REINFORCEMENT-TEST SEQUENCES IN PAIRED-ASSOCIATE LEARNING

by

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Abstract

Learning of paired-associate items was studied in relation to different repetitive sequences of reinforced (R) trials and test (T) trials. One purpose was to obtain evidence as to whether either learning or forgetting occurs on unreinforced T trials; a second was to adduce principles bearing on the problem of optimal programming of R and T trials.

The general design shared by the two experiments conducted may be summarized as follows:

Condition	Cycle 1 2 3 4 5 6 7 8 9 ....
1	R T R T ....
2	R R T R R T ....
3	R T T R T T ....
4	R R T T R R T T ....

Each of these R - T sequences was repeated until a criterion was reached--in Experiment I, 24 cycles, and in Experiment II, two consecutive perfect performances on all pairs. Each cycle consisted in presentation of the entire list of 20 items in a random order.

Subjects were 100 college students, 50 in each experiment. The list for Experiment I had nonsense syllables as stimuli and two-digit numbers as response members; the list for Experiment II had the same stimuli with common nouns as response members. In each list, five items were assigned

to each of the four conditions. Reinforced trials were paired presentations of stimulus and response members. Test trials were presentations of stimulus members alone; the subject was instructed to attempt to recall the response, but no information was given concerning correctness of the response.

Performance on Ts given successively without intervening reinforcement showed no significant change in correct response probability--suggesting that neither learning nor forgetting occurred on T trials per se. The course of learning was, however, affected to a major extent by the ratio of Ts to Rs and by their arrangement in the various repetitive sequences. Learning curves plotted in terms of error proportion on the first T following the n^{th} R trial lined up in the order: Condition 3 (lowest), 1, 4, 2. Thus, some process of importance to the course of acquisition clearly occurs on test trials, and results in increased effectiveness of subsequent R trials. When acquisition is considered in relation to the total amount of experimental time, the conditions with highest densities of R trials are most efficient on early trials, but this relation tends to reverse on later trials, and over all Condition 1 (RTRT...) appears to be nearly optimal.

Latencies of correct responses were significantly lower than those of incorrect responses. Overall mean latencies for precriterion correct and error responses and for postcriterion errors clustered at a level of $4.2 \pm .5$ sec., whereas mean latencies for postcriterion correct responses all fell between 2.8 and 2.9 sec. Considering the first response following the n^{th} reinforcement, a close correspondence was found between the ordering of frequency learning curves (proportion of errors) for the

various conditions and corresponding curves for correct response latency. The frequency distributions of latencies for correct and for incorrect responses at different stages of learning generated families of empirical functions similar to beta-distributions, with virtually equal modes for all conditions.

Analyses of the frequency data in terms of stimulus sampling models indicated that initial acquisition of correct responses proceeded in essentially the manner prescribed by a one-element, all-or-none model, but that under some conditions retention losses were significantly greater than allowed for by a one-element process. A stimulus fluctuation model provided a relatively good account of acquisition and retention phenomena and a rational interpretation of the different rates of learning under the different R - T sequences. The tentative conclusion from this analysis is that interspersing R trials with T trials increases the probability that components, or aspects, of a stimulus which have not been conditioned to the correct response on the earlier R trials of a series will be sampled and thus have opportunities to be conditioned on later R trials. Whether T trials simply allow time for stimulus fluctuation to occur between Rs or provide occasions for some active process of stimulus resampling remains a question for further analysis.

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Chapter I

Introduction

The purposes of this study were two-fold: to generate new evidence concerning theoretical issues having to do with the role of reinforcement and test behavior in paired-associate learning, and to explore different types of reinforcement-test sequences in the hope of making progress toward principles of optimal programming.

It is generally assumed that learning of paired-associate items depends upon two major factors: the subject's behavior in test phases, that is, active attempts at recall of correct responses together with observation of rewarding or punishing consequences, and the presentation of information by the experimenter. In the standard anticipation procedure, which has been used in the vast majority of paired-associate experiments, these two aspects are confounded. Each trial begins with a presentation of the stimulus member of a pair alone, to which the subject attempts to recall the correct response; then the stimulus and response members are presented together and the subject has an opportunity to experience reward or punishment.

Several years ago one of the authors began a systematic analysis of these theoretically separable aspects of an anticipation trial, the presentation of the stimulus alone, henceforth denoted T, for "test";

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and the paired-presentation of stimulus and response members, henceforth denoted R, for "reinforcement" (Estes, 1960). It is clear that learning in the sense of increases in probability of the correct response occurs on R presentations; and to a first approximation at least, the changes in response tendency appear to occur on an all-or-none basis (Estes, 1960, 1961) though second order deviations from the all-or-none pattern are observed under some conditions (Estes, Hopkins, and Crothers, 1960; Postman, 1963). The first objective of the present study is to gain further evidence concerning the change in correct response tendency produced by an R occurrence, and, in particular, to study the extent to which the effects of an R occurrence are invariant with respect to the type of trial sequence in which it is imbedded.

To permit experimental examination of the functions of the R and T components of an anticipation trial, we shall use the "RT" procedure, in which paired-presentations of the stimulus and response members of an item and recall tests to the stimulus member alone are administered independently (Estes, 1960; Estes, Hopkins, and Crothers, 1960). Thus an item may receive more than one R between two successive Ts or repeated Ts without intervening Rs, as called for by the experimental design.

The second objective of this study is to examine the function of T occurrences when they are intermixed with Rs in various types of sequences.

There are theoretical and empirical bases for at least the following three alternative assumptions regarding the functions of test trials in paired-associate learning: (1) test trials are neutral; (2) forgetting of correct responses, learning of incorrect responses, or learning of correct responses occurs during test trials; (3) no systematic changes in response probability occur on test trials, but the administration of test trials modifies the effects of subsequent reinforced trials.

Some evidence in the literature bears upon at least the first two of the three assumptions concerning test trials. However, the relevance of some studies becomes clear only when one reanalyzes data gathered for other purposes.

The first alternative, the neutrality assumption, implies that nothing is occurring during test trials in terms of the probability of correct responses to be learned. That is, if the subject is given more than one T trial in succession without intervening Rs, his performance should not change significantly over the successive T trials. This neutrality assumption seems to be supported by the data collected in miniature experiments by Estes, Hopkins, and Crothers (Experiment II, 1960), Jones (Experiment II, 1962), Eimas and Zeaman (1963), Postman (1963), and Seidel (1963). In these experiments, the subject was given from one to six R trials, followed by a block of two to four T trials. No changes in response probability were found over the successive Ts. Thus, these studies provide information about test trials at very early stages of learning of a given list.

The data collected by Richardson (1958) and Goss, Morgan, and Golin (1959) show only relatively small, and in most cases probably insignificant, differences among T trials in a block of 5 to 16 T trials given after the subject attained a learning criterion of 87.5% to 100% correct performance on a single run through the list.

Regarding the second assumption, consider a block of T trials given after a number of R trials. If the successive T trials are assumed simply to increase the time between reinforcement and test, then during the successive T trials forgetting might be expected to occur and the probability of a correct response on the last T trial would be lower than on the first T trial of the block. This assumption is supported by an RTT experiment reported by Estes, Hopkins, and Crothers (Experiment I, 1960), yielding fewer correct responses on the second T trial than on the first T trial.

There also is evidence that an increase in the probability of correct responses over test trials may occur under some conditions. Landauer (1962) reported a significant increase in correct recalls from a first test to a second, but he gave a nonreinforced recognition test between the two tests. Peak and Deese (1937), Richardson (1960), Goss, Nodine, Gregory, Taub, and Kennedy (1962), and Butler and Peterson (1965) all showed significant growth in correct responses over a block of 5 to 52 T trials given after the subjects reached their criterion of acquisition. In the majority of the conditions reported in these studies, however, the probability of correct responses on the last T trial of the block of test trials after acquisition was lower than the probability of correct responses at the end of the acquisition period.

An unpublished study by Estes (1963) bears on the third assumption. He made up a learning list consisting of paired-associates with nonsense syllables as stimuli and digits as responses. In one condition, the subjects learned the list by an R T R T R T ... method (analogous to the conventional anticipation method). In the other conditions the subjects learned by the $R_1\ R_2\ R_3\ \ldots\ R_n\ \ T$ method, when n is some whole number, the maximum being 40. The results were clearcut: for the first condition, the asymptote of the learning curve was reached on about the 15th trial and was, of course, 100% correct. On the other hand, the R R R ... T condition never reached the 100% asymptote; here when $n = 40$, the level of correct responding was only 80%. This result implies that T trials are a necessary condition to produce perfect learning. If this interpretation is correct, then proper utilization of tests is a major factor in practical and educational applications, especially in the area of foreign language learning. That is, "Are tests necessary?", and if so, "How often in order to produce 100% correct performance in the most economical and effective way?"

