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FORGETTING: INTERFERENCE OR DECAY?[1]

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The present study was carried out to test decay and interference theories of forgetting. The number of retroactive tones and the duration of the retroactive interval were covaried in two experiments using a pitch-recognition memory task. This task was chosen since rehearsal and encoding strategies are minimal in this nonverbal or perceptual memory paradigm. Also, the acquisition process was held constant under the various retroactive interval conditions. Both the retroactive interval duration and the number of tones in the retroactive interval contributed to forgetting. Hence, these effects will eventually have to be taken into account by extant theories of memory.

One of the unresolved issues in the study of the processes underlying memory is whether forgetting over time is due to the number of retroactive stimuli (interference) or simply to the passage of time (decay). An experimental approach to this problem has been to vary the rate of presentation and recall of verbal items (Conrad, 1957; Conrad & Hille, 1958; Fraser, 1958).

Decay theory predicts that the amount recalled should vary directly with the rates of presentation and recall. However, conflicting results have been reported. Conrad (1957) and his associates (Conrad & Hille, 1958; Fraser, 1958) have presented evidence that supports decay theory, whereas Moray (1960) and Pollack, Johnson, and Knaff (1959) have found an inverse relationship between rate of presentation and memory. As pointed out by Postman (1964), a methodological difficulty involved in this experimental paradigm is the uncontrolled rehearsal time available to *S*s. Since rehearsal can facilitate or disrupt memory (Postman & Phillips, 1961; Rohrer, 1949), it is not clear that the extra time available for rehearsal at slower rates of presentation should always work against the decay hypothesis.

In more recent studies (Norman, 1966; Waugh & Norman, 1965), *E*s have tried to control rehearsal experimentally by instructing *S*s to rehearse only the last item. In these studies, rate of forgetting seems to be independent of time, but completely dependent on the number of interfering items. However, Norman (1966) has shown that increasing the rate of presentation of digits also decreased the perception or acquisition of the digits to be remembered. That is, the extra time available for perceptual processing at slower rates of presentation increased the acquisition of the items relative to faster rates of presentation.

Hence, previous studies varying the rate of presentation of items have probably affected both the perceptual and retentive processes. In fact, Aaronson (1967), reviewing the short-term memory literature, concluded that faster rates of presentation usually reduce the time available for perception and, therefore, decrease memory performance. Since retention may not be independent of perception, the results of these studies are inconclusive with respect to decay and interference theories. For example, in Norman's (1966) study, the acquisition process may have interacted with a time decay process so that faster rates of decay existed for the more poorly learned items. This possibility, along with the problems of rehearsal mentioned earlier, makes it difficult to discriminate between decay and interference theories.

It seems unlikely that decay and interference theories can be tested in a verbal memory paradigm which lends itself to rehearsal and encoding strategies of an *S* over which *E* has no control. Another possibility

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might be the study of nonverbal or perceptual memory in a recognition memory task. The paradigm employed in studying nonverbal memory is a "delayed comparison task."[3] In this task, a standard stimulus is followed after some interval by a comparison stimulus, and *S*'s task is to respond whether the signals were the same or different. The interval separating the standard and comparison stimuli is referred to as the retroactive (RI) interval.

In perceptual or nonverbal memory, effective rehearsal and encoding are assumed to be minimal (Massaro, 1969; Wickelgren, 1966). For example, it has been demonstrated that rehearsal instructions do *not* improve performance in recognition memory for pitch (Massaro, 1969; Wickelgren, 1969). When several standard tones are used, *S*s are not able to encode the tones verbally and must rely on the perceptual trace of the standard tone in making their decision. Furthermore, in the present studies, the rate of presentation of the RI tones can be decreased without leaving empty or blank RI intervals, as is necessary in verbal memory studies. This is accomplished by increasing the duration of the RI tones as the rate of presentation is decreased.

