to the S as his score for that condition.[5] The mean of these scores across the 18 Ss was tested for difference from zero. Application of this test indicated that in none of the conditions was there a significant relationship between retention and the number of responses made in the retention interval.

DISCUSSION

The results of this experiment provide information on some variables effective in producing forgetting in STM.

[5] As suggested by J. E. Keith Smith, personal communication. A discussion of the linear trend component analysis can be found in Winer (1962).

Elapsed Time, Evidence for Decay?

The general results of this experiment provide no evidence to support the principle of time-loss in STM. When the factors shown to be effective in producing interference are minimized, there is no evidence that would lead one to conclude that information decays.

If Not Decay, Then What?

The results of this experiment indicate several possible low-level sources of interference. When a 15-sec retention interval is filled with a tonal detection task, there is no discernible forgetting. But, when the same retention interval is filled with a single repeated syllable to which the *S* must attend carefully, one quarter of the words he was to retain are forgotten.

The major characteristic that differentiates these two filler activities is the verbal nature of the syllabic detection task. Both are auditory discrimination tasks. Perhaps certain patterning and range features are necessary before sounds are considered verbal material. And, only with these features will auditory material interfere with the short-term retention of verbal items.

A secondary difference between the two filler tasks lies in the strategies the Ss employ in performing them. The tonal detection task consists of a continuous background of white noise and an occasional signal tone. The syllabic tasks, on the other hand, consist of a background series of syllables with an occasional signal syllable. In the syllabic task, the *S* is presented with units of material each of which he analyzes to decide whether a signal is present. In the tonal detection task, it is not clear what unit the *S* bases his decision on. The tonal task is by nature a continuous waiting situation. The *S* may break the time into units and analyze them as he would the syllabic task. Or, he may monitor the energy level until it passes a criterion indicating the presence of a signal. Unless he breaks the time into units as small or smaller than the syllables, he is not likely to make as many decisions as he does in the syllabic tasks. Consequently, the number of decisions made in the interval is considered a second possible source of interference.

Compare the magnitude of the effect of these low-level sources of interference with that of traditional filler activities. Murdock (1961) and Peterson and Peterson (1959) filled retention intervals of varying lengths with a counting backward task. At the end of a comparable 15-sec period, their results showed only 20% retention of word or consonant triplets, scored as a whole. When the data from this experiment are scored in the same way, the silent syllabic condition shows 64% retention, the vocal syllabic condition, 50%. This means that a good portion of the interference from the counting backward task comes from the mere interpolation of verbal material. Thus, any filler task employing the presentation of verbal material and/or requiring a vocal response from the S includes effective sources of interference, regardless of whatever else the S must do.

In conclusion, on the basis of the current experimental results, any model attempting to account for the forgetting that takes place soon after presentation must be able to acount for the basic interfering effects of items with low levels of similarity (e.g., verbal material of one class interfering with verbal material of another class). A model need not include notions of changes in the retained information due to time alone. Forgetting is produced by characteristics of the events of filled time, not by time itself.

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