On the basis of our survey of the relevant literature, we planned the present study under the working hypothesis that T trials are essentially neutral with respect to systematic changes in response probability on these trials per se. Our tentative conclusion was that the retention loss over two adjacent test trials observed in some studies may simply be a spontaneous regression effect (Estes, 1955a) which occurs as a function of the time taken by test trials rather than of special events or processes occurring on the trials; in this event, the retention losses should be limited to the early phases of learning.

Further, we have proceeded on the assumption that the systematic increases in correct response probability sometimes observed over blocks of tests represent simply a recovery from the temporarily disrupting effects of a sudden transition from a uniform series of training trials to a uniform test series. To check further on these conclusions, and also to obtain evidence concerning the possible potentiating effects of T trials upon subsequent R occurrences, we arranged to run rather lengthy series of replications of several basic sequences of Rs and Ts. As will become apparent in later sections, the sequences were chosen so as to provide for tests of the effects of R trials which are or are not preceded by other R trials or by T trials, and for the assessment of changes in response probability over T trials without intervening reinforcement at various stages of learning. In addition we arranged to trace in parallel changes in correct response frequency and latency as functions of various types of RT sequences.

Chapter II

Method

Experimental Designs

Two experiments were conducted in the present investigation. The two experiments differed only in terms of learning materials, time intervals of pair presentations, and the equipment used. Both Experiment I and Experiment II had four experimental conditions, each of which comprised a specific reinforcement-test sequence. The summary of the general experimental design is shown in Table 1, R in the table standing for a reinforcement trial and T for a test trial.

Table 1

Reinforcement-Test Sequence for Each Experimental Condition in Both Experiment I and Experiment II

Condition	Cycle 1 2 3 4 5 6 7 8 9 ....
1	R T R T R T ....
2	R R T R R T R R T ....
3	R T T R T T R T T ....
4	R R T T R R T T R R T T ....

Each of these reinforcement and test sequences was repeated until a given subject reached the criterion set for the experiment.

The learning task for each subject consisted of a set of 20 paired associates, a different set of pairs being used in each experiment.

In order to minimize effects of item differences within each experiment, for each subject the 20 pairs were partitioned randomly into four subsets of 5 items and one subset was assigned to each of the four experimental conditions. The randomization of the item assignments was done by computer in Experiment I, and by a random number table in Experiment II.

On each experimental cycle, each pair was presented to a subject in each experiment with either an R or a T procedure depending on the sequence to which the pair was assigned. On an R trial, both the stimulus and the response members of a given pair were presented to the subject for a specified time. On a T trial, only the stimulus member of a given pair was shown, and the subject attempted to recall the correct response; no information was given the subject concerning correctness or incorrectness of his response on a T trial. The order of occurrence of items within each cycle was randomized separately for each subject.

The experimental procedures which differed between the two experiments will be described separately in the respective sections.

Subjects

In total 102 subjects participated in the two experiments, 51 in each. One subject in each of the two experiments failed to reach the criterion within the scheduled session of learning and the data of these two subjects were discarded. Consequently, 50 subjects in each experiment contributed to the data analyses. Twenty-five of the subjects participating in Experiment I were undergraduate and graduate students at Stanford University who were paid for their services. The other 75 subjects were students enrolled in the introductory psychology course at Stanford University, and their participation was required for course credit. Each of the subjects in both experiments was tested individually.

Experiment I

Experimental Materials

For Experiment I, 20 paired associates were constructed with nonsense syllables as stimulus members and two-digit numbers as response members of the pairs. The CVC three letter nonsense syllables were chosen from the nonsense syllables table published by Noble (1961). The m-values (meaningfulness) of the nonsense syllables ranged between 1.50 and 1.69. Restrictions on the stimulus members of the pairs were as follows: (1) A given consonant was used only once among the first letters of the syllables. (2) The second letters of syllables were A, U, and O four times each, I, five times, and E, three times. (3) For the third letters, as many different consonants were used as possible while keeping the m-values of the CVC within the range of 1.50 to 1.69 in Noble's table. Syllables suggestive of socially tabooed words were avoided.

The numbers used as response members of the pairs were selected from Fisher's random number table (1963) subject to the following restrictions: (1) For the first digit, no "0" was used, and each digit was repeated a minimal number of times (specifically, 1, 2, 4, 5, 6, 7, and 8 were each used twice, and 3 and 9 were each used three times). (2) For the second digits, each of the 10 possible digits was used twice. (3) The two digit number which could be made by interchanging the first and second digits of a previous number was avoided; for example, since "15" was one of the responses, "51" was not employed. (4) Digits were not repeated in the same response; that is, numbers such as 11, 22, 33, ..., 99 were avoided.

The pairs constructed for Experiment I were as follows:

BIY	--	97	NAJ	--	61
COJ	--	31	PIH	--	28
DIJ	--	65	QOP	--	59
FIH	--	38	REH	--	73
GOH	--	52	SOQ	--	17
HUY	--	89	TEH	--	93
JAF	--	94	VUS	--	86
KIQ	--	42	WEF	--	70
LUW	--	26	YAB	--	34
MUX	--	15	ZAK	--	40

Experimental Apparatus

For Experiment I, an automated experimental situation was achieved by using the verbal associative learning apparatus installed in a pair of adjoining rooms at the Institute for Mathematical Studies in the Social Sciences at Stanford University. The apparatus was designed by R. C. Atkinson and W. K. Estes and engineered by the Stanford Research Institute.

In the experimenter's room, the major control component was built around a 526 IBM Summary Punch. For each subject a deck of 496 IBM cards was prepared. Sixteen of the cards were for the practice task prior to the main task, and 480 cards were for the main experiment. Part of each IBM card was pre-punched with information to control stimulus presentations and part was reserved for recording data. Column positions on the card were controlled by the control panel of the 526 and its star wheels. The information read was stored in banks of IBM relays.

Intertrial intervals, 2 sec. in Experiment I, were controlled by an ATC-E3400 timer with a 2 to 30 second range. At the end of an intertrial interval, the stimulus display was activated. Exposure of an IEE In-line Digital Display was controlled by an ATC-E1101 timer with a range from .1 sec. to 10 sec. During the intertrial interval, the contents of the Berkeley timer and response key relays were punched out on the IBM card by the IBM 526. Then the card was advanced and the procedure was repeated automatically until the entire 496 cards were run.

The experimenter's room containing all of the control equipment and the subject's room containing the display panels and response keys used by the subject were connected via a two-way intercommunication system.

The subject's chamber was sound-deadened and air conditioned. The subject sat in a chair 5.5 feet away from the display panels, which consisted of the two windows: an upper panel and a lower panel. The size of each panel was 2 in. × 12 in. The two panels were identical except for position. Eight letters or digits could be displayed in each of them. For Experiment I, three letter positions of the left side of the upper panel were used for the stimulus presentation on both R and T trials. The response digits were shown on two letter positions of the right side of the lower panel on the R trials. Nothing was presented in the lower panel on the T trials.

On the table in front of the subject's chair were two columns of response buttons of 7/8 in. × 1 in. in size. Each of the columns contained 10 response keys, numbered 0 to 9 from the bottom in ascending order, the bottom being closest to the subject. After the stimulus had appeared on the display panel on a T trial, the subject indicated his response by depressing first one key in the left-hand column and then one in the right-hand column second, thus generating a two digit number. As soon as the subject depressed each key, it was lighted up until the response was recorded by the IBM 526 in the control room. The operation took less than 1 sec. Response time was measured from onset of the stimulus to the depression of the second of the two response keys. In order to depress the keys, the subject was instructed to use only the forefinger of the preferred hand.

Experimental Procedures

Upon arriving at the subject room, each of the 51 subjects who participated in Experiment I was instructed to learn 20 paired-associates as quickly as possible. The two kinds of trials, R and T, and the method of responding were explained.

First a practice task was given to each subject in order to familiarize him with the nature of the experimental task. This practice task was intended to prevent the large "warm-up" effect often observed in paired-associate studies which might show up as a changing conditioning probability at the very early stage of learning. The practice list contained 4 pairs, each representing one of the four experimental conditions indicated in Table 1. The stimuli of the practice pairs were symbols such as "$", "=", "+", and "*"; and the responses were the numerals "25", "76", "54", and "80" respectively. These numbers were not included in the main list of the experiment. The response procedures of the practice task were identical to those of the main task. Four trials were given to each subject as his practice task.

After a brief rest, the main experimental task was given. In Experiment I each subject was given 24 trials on each item. During the 24 trials, the subject had 12 R trials and 12 T trials in Conditions 1 and 4, since the respective experimental sequences were R T R T ... and R R T T .... In Condition 2, he had 16 R trials and 8 T trials, the sequence being R R T R R T ...; and in Condition 3, 8 R trials and 16 T trials, the sequence being R T T R T T ....