Another advantage of the "delayed comparison task" is that the rate of presentation of the RI tones can be varied without changing the presentation time of the standard tone. As mentioned earlier, retention may not be independent of perception. Therefore, it would be desirable to test decay and interference theories while holding the perception or acquisition of memory constant. By keeping the standard tone duration constant and following it immediately with an RI tone, the perception of the tone should be constant under all rates of presentation of RI tones. Hence, in the present study, the perception of the standard tone and the effective time for rehearsal were constant under all rates of presentation of the RI items.

The present studies covaried the number of retroactive tones and the duration of the retroactive interval in a pitch-recognition memory task. In Exp. I, four RI interval durations were covaried with one or two tones in the RI interval. In Exp. II, three RI durations were factorially combined with 1, 2, 3, or 4 tones in the RI interval. These levels should be sufficient to analyze the decay and interference components of forgetting. Decay theory predicts that forgetting should be a direct function of the RI duration, independent of the number of tones in the RI interval. Interference theory predicts that forgetting should be directly related to the number of RI tones and independent of the RI interval duration.

[3] At one time, the method of delayed comparison was used extensively to study the changes of nonverbal memory traces over time (e.g., Pratt, 1933).

Method

Apparatus.—All experimental events were controlled by a PDP-8 computer. A digitally controlled oscillator (Wavetek Model 155) was used to produce the pure tones. The stimuli were presented over matched headphones (Grason-Stadler Model PDH-39). The intensity of the tones was 61 db. SPL. The *S*s recorded their "same" or "different" responses on a portable computer card punch (Wright Model 2600).

Procedure.—The onset of the standard (S) tone, lasting .5 sec., started the trial. The S tone was followed immediately by the retroactive (RI) interval tones. The last RI interval tone was followed by the comparison (C) tone, which lasted .5 sec. The *S*s then made their responses. They were instructed to respond whether the last tone was the same or different from the first tone. No feedback was given with respect to the correctness of *S*s' responses.

All conditions except the RI interval duration were completely random within a given session at one of the RI interval durations. A session consisted of four trial blocks of 80 trials each. The intertrial interval was 6 sec., and there was a 1-min. interval between trial blocks. No more than two sessions were given in 1 day.

Experiment I

Subjects.—Two males and one female attending the University of California were employed in the present study. They were paid $1.93/hr for their services. These *S*s had participated in a previous pitch memory study.

Design.—Four S tones (720, 740, 760, and 780 Hz.), four RI interval durations (.4, 1, 2, and 4 sec.), one or two RI tones, and three S-C tone differences (+20, 0, and −20 Hz.) were factorially combined. Any S tone was equally likely to occur, and the C tone was equal to the S tone about half the time. The possible RI tone values were 500, 600, 800, and 1,000 Hz. Any of the four RI tones was equally likely to occur in the one-tone condition. In the two-tone condition, the tones were either 500 and 800 or 600 and 1,000 Hz., occuring in either a low-high or a high-low order.

Three sessions of 320 trials each were presented at each of the four possible retroactive interval durations according to a standard Latin square.

Experiment II

Subjects.—The Ss were two males and one female attending the University of California. They were paid $1.93/hr for their services. W. C. also participated in Exp. I, and C. A. had participated in an unrelated pitch memory study.

Design.—Four S tones (720, 740, 760, and 780 Hz.), three RI interval durations (1.2, 2.4, and 3.6 sec.), 1, 2, 3, or 4 RI tones, and three S-C tone differences (+20, 0 and −20 Hz.) were factorially combined. Any S tone was equally likely to occur, and the C tone was equal to the S tone about half of the time. The possible RI tone values were 500, 600, 900, and 1,000 Hz. Referring to these RI tones as A, B, C, and D, respectively, the tones could occur in the following four possible temporal orders: ABCD, BDAC, CADB, and DBCA. For example, if two RI tones were presented on a given trial, the equally likely possible orders were: AC, BD, CA, and DB.

Three sessions of 320 trials each were presented at each of the three possible retroactive interval durations according to a standard Latin square. Each *S* was presented with a different Latin square. Therefore, the overall effects due to the sequence in which the three RI intervals were presented should be minimal.