The items were presented in 24 successive cycles, each cycle including all 20 items in a random order. The assignment of an item to the R or the T procedure in any cycle was determined by the condition to which the item belonged. Thus in the first cycle, all items received R trials; in the second cycle, items belonging to Conditions 2 and 4 received R trials while those of Conditions 1 and 3 received T trials, and so on. There was no identifiable interval between cycles beyond the usual intertrial interval.

On R trials, the stimulus and response members were exposed together for 2 sec., the display being followed by an interval of 2 sec. On a T trial, only the stimulus member of a given pair was shown; at the outset of the stimulus display on a T trial, a Berkeley EPUT timer was activated, and the subject's response stopped the Berkeley timer and operated a response relay. Since latency was one of the learning measures considered in Experiment I, response time was therefore determined by the subject himself (self-paced procedure). Upon operation of the response relay the display terminated and the intertrial interval of 2 sec. began. No feedback was given to the subject at any time on a T trial.

The entire experimental session, including the practice task, ranged from 57 min. to 80 min., depending on the subject.

Experiment II

In Experiment I of the present study, the stimulus members of the pairs were nonsense syllables and the responses were two-digit numbers. There proved to be little evidence of learning on test trials, but the possibility must be considered that the effects of test trials would be qualitatively different if the response members of the pairs were words. With words as responses, such factors as ease of response rehearsal and multiplicity of associations might yield additional opportunities for learning of some kind on test trials. Further, with words as responses, at the early stage of learning when the whole response list is not initially known to the subjects, there might be more room for response learning than in the experiment with numbers as responses.

Thus, Experiment II was conducted with the same overall design, and so far as was feasible the same procedures, but with common English words rather than numbers as response members of the paired associate items.

Experimental Materials

Twenty paired associate items were constructed with nonsense syllables as stimulus members and familiar words as response members of the pairs for Experiment II. The stimulus items were the same ones used in Experiment I. The response words were common nouns selected from Thorndike-Lorge Frequency Count (1944). Each of the words occurred more than 100 times per million.

The pairs used are shown below:

BIY	--	Wall	NAJ	--	Tree
COJ	--	Valley	PIH	--	Car
DIJ	--	Line	QOP	--	Gate
FIH	--	Yard	REH	--	Machine
GOH	--	Rain	SOQ	--	House
HUY	--	Door	TEH	--	Ear
JAF	--	Bird	VUS	--	Post
KIQ	--	Season	WEF	--	Iron
LUW	--	Article	YAB	--	Fruit
MUX	--	Job	ZAK	--	North

Experimental Procedures

Each of the twenty pairs was typed in the center of a 3×5 white card: this side of the card was shown on R trials. On the other side of the same card was typed only the stimulus member of the pair to be shown on T trials.

In the experimental room, the experimenter and the subject sat face to face with a 3×5 foot table in between. On the table at a distance of 2 feet from the edge of the subject's side was a 10×15 inch screen which served as a barrier between the experimenter and subject. The cards were presented manually to the subject on the lower right edge of the screen.

On an R trial, a subject was instructed both to spell a given stimulus syllable aloud and to read the response word during the 5 sec. exposure time. On a T trial, the subject was instructed to say the response word appropriate to the stimulus presented. The time given to the subject to respond on T trials was also 5 sec. A failure to respond within the 5 sec. interval was classified as a blank response and counted as an error. There was no delay between successive card presentations within a cycle through the list. A Lafayette Recycling Timer clicked every 5 sec. and regulated the presentation of the cards. The twenty cards were well shuffled during the inter-cycle interval, which lasted approximately 10 sec.

The practice task was given to the subject prior to the main task. The subject was required to learn two items: IEC-Ball with the RT sequence (Condition 1) and ABC-School with sequence RRT (Condition 2). The subject was informed about the other sequences (Conditions 3 and 4) as well. After a brief pause the main experiment followed.

The learning criterion of Experiment II was two consecutive perfect performances for each pair in the list; that is, learning was terminated at the end of the cycle on which the subject made two consecutive correct responses in the protocol for the item he learned last among the 20 pairs. The termination point did not necessarily fall at the end of a reinforcement-test sequence for any given condition. For instance, if the item the subject learned last was in Condition 1, and he reached the criterion during the 10th cycle, he terminated the experimental task with T trials for items of Condition 1, and with R trials for items of Conditions 2, 3, and 4.

According to the learning criterion employed in Experiment II, the earliest possible termination of the experimental task could occur on the 6th cycle with the subject having experienced at least two T trials for each of the four conditions. Consequently, the number of cycles needed for each subject was greater than or equal to 6. Since the length of each reinforcement-test sequence was two trials in Condition 1, three in Conditions 2 and 3, and four in Condition 4, it is impossible to make a simple general statement about the number of T trials given only the number of cycles (N) the subject needed to reach the criterion. Specifically, the number of T trials for Condition 1 is $N/2$ when N is an even number, $(N-1)/2$ when N is odd. For Condition 2, the number of T trials is $N/3$ if $N = 3n$, where n is any integer; $(N-2)/3$ if $N = 3n-1$; and $(N-1)/3$ if $N = 3n-2$. For Condition 3, there were $2N/3$ T trials if $N = 3n$; $(2N-1)/3$ T trials if $N = 3n-1$; and $2(N-1)/3$ T trials if $N = 3n-2$. For Condition 4, the number of T trials was $N/2$ if $N = 4n$, $(N-1)/2$ if $N = 4n-1$, $(N-2)/2$ if $N = 4n-2$, and $(N-1)/2$ if $N = 4n-3$.

The experimental session including the practice task ranged from 40 min. to 110 min. averaging approximately 58 min.

Chapter III

Results

Individual Differences

In each of the two experiments of the present study, each subject learned the pairs in all of the four experimental conditions. Consequently, each subject served as his own control for comparing the experimental conditions. However, there might have been some differences in learning ability or motivation among the subjects who appeared early in a given experiment and those who came later. Also there might have been some differences in Experiment I between the volunteer subjects and the subjects who participated in the experiment for the course requirement. To test these questions, 50 subjects in each experiment were divided into five equal blocks, 10 in each, according to the order in which they were run in a given experiment, the 10 subjects in block 1 being those who appeared earliest.

In Experiment I, the differences among blocks were tested in terms of the mean number of trials to the last error in Condition 1. The analysis showed no difference among the blocks of subjects: $F(4, 45) = 1.57$. There was no significant difference between the paid volunteer subjects and the subjects from the introductory psychology course: $t = 1.12$ with $df = 48$.

In the same fashion, in Experiment II, a simple analysis of variance was carried out for the five blocks in terms of the mean cycles needed to reach the learning criterion of two consecutive perfect performances for each pair in the list. Again no differences were found among the blocks: $F(4, 45) = .38$.

Since the subjects for Experiments I and II were drawn from the same student population, and since successive blocks of subjects within each experiment proved homogeneous in ability, it is unlikely that there were any significant differences in subject variables between the experiments. Thus we shall proceed on the assumption that any differences in results between Experiments I and II may be attributed to the differences in procedures.

Frequency Analyses

We consider first those aspects of the frequency data which bear most directly upon the question of learning or forgetting during sequences of unreinforced test trials. Table 2 presents the proportions of errors on the first and second test trials, T_1 and T_2, of each successive replication of the RTT or RRTT sequence, respectively, for Conditions 3 and 4 of both Experiments I and II. For example, under Experiment I, Condition 3, the values .944 and .960 in the first column and first two rows are the error proportions for T_1 and T_2, respectively, of the first RTT sequence; the values .808 and .844 are the error proportions for T_1 and T_2 respectively, of the second RTT sequence. Similarly, for Experiment I, Condition 4, the values .804 and .860 are the error proportions for T_1 and T_2 of the first RRTT sequence, .572 and .576 for T_1 and T_2 of the second RRTT sequence, and so on.

Table 2

The Proportions of Errors on T_1 and T_2 of Each Replication for Conditions 3 and 4 in Each Experiment

	Replication							
	1	2	3	4	5	6	7	8
Experiment I								
Condition 3 (RTT)								
$P(E_1)$	.944	.808	.588	.424	.252	.224	.156	.084
$P(E_2)$	.960	.844	.584	.404	.260	.216	.152	.080
Condition 4 (RRTT)								
$P(E_1)$	.804	.572	.348	.200	.152	.120		
$P(E_2)$	.860	.576	.332	.212	.156	.108		
Experiment II								
Condition 3 (RTT)								
$P(E_1)$	.876	.460	.160	.060	.008	.012	.004	.000
$P(E_2)$	.860	.408	.144	.040	.008	.012	.004	.000
Condition 4 (RRTT)								
$P(E_1)$	.560	.220	.048	.024	.000	.004	.000	
$P(E_2)$	.600	.192	.052	.012	.000	.004	.000	

The data of the first two replications, which showed the most difference between the two Ts within a replication, were pooled and the differences between mean estimates of $P(E_1)$ and $P(E_2)$ were tested by t-test. The obtained ts were as follows, all with $df = 49$: in Experiment I, for Condition 3, $t = .27$, for Condition 4, $t = .28$; and in Experiment II, for Condition 3, $t = .37$, and for Condition 4, $t = .07$. All of these ts have probabilities greater than .50. The differences between $P(E_1)$ and $P(E_2)$ values for the later replications were smaller than those of the first two replications and obviously insignificant.

Evidently we may conclude that there are no significant changes in correct response probability, in the direction either of learning or of forgetting, over two successive test trials when there is no intervening reinforcement of the given item.

An additional source of information concerning the probabilities of some type of learning on test trials is available in the data for repetitions of correct responses and shifts from incorrect to correct, over pairs of unreinforced tests. Table 3 gives estimates of $P(C_2: C_1)$ and $P(C_2: I_1)$, the probabilities of a correct response on T_2 given a correct or an incorrect response, respectively, on T_1, for each replication of RTT (Condition 3) and RRTT (Condition 4). These conditional probabilities were estimated by the appropriate proportions in the data pooled over all subjects and appropriate items. For example, to obtain the estimate of $P(C_2: C_1)$, the proportion of joint occurrences of correct responses on T_1 and T_2 were pooled over all five items of the given condition for all subjects on a given replication and this proportion was divided by the proportion of correct responses on the T_1 trial of that replication. The principal trends are that these conditional probability estimates increase drastically over successive

Table 3

Conditional Probabilities of Correct Responses on T_2 of Each Replication Given a Correct Response, $P(C_2: C_1)$, or Given an Error, $P(C_2: I_1)$, on T_1

	Replication									
	1	2	3	4	5	6	7	8	9	Mean*
Experiment I										
Condition 3										
$P(C_2: C_1)$	.500	.708	.806	.965	.925	.959	.962	.978		.928
N	14	48	103	144	187	194	211	229		1130
$P(C_2: I_1)$	.013	.025	.143	.094	.190	.179	.231	.286		.087
N	236	202	147	106	63	56	39	21		870
Condition 4										
$P(C_2: C_1)$	.653	.822	.920	.950	.962	.977				.924
N	49	107	163	200	212	220				951
$P(C_2: I_1)$	.015	.126	.195	.140	.184	.267				.109
N	201	143	87	50	38	30				549
Experiment II										
Condition 3										
$P(C_2: C_1)$	.871	.978	.986	.987	1.000	1.000	.996	1.000	1.000	.992
N	31	135	210	235	247	247	249	250	250	1854
$P(C_2: I_1)$	.037	.139	.175	.467	.000	.000	1.000	---	---	.098
N	219	115	40	15	3	3	1	0	0	396
Condition 4										
$P(C_2: C_1)$	.827	.979	.983	1.000	1.000	1.000	1.000			.982
N	110	195	238	244	250	249	250			1536
$P(C_2: I_1)$	.064	.200	.250	.500	---	.000	---			.121
N	140	55	12	6	0	1	0			214

*Mean over all replications except the first.

replications for both experiments and both conditions. In the case of $P(C_2: C_1)$, this increase is expected regardless of whether learning is proceeding according to an all-or-none model or some type of incremental model (see Estes, 1964). The lower values of $P(C_2: C_1)$ on early replications for Experiment I are probably due to the greater incidence of guessing with digits rather than words as responses. When a subject is choosing from a relatively limited set of response alternatives, as in Experiment I, some responses will be correct by chance on the T_1 trial of a replication but will be unlikely also to be correct on the following T_2 trial.

The quantity $P(C_2: I_1)$ similarly increases over replications in all cases and is generally higher for the RRTT than for the RTT condition. The progressive increase over replications suggests that the rate, or probability, of acquisition of correct associations is progressively increasing over the experiment (a "learning to learn" effect). The observed increase is considerably too great to be accounted for by the learning of response sets; if the set of responses being used in the list for a given subject were fully learned and the subject guessed on all trials when he had not learned the appropriate correct association, the probability of a success by guessing on any item would be only .05. The values of $P(C_2: I_1)$ are of about this order of magnitude on the first replication but increase to substantially higher levels on later replications.

The values of the two conditional probability estimates averaged over all but the first replication for each condition, given at the right of Table 3, exhibit the pattern associated with all-or-none acquisition processes--that is, very high values of $P(C_2: C_1)$ and relatively low values of $P(C_2: I_1)$. The former values are close enough to unity to suggest that little retention loss occurs once a correct response has occurred to a given item. The values of $P(C_2: I_1)$ are somewhat larger than could be accounted for on the basis of successes by guessing if the subjects, when responding on unlearned items, make their response selections from the full set of available responses. The observed levels, in the neighborhood of .10, could result either from superior guessing strategies, in which responses belonging to learned items are not used in guessing, or from a failure of associative learning in this situation to conform closely to the all-or-none principle. Further evidence concerning these possible interpretations will be given in a later section.

Better evidence concerning changes in learning rates, or "conditioning probabilities," is given in Table 4, which includes for Conditions 3 and 4 of both experiments the proportions of instances on which an item was correct for the first time following a given reinforcement. Reading across the first row, for example, one sees that for items of Condition 1, Experiment I, the proportion .092 was correct on the first test trial following the first reinforcement; the proportion .185 was correct for the first time on the test trial following the second reinforcement, and so on. Reading down the second column for Experiment I, we see that on the first test trial following the second reinforcement, the proportions of items correct for the first time were .185, .168, .146, and .196, for Conditions 1, 2, 3, and 4 respectively. According to any all-or-none interpretation of learning, these proportions give estimates of the

Table 4

Proportion of Items First Correct after

a Given Reinforcement

		R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
Experiment I									
Cond. 1	P(C)	.092	.185	.195	.262	.282	.329	.415	.290
	N	250	227	185	149	110	79	53	31
Cond. 2	P(C)		.168		.346		.353		.420
	N		250		208		136		88
Cond. 3	P(C)	.056	.146	.304	.262	.425	.174	.286	.364
	N	250	233	194	122	87	46	35	22
Cond. 4	P(C)		.196		.333		.387		.381
	N		250		198		119		63
Experiment II									
Cond. 1	P(C)	.148	.432	.554	.574	.609	.222		
	N	250	213	121	54	23	9		
Cond. 2	P(C)		.388		.582		.656		
	N		250		153		64		
Cond. 3	P(C)	.124	.443	.544	.500	.462	.000		
	N	250	219	114	36	13	2		
Cond. 4	P(C)		.440		.571		.627		
	N		250		140		51		

probability that an association forms on any given reinforced trial; according to an incremental interpretation, such as that associated with the linear model, these proportions are related in relatively complex ways to learning-rate parameters, and about all that can be said about them in general is that they should increase over successive replications. According to an all-or-none model, these proportions should be constant over replications if the basic conditioning probability is constant but should increase if there is any "learning to learn" effect.

Considering the sets of values within columns, that is following constant numbers of reinforcements, and neglecting instances based on small N's, we conclude that the probability of an item's first shifting from the incorrect to the correct state increases substantially over replications and that this increase is primarily a function of a number of preceding reinforcements rather than of the number of preceding test trials. This pattern is particularly striking in the data of Experiment II. Consider, for example, the first two replications of Conditions 3 and 4. The probability of an item shifting from incorrect to correct is nearly four times as great on the second reinforced trial as on the first; but this probability is virtually the same whether the second reinforcement is or is not preceded by two test trials.

In many respects the most instructive results, from both theoretical and practical standpoints, are the learning curves exhibiting response frequency as a function either of number of preceding reinforcements or of total trials. If T trials are strictly neutral with respect to changes in correct response probability, then learning curves of the first type should be identical, except for sampling error, for all four conditions. Previous analyses indicate that no significant changes in correct response probability occur on T trials, but the possibility remains that the presentation of T trials might affect the learning on subsequent R trials. To check on this point, we turn to Fig. 1, which presents the proportion of errors on the first test trial following each reinforcement for each of the four conditions.