Results

The present recognition memory experiments qualify as choice experiments. Using the analytical tools developed in psychophysics (Green & Swets, 1966), we can derive a measure of memory performance that is assumed to be independent of response biases. Assuming that both a memory and a decision system operate in a recognition experiment, the present study is concerned with the effects of the number of RI stimuli and time on the memory system. These variables probably also affect the decision system (Massaro, 1969), but as yet

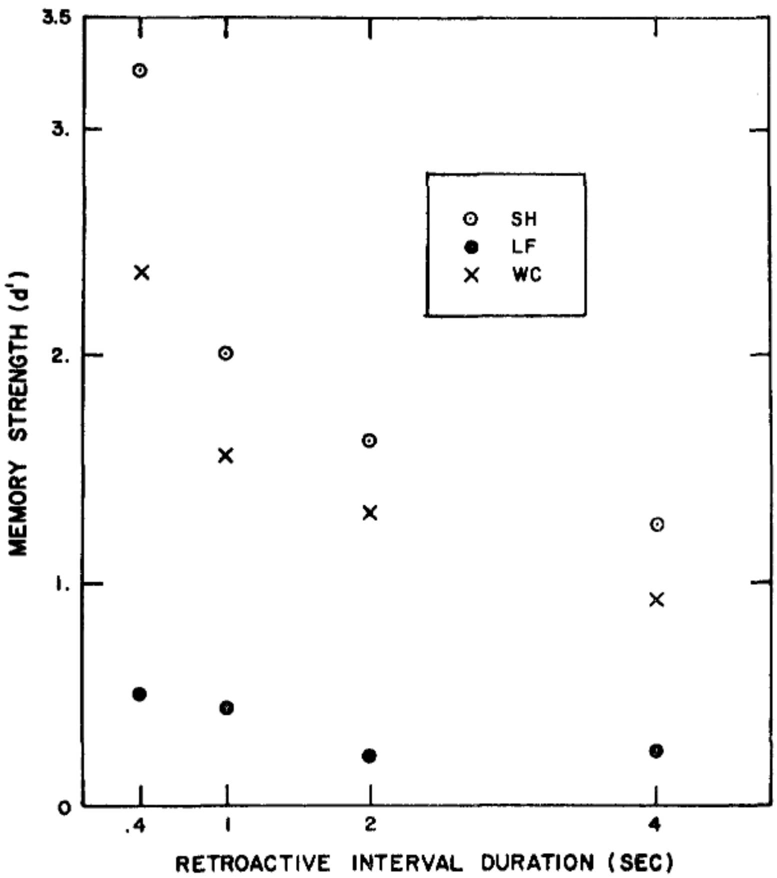

FIG. 1. Average memory strength (d') values for each *S* as a function of the RI interval duration for Exp. I.

TABLE 1

Individual Correct (C) and Incorrect (IC) Recognition Probabilities as a Function of the RI Interval Duration and the Number of Tones in the RI Interval for Exp. I

Number of tones	Duration (in sec.)							
	.4		1		2		4	
	p(C)	p(IC)	p(C)	p(IC)	p(C)	p(IC)	p(C)	p(IC)
SH								
1	.99	.12	.97	.29	.93	.33	.92	.41
2	.97	.13	.83	.26	.71	.22	.61	.27
WC								
1	.97	.23	.89	.19	.76	.25	.66	.31
2	.95	.32	.77	.40	.71	.24	.63	.27
LF								
1	.86	.74	.83	.65	.78	.66	.62	.52
2	.84	.66	.60	.46	.44	.41	.52	.43

Note.—SH, WC, and LF are initials of *S*s in Exp. I.

no theory has been developed to account for the results.

In the present studies, a "same" response on a trial when the C tone was equal to the S tone was defined as a correct recognition. A "same" response on a trial when the C tone was unequal to the S tone was defined as an incorrect recognition. The correct and incorrect recognition probabilities were computed for each *S* at each Tone × Duration condition. The d' values were computed from these probabilities by using the tables given by Elliot (1964).