The reinforcement-test sequences for Conditions 1, 2, 3, and 4 were respectively R T R T ..., R R T R R T ..., R T T R T T ..., and R R T T R R T T .... Consequently, for Condition 1, the proportion of errors on the i^{th} T trial was plotted as the point immediately after the i^{th} R trial on the abscissa of Fig. 1, where $i = 1, 2, \ldots, 12$ in Experiment I, and $i=1, 2, \ldots, 14$ in Experiment II. For Condition 2, the tests occurred only after the even numbered R trials, and thus points are plotted for $i = 2, 4, \ldots, 16$ in Experiment I, and $i = 2, 4, \ldots, 18$ in Experiment II. In the same fashion, for Condition 3, the error proportions are plotted for the first of the two T trials following every R_i, where $i = 1, 2, \ldots, 8$ in Experiment I and $i = 1, 2, \ldots, 9$ in Experiment II. For Condition 4, the error proportions are plotted for the first of the two T trials following each even-numbered R trial, one point for each RRTT replication, with $i = 2, 4, \ldots, 12$ in Experiment I and $i = 2, 4, \ldots, 14$ in Experiment II.

Whereas the points plotted on any given ordinate of Fig. 1 represent performance following a constant number of reinforcements, the conditions differ with respect to the number of preceding test trials and therefore the total number of preceding trials. Considering, for example, the values for the first test trial after the eighth

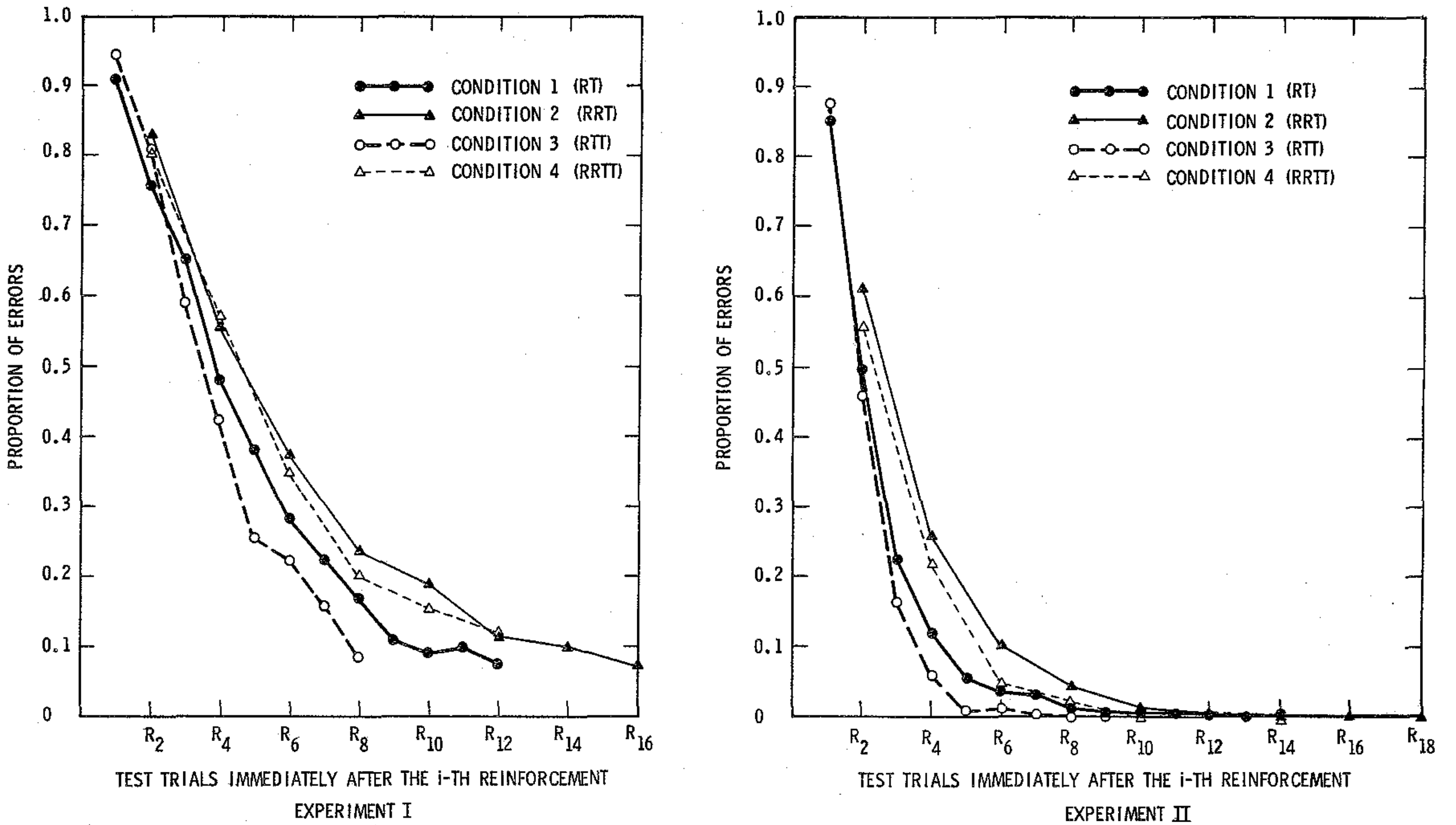

Fig. 1 Learning Curves in Terms of the First Test Trial Following Each Reinforcement (Even-numbered Reinforcements Only in the Case of Conditions 2 and 4).

reinforcement, the point for Condition 1 was preceded by 7 T trials, that for Condition 2 by 3 T trials, that for Condition 3 by 14 T trials, and that for Condition 4 by 6 T trials. We note immediately that the curves for both experiments line up in the order of the number of T trials preceding a given plotted point. Thus, in each experiment the curve for Condition 3 is lowest throughout, that for Condition 1 next, then that for Condition 4, and finally the curves of Condition 2, in each case highest. However, it does not appear likely that number of preceding T trials per se is the critical variable, for Conditions 1 and 4 differ only by one unit in the number of Ts preceding any plotted point, but their curves are well-separated for both experiments and, in particular, diverge considerably more than the curves for Conditions 2 and 4 which differ by a 2 to 1 ratio in the number of T trials preceding a given point. Evidently, the major factor must be the spacing out of reinforced trials by blocks of one or more T trials. Further investigation will, of course, be necessary to determine whether we have reached the optimum with Condition 3 of the present study or whether learning would be still faster if more than two T trials intervened between successive reinforcements.

Taking together these findings and those of the previous section, we can see that the answer to questions concerning the effects of test trials on paired-associate learning is not going to be simple. When we simply look at performance on test trials which are given successively with no intervening reinforcement, we observe no significant change in correct response probability, suggesting that neither learning nor forgetting is occurring. However, some process of importance to the overall course of acquisition clearly does occur on test trials and the result of this process is to increase the effectiveness of subsequent reinforced trials. We cannot within the present experimental design separate the effect of any activity occurring on test trials from effects of the time taken by the test trials. However, the substantial differences between the curves for Conditions 1 and 3 in each panel of Fig. 1 rather suggests the former interpretation. In Condition 1 the time between successive reinforcements of a given item is already rather large in terms of the intervals ordinarily occurring in learning experiments, and it is hard to believe that simply the increase in temporal spacing involved in going from Condition 1 to Condition 3 could produce effects as large as those observed.

From a practical standpoint it is of interest to compare the four conditions with respect to efficiency in the sense of the level of performance attained after a given total amount of time in the experimental situation. Evidence on this point is provided by Fig. 2 in which we have plotted for each cycle (that is, each successive randomized presentation of the 20 items of the list for a given subject) the proportion of errors for all conditions having a test trial on that cycle. All conditions are represented simultaneously only on the twelfth and twenty-fourth cycles, but overall trends for the four conditions are not difficult to compare. Since we have determined in the preceding section that learning of the correct response occurs only on reinforced trials, one might have expected that in this figure the curves would line up in order of the density of reinforcements over the trials preceding any given plotted point. To some extent, this expectation is borne out; for

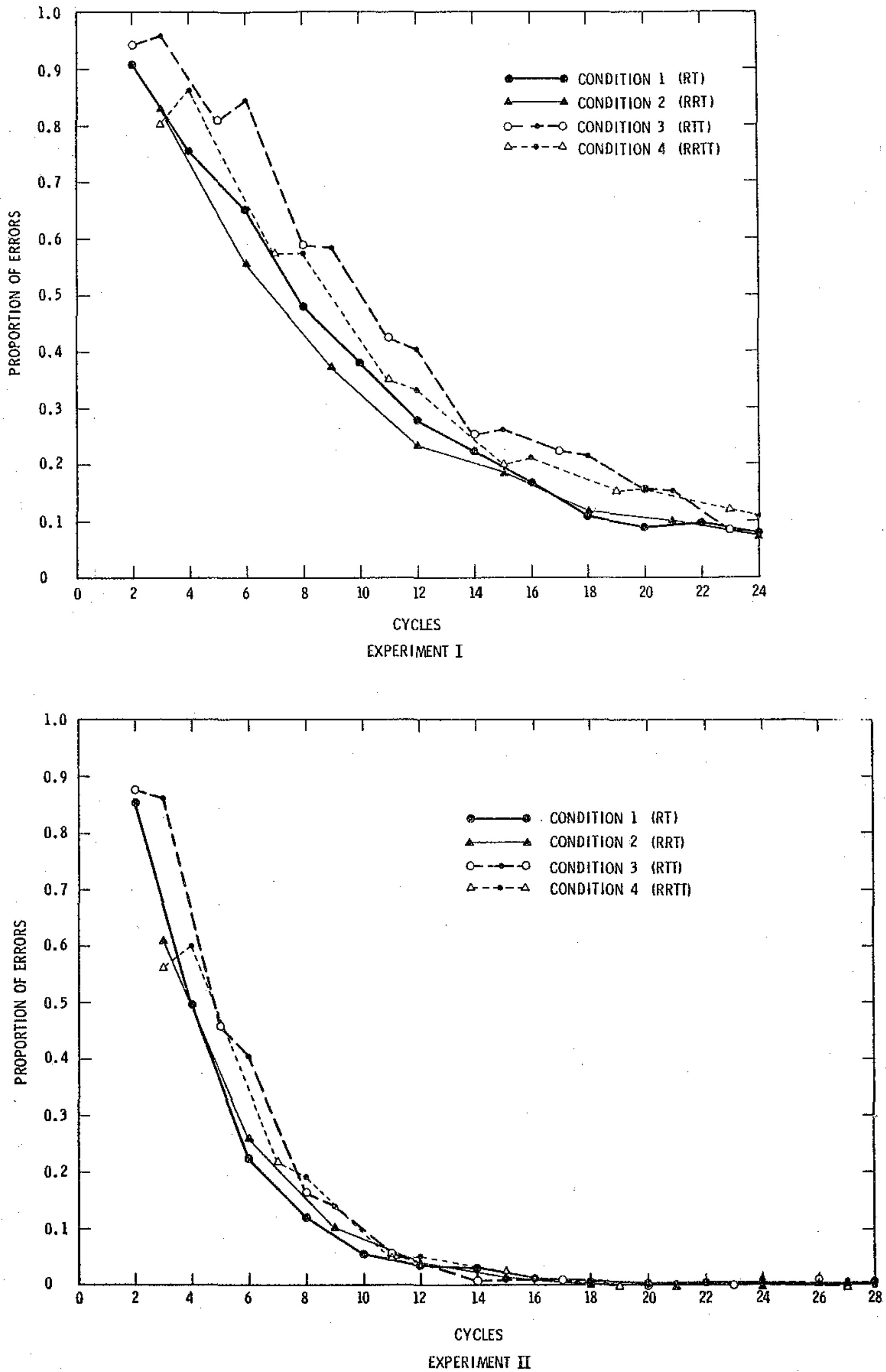

Fig. 2 Learning Curves in Terms of Cycles.

example, Condition 2, though consistently running above all of the others in the curves of Fig. 1, exhibits the most rapid improvement in performance as a function of cycles in Experiment I (see upper panel of Fig. 2) and is one of the two most efficient in Experiment II. More striking is the efficiency of the RTRT condition, the performance curve for which overtakes and passes that of Condition 2 (RRT) relatively late in Experiment I and relatively early in Experiment II and runs below all of the other curves over the terminal cycles of both experiments. Roughly speaking one may say that early in the series of training trials the most efficient use of a given unit of experimental time is the presentation of a reinforced trial, but that later in the sequence this becomes less true and under some circumstances one may actually gain in efficiency by replacing some reinforcements with unreinforced test trials.

The picture of relative acquisition rates for the various conditions given by the learning curve analyses is supplemented by various statistics for errors and trials to criterion in Tables 5, 6, and 7. The statistics of Table 5 simply show in another way the fact that when given sized blocks of reinforcements are interspersed with pairs of test trials rather than single test trials, the relative frequency of protocols containing large numbers of errors is substantially increased. The higher error incidence for Condition 3 over 1 and Condition 4 over 2 shows up even when the data are converted to average errors per test trial; this observation suggests a question as to whether, although learning in the sense of increasing correct response probability certainly did not occur on test trials, there might have been learning in the sense of an increase in probability of errors which happened to occur.

Table 5

The Distribution of the Errors over All Tests, the Total Errors, and the Mean Errors per Protocol for Each Condition

	Experiment I				Experiment II			
No. of Errors over All Ts	Cond. 1 (RT) freq.	Cond. 2 (RRT) freq.	Cond. 3 (RTT) freq.	Cond. 4 (RRTT) freq.	Cond. 1 (RT) freq.	Cond. 2 (RRT) freq.	Cond. 3 (RTT) freq.	Cond. 4 (RRTT) freq.
0	16	38	4	23	34	95	27	90
1	31	64	5	17	89	86	11	25
2	33	43	21	54	64	42	91	76
3	37	42	12	23	37	21	19	15
4	32	22	44	37	14	4	62	30
5	27	13	23	20	5	1	7	5
6	23	13	32	18	1	1	20	5
7	20	9	15	13	5	0	5	2
8	8	6	25	6	0	0	5	1
9	8		5	7	0	0	0	0
10	4		10	11	0		1	1
11	3		9	4	0		0	0
12	8		10	17	1		0	0
13			10		0		2	0
14			8		0		0	0
15			4				0	
16			13				0	
17							0	
18							0	
Total Errors	1054	618	1745	1110	462	260	764	429
No. of Total Ts*	12	8	16	12	14	9	18	14
Mean Errors per Subject Item over All Ts	4.216	2.472	6.980	4.440	1.848	1.040	3.056	1.716
S.D.	2.919	2.060	4.108	3.396	1.550	1.093	2.103	1.766

*The numbers of total Ts in Experiment II were determined by the slowest learner among the subjects.

Some evidence on this last point is provided by Table 6 which gives the frequency distribution of overt errors on the first six test trials of each condition in Experiment II.

Table 6

Overt Errors on T_1 through T_6 in Experiment II

Condition \ Frequency/Protocol	1	2	3	4	Total No. of Overt Errors	Average Overt Errors per Test
1 (RT)	71	3	1	0	80	.0229
2 (RRT)	54	2	1	0	61	.0271
3 (RTT)	98	15	1	1	135	.0300
4 (RRTT)	73	9	1	1	98	.0280

However, these data appear to lend little support to such a hypothesis. The frequencies of overt errors over the first six test trials, in which all conditions are equally represented, are about in proportion to the mean errors per protocol shown for Experiment II in Table 6. The incidence of repeated overt errors, that is, instances of repetition of the same overt error by the same subject for a given item, is disproportionately higher for Conditions 3 and 4, but the absolute frequencies of these repetitions are so small as to be almost negligible with respect to theoretical implications. Further, of the 15 occurrences of overt errors repeated twice in Condition 3, nine occurred within the T_1 T_2 trials of a single RTT replication and of the nine similar cases in Condition 4, six occurred within the T_1 T_2 trials of a single RRTT replication.

In preparing Table 7, the criterion of acquisition was set at four consecutive correct responses for Experiment I and two consecutive correct responses for Experiment II. With these criteria applied to individual items in each experiment, distributions of trials to the last error, mean number of test trials before the last error and mean number of reinforcements before the last error were computed. The last named statistic is perhaps the most informative, and bears out the conclusion from preceding analyses that the effectiveness of each reinforcement is greatest when the ratio of reinforcements to tests in a given condition is lowest.

Latency Analyses

The following analyses are limited to Experiment I, for which response times (latencies) were recorded. Fig. 3 gives learning curves in terms of the mean latency in seconds per trial for correct and incorrect responses considered separately for each condition. Latencies of correct responses were significantly lower than latencies of incorrect responses throughout the series for all of the four conditions. Latencies of correct responses pooled for all conditions started at a mean of 3.718 sec. (S. D. = .156 sec.) and steadily decreased over trials, terminating at a mean of 2.662 sec. (S. D. = .024 sec.). The only significant exceptions to the essentially monotone decrease in mean correct response latency over trials occur in the early replications of the RTT sequence of Condition 3 and the RRTT sequence of Condition 4. In these instances, relatively sharp decreases from T_1 to T_2 of a