Experiment I

The individual correct and incorrect recognition probabilities were computed for each of the eight RI Tone × RI Duration conditions pooled over S tone frequency and sessions. This gives about 240 observations contributing to each correct and incorrect recognition probability presented in Table 1.

A Subject × Tones × Duration analysis of variance was performed on the d' values. The significant main effect of the RI interval duration, F (3, 6) = 5.88, $p < .05$, and Fig. 1 indicate that memory performance decreased as the RI interval increased. Although the main effect of the number of tones in the RI interval was not significant, F (1, 2) = 5.65, $p < .2$, due to the small power of the present study, Table 1 shows that memory performance was lower for two tones than one tone in the RI interval for each *S*.

Experiment II

The individual correct and incorrect recognition probabilities were determined for each of the 12 RI Tone × RI Duration conditions pooled over S tone frequency and sessions. This gives about 120 observations contributing to each corect and incorrect recognition probability presented in Table 2.

A Subject × Tones × Duration analysis of variance was performed on the d' values. The significant main effect of the number of tones in the RI interval, F (3, 6) = 9.07, $p < .025$, and Fig. 2 indicate that memory performance decreased as the number of tones in the RI interval increased. The fact that memory performance also decreased as the RI interval duration increased can be seen in Table 2 and the marginally significant RI duration main effect, F (2, 4) = 4.91, $p < .1$. The Duration × Tones interaction was not significant, F (6, 12) = .85.

The relative contribution of the RI duration and the number of RI tones to forgetting cannot be quantitatively determined from the present study. However, it can be concluded that both contribute to forgetting and these effects will eventually have to be taken into account by extant theories of memory.

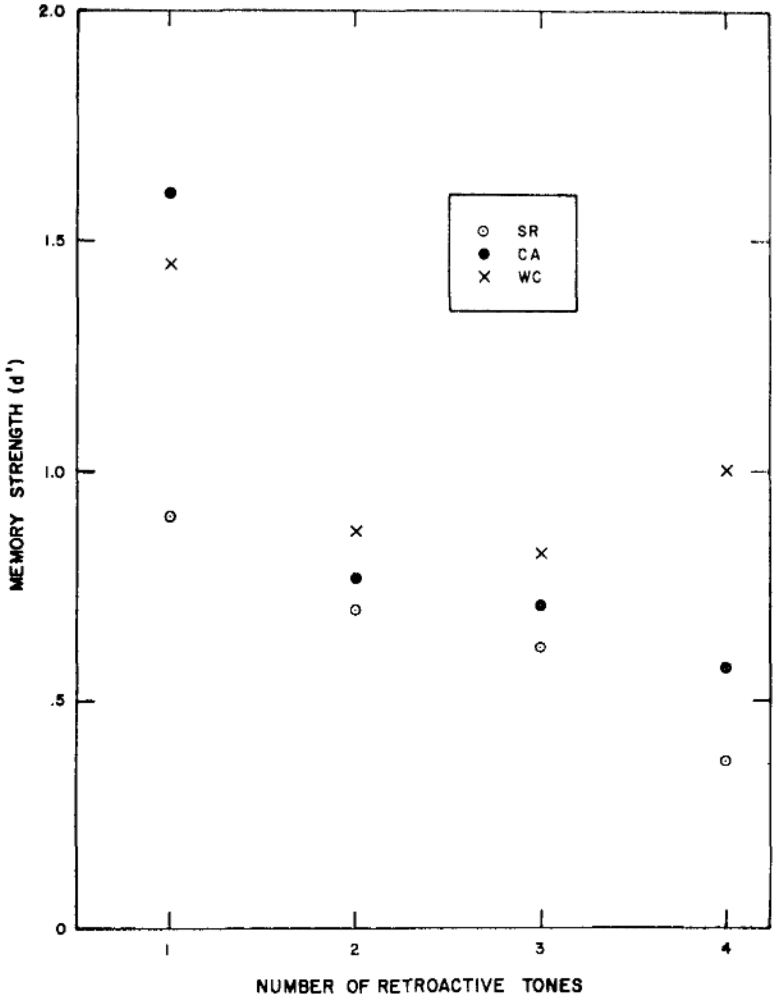

FIG. 2. Average memory strength (d') values for each S as a function of the number of tones in the RI interval for Exp. II.