Table 7

The Distribution of Trials to the Last Error, the Mean Tests before the Last Error

and the Mean Reinforcements before the Last Error

No. of Trials	Experiment I				Experiment II			
	Condition 1 (RT)	Condition 2 (RRT)	Condition 3 (RTT)	Condition 4 (RRTT)	Condition 1 (RT)	Condition 2 (RRT)	Condition 3 (RTT)	Condition 4 (RRTT)
0	16	39	4	24	34	96	27	91
1								
2	31		1		90		8	
3		63	22	2		86	97	9
4	29			60	63			92
5			3				15	
6	33	43	47		33	39	63	
7				13				10
8	24		19	49	18		5	36
9		30	39			20	20	
10	27				3			
11			6	11			7	1
12	20	20	31	28	3	6	6	7
13								
14	22		6		4		0	
15		19	8	3		2	0	2
16	15			11	1			2
17			8				0	
18	7	11	12		0	1	0	
19				4				0
20	5		5	13	0		1	0
21		11	15			0	1	
22	6				0			
23			4	7			0	0
24	15	14	20	25	1	0	0	0
25								
26					0		0	
27						0	0	0
28					0			0
Total Ts	1172	669	1882	1232	468	264	768	444
No. of Ts per Pair	12	8	16	12	14	9	18	14
Mean Ts before the Last Error per Item	4.688	2.676	7.528	4.928	1.872	1.056	3.072	1.776
S.D.	3.305	2.320	4.319	3.628	1.601	1.143	2.118	1.744
Mean Rs before the Last Error	4.688	5.352	3.868	5.280	1.872	2.112	1.608	1.864

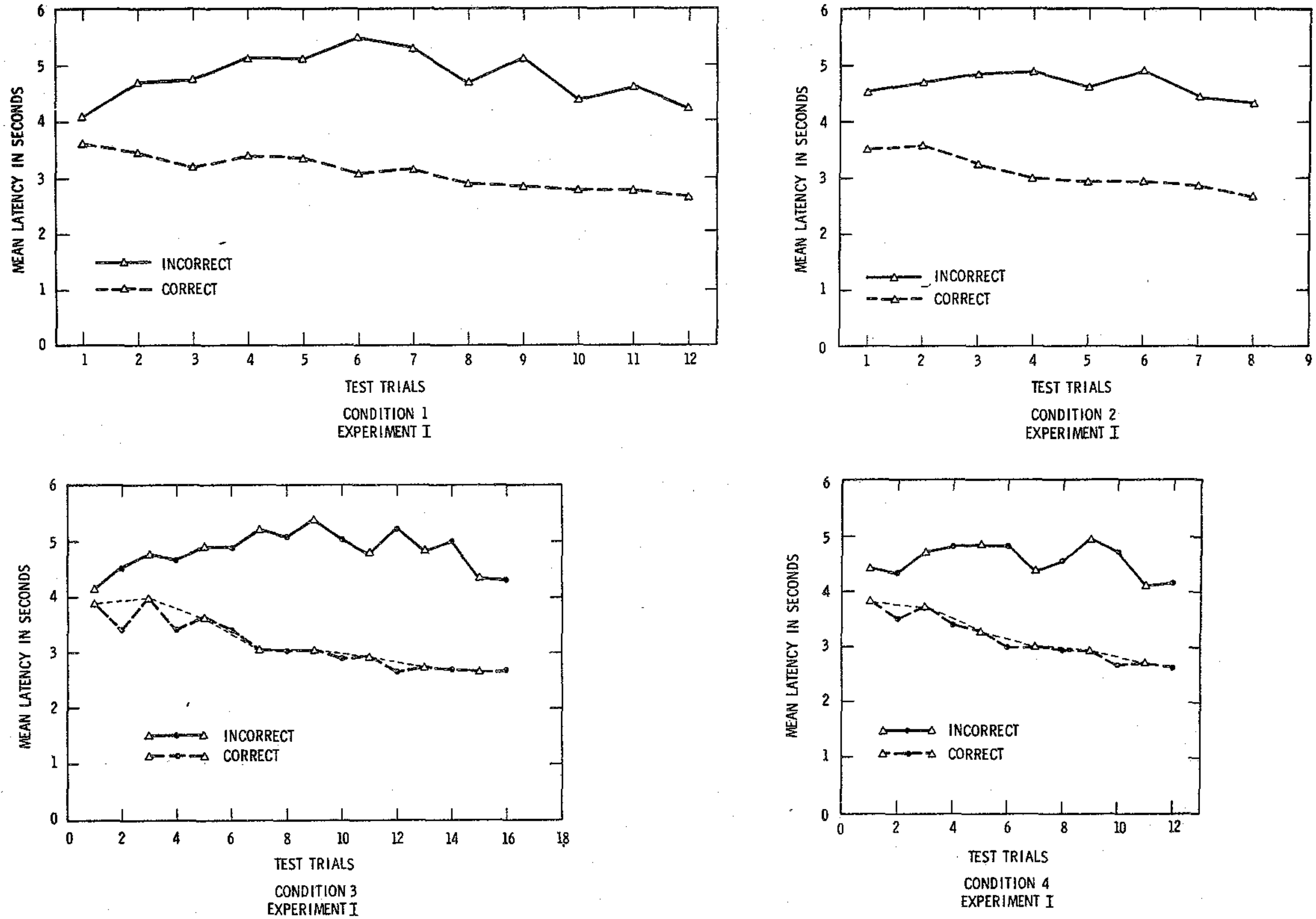

Fig. 3 Latency Curves.

given replication were followed by increases in latency on the T_1 trial of the next replication.

Error latencies were uniformly higher on the average than correct response latencies. The curves of incorrect response latencies pooled for all conditions started out at a slightly higher level, (4.258 sec., S. D. = .069 sec.) on the average, than the correct response curves. Then the curves rose rather steadily until they passed through maximum values about half way through the learning series, and subsequently declined to a terminal mean of 4.293 sec. (S. D. = .069 sec.) which was slightly higher than the initial value.

It is possible that items were in distinctly different states of learning in the pre- and postcriterion portions of the trial series. Evidence bearing on this point is presented in Table 8, which includes mean latencies for pre- and postcriterion portions of the data separately for each of the four conditions. The criterion was defined by the first occurrence of four consecutive correct responses in the protocol for a given subject item. The postcriterion trials for each sequence were renumbered from 1, beginning with the first criterion trial.

Consider first the precriterion latencies. Throughout the four conditions, a rather high degree of constancy over trials was observed for both correct and incorrect latencies. The differences between correct and error latencies were relatively small, with the error responses having longer latencies for each of the four conditions.

During postcriterion trials, latencies of correct responses revealed overall a systematically decreasing trend from the beginning to end, the largest decreases occurring during the first four T trials, which

Table 8

Mean Latency for Correct and Error Responses in Experiment I

Section A. Condition 1

	Precriterion				Postcriterion			
	Correct		Error		Correct		Error	
Trial	L*	N**	L	N	L	N	L	N
1	4.83	7	4.07	227	3.86	217	0	0
2	3.65	14	4.69	189	3.35	217	0	0
3	2.86	11	4.72	163	2.98	217	0	0
4	3.99	21	5.12	120	2.92	217	0	0
5	4.57	22	5.10	95	2.74	193	3.98	9
6	3.80	22	5.50	68	2.62	177	4.87	3
7	3.73	15	5.34	55	2.55	160	0	0
8	4.12	7	4.74	41	2.39	130	4.14	3
9	4.56	8	5.11	25	2.44	109	0	0
10	4.08	7	4.70	19	2.41	74	4.52	2
11	7.85	1	4.48	20	2.15	47	0	0
12	0	0	4.21	15	2.35	16	0	0
Mean	4.015		4.735		2.897		4.229	

Section B. Condition 2

	Precriterion				Postcriterion			
	Correct		Error		Correct		Error	
Trial	L	N	L	N	L	N	L	N
1	4.94	3	4.53	208	3.64	195	0	0
2	4.60	9	4.68	139	3.16	195	0	0
3	3.68	12	4.84	93	2.91	195	0	0
4	3.51	16	4.88	59	2.77	195	0	0
5	3.91	8	4.60	47	2.49	172	3.32	3
6	5.16	8	4.95	28	2.53	141	5.72	4
7	3.34	4	4.60	21	2.47	100	2.88	2
8	0	0	4.14	14	2.16	39	0	0
Mean	4.041		4.664		2.881		4.289	

*Latency
**Frequency

Table 8 (Continued)

Section C. Condition 3

	Precriterion				Postcriterion			
	Correct		Error		Correct		Error	
Trial	L*	N**	L	N	L	N	L	N
1	4.13	10	4.14	236	3.67	206	0	0
2	3.67	5	4.52	240	3.44	206	0	0
3	4.45	21	4.77	202	3.05	206	0	0
4	3.97	9	4.68	211	2.86	206	0	0
5	4.63	26	4.90	147	2.65	191	2.75	3
6	4.55	8	4.88	146	2.67	182	5.76	4
7	4.44	9	5.22	106	2.54	178	0	0
8	4.50	8	5.08	101	2.54	171	2.90	1
9	4.27	16	5.45	62	2.38	140	5.84	1
10	3.77	10	4.96	62	2.37	133	3.12	2
11	5.11	9	4.81	55	2.36	96	0	0
12	2.74	3	5.28	53	2.34	77	0	0
13	4.91	6	4.88	38	2.21	30	0	0
14	3.74	3	5.00	36	2.28	27	0	0
15	3.49	5	4.55	19	1.87	5	0	0
16	0	0	4.30	20	2.29	4	0	0
Mean	4.324		4.752		2.800		4.206	

Section D. Condition 4

	Precriterion				Postcriterion			
	Correct		Error		Correct		Error	
Trial	L	N	L	N	L	N	L	N
1	4.09	25	4.43	201	3.83	201	0	0
2	4.25	9	4.35	215	3.29	201	0	0
3	4.28	21	4.73	143	3.05	201	0	0
4	5.26	7	4.82	143	2.82	201	0	0
5	5.07	16	4.89	86	2.75	188	4.57	2
6	4.38	8	4.84	83	2.53	185	3.72	2
7	4.21	13	4.39	50	2.57	157	3.20	2
8	5.12	7	4.55	53	2.51	148	0	0
9	4.04	13	4.99	36	2.39	99	0	0
10	3.64	7	4.75	38	2.42	84	3.16	1
11	4.48	3	4.11	29	2.51	26	0	0
12	0	0	4.22	25	2.30	24	0	0
Mean	4.383		4.591		2.875		3.734	

*Latency
**Frequency

were the criterion run, in all cases, and both the overall means and the terminal levels were very similar for all four conditions.