DISCUSSION

The results of the present study have indicated that both the RI duration and the number of tones in the RI interval are directly related to forgetting. Thus, both decay and interference processes seem to be necessary to describe these results. A possible theoretical approach would be to assume that there are two independent memory traces decaying with respect to time and items, respectively. However, Massaro (1969) has shown that the rate of forgetting over time is highly dependent on the nature of the RI interval stimulus. Hence, the hypothesized trace that decreases over time would also have to account for the effects of the nature of the RI stimulus. Of course, this would require analyzing the deterioration of the trace in terms of the interfering effects of the RI stimulus.

Therefore, regardless of the number of traces a theory of memory employs, it will have to account for forgetting in terms of the nature of the retroactive stimuli. Unfortunately, the differential effects of different RI stimuli will not always be directly related to the psychophysical dimensions of the stimuli. For example, Posner, Boies, Eichelman, and Taylor (1969) have shown that a central processing task (addition) produced more interference than visual noise on the retention of visual information (physical form). Hence, the interfering effects of a retroactive stimulus may not be directly related to the physical nature of the stimulus but rather to the nature of the processing that the stimulus undergoes. For example,

TABLE 2

INDIVIDUAL CORRECT (C) AND INCORRECT (IC) RECOGNITION PROBABILITIES AS A FUNCTION OF THE RI INTERVAL DURATION AND THE NUMBER OF TONES IN THE RI INTERVAL FOR EXP. II

Number of tones	Duration (in sec)					
	1.2		2.4		3.6	
	p(C)	p(IC)	p(C)	p(IC)	p(C)	p(IC)
SR						
1	.82	.48	.80	.44	.75	.47
2	.65	.38	.56	.27	.60	.34
3	.68	.47	.64	.34	.53	.32
4	.54	.43	.47	.30	.47	.34
CA						
1	.82	.21	.85	.15	.68	.30
2	.73	.32	.57	.25	.54	.40
3	.69	.28	.59	.35	.57	.40
4	.68	.35	.61	.35	.47	.37
WC						
1	.85	.24	.82	.31	.78	.34
2	.57	.22	.68	.33	.60	.31
3	.74	.26	.56	.30	.50	.31
4	.77	.33	.70	.27	.51	.27

Note.—SR, CA, and WC are initials of *S*s in Exp. II.

the results of an earlier study (Massaro, 1969) indicated that the effects of RI stimuli on memory are highly dependent on the processing strategies of *S*.

The result of another study of pitch memory (Wickelgren, 1969) is also relevant to the present discussion. The results with a single stimulus filling the RI interval indicated that that rate of forgetting was a monotonic decreasing function of the RI interval duration. In that study, the rate of forgetting could have been dependent on the RI stimulus duration or simply the RI interval duration. However, the present study has shown that the rate of forgetting also increased with the number of tones in the RI interval. Thus, it seems that the critical variable affecting memory is the RI stimulus duration rather than the RI interval duration. The present study supports this conclusion. That is, if the rate of forgetting is a monotonic decreasing function of each RI stimulus duration, n items would always produce more forgetting than $n-1$ items in the RI interval.

In summary, a theory of memory will have to account for the following phenomena. First, the rate of forgetting is a decreasing function of the duration of each RI stimulus. Second, the effects of different stimuli in the RI interval are dependent on the psychophysical properties of the stimuli, the number of stimuli, and the strategies of *S*s. A tentative conclusion consistent with these findings is that forgetting is directly related to the amount of perceptual processing of other stimuli during the RI interval.

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