A point of special interest is the pattern of overall means, those for precriterion correct and error responses and for postcriterion errors being clustered at a level of about $4.2 \pm .5$ sec. whereas those for postcriterion correct response are virtually equal (the means for all four conditions falling between 2.8 and 2.9 sec.).

The close similarity in form of the postcriterion correct response curves for all four conditions, despite the differences in R and T sequences, suggests that the decrease in latencies is a function primarily of correct response occurrences, and may have to do with a progressive increase in response availability, or retrievability, rather than of the formation of association between stimuli and correct responses. On this hypothesis, the function of an effective reinforcement is to transfer an item from the initial "unlearned" state, in which correct response probability is low, response latency high and relatively constant, to a "learned" state, in which correct response probability is near unity and latency systematically decreasing.

An implication of this hypothesis is that there should be close correspondences between families of learning curves for the four training conditions plotted in terms of response frequencies and in terms of latencies. Relevant evidence is provided by Fig. 4, in which learning curves for correct and error response latencies are plotted as a function of the number of reinforcements.

The lower panel of Fig. 4 presents the mean latencies of correct responses immediately after the i^{th} reinforcement for each of the four

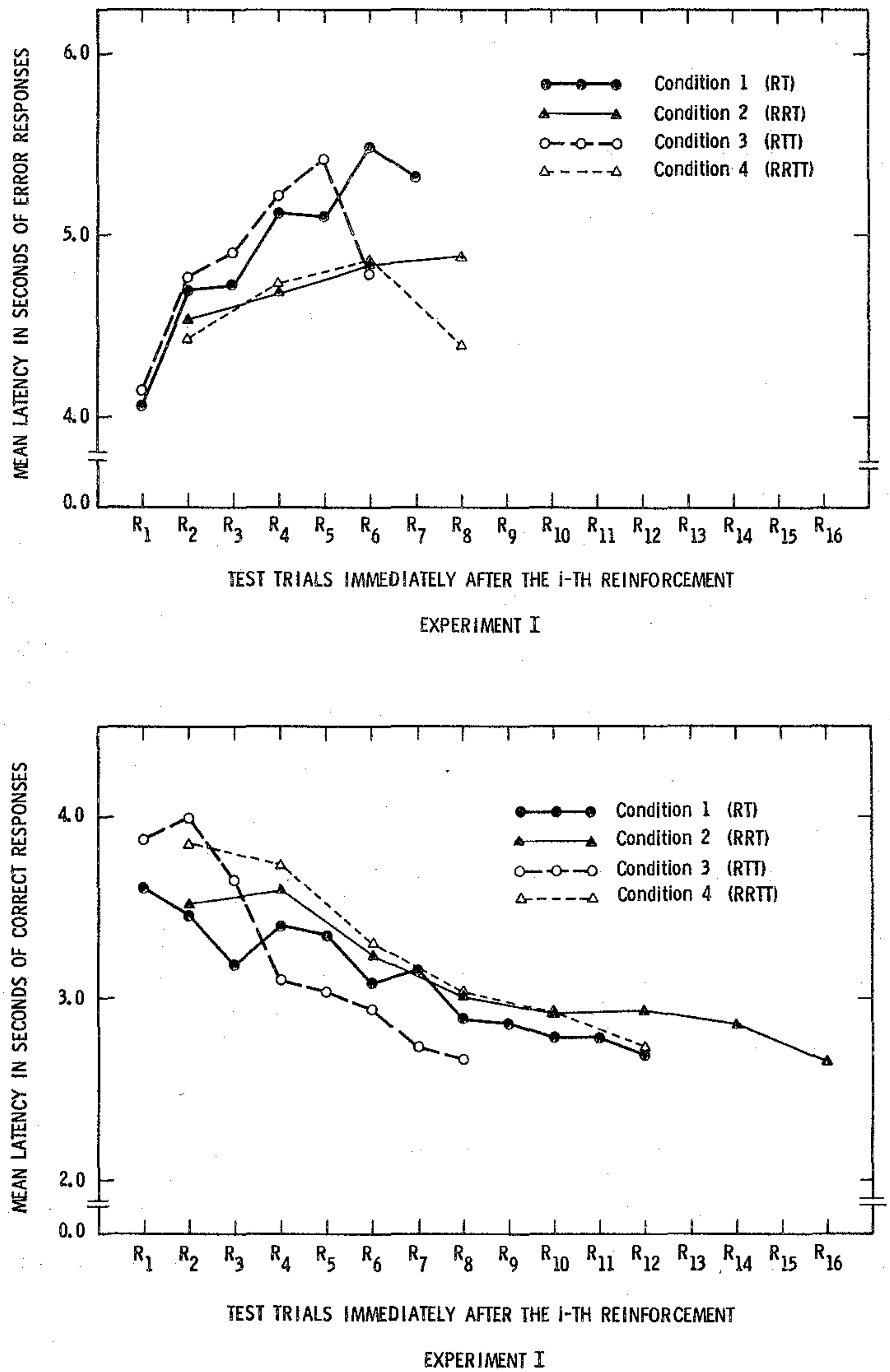

Fig. 4 Mean Latencies Immediately after the i-th Reinforcement

conditions in Experiment I. The principle for plotting the curves was analogous to that of Fig. 1, the construction of which was detailed in the previous section. It is interesting to note that the overall course of decreasing latencies of correct responses is very similar to that of learning curves for error proportions in Fig. 1. In both of these figures, the rank order of the curves was Condition 3, Condition 1, Condition 4, and Condition 2, those of Condition 3 decreasing most rapidly as a function of number of reinforcements.

The same kind of analysis for the error latencies is shown in the upper panel of Fig. 4. By the 8th reinforcement the number of cases available for the analyses became very small, and thus later trials are omitted from the presentation; each of the points shown in the figure is based on more than 50 observations. The overall trend of the latency curves of error responses is opposite to that of the latency curves of correct responses, all of the curves showing an upward trend until at least the 5th reinforcement. During this stage, the latencies for the items in Condition 3 were longest, being followed by Conditions 1, 4, and 2 in descending order. The basis for the increase in error latencies as a function of reinforcements is not obvious; conceivably it represents merely a bias in item selection, the items on which errors still occur after several reinforcements being on the average the more difficult.

A similar comparison was undertaken for correct response and error latencies plotted as a function of total time from the beginning of training, as in the frequency curves of Fig. 2, but differences among the curves for the four conditions proved too small and unsystematic to merit detailed analysis.

In order to permit examination of changes in the latency distributions for each condition during learning, the entire experimental session was divided into four equal blocks (quartiles). Each quartile of Conditions 1 and 4 had three T trials; Condition 2, two T trials; and Condition 3, four T trials. Individual latencies were tallied into 20 categories, with a class interval of .50 sec. Fig. 5 presents the frequency distributions so obtained for correct response latencies. For each condition, a family of empirical functions similar in form to beta-distributions was generated. As learning progressed all of the frequency functions became more and more sharply peaked, while in nearly all instances the modal category remained constant. Irrespective of the stage of learning most of the correct responses had latencies of 2.00 to 2.50 sec.

A similar analysis was done for the error responses, with the results shown in Fig. 6. The overall pattern of the family of curves is similar for all four conditions. Again the modes remain approximately constant throughout learning, but with the modal category generally falling at about 3.00-4.00 sec. Changes in peakedness are just the reverse of those shown for correct response latencies in Fig. 5. The excess of long response times in the last latency category (9.50 to 10.00 sec.) is accounted for by a technical limitation in the apparatus used. The Berkeley EPUT timer could not record latencies longer than 10 sec., so all responses longer than 10 sec. were counted as 10 sec. latencies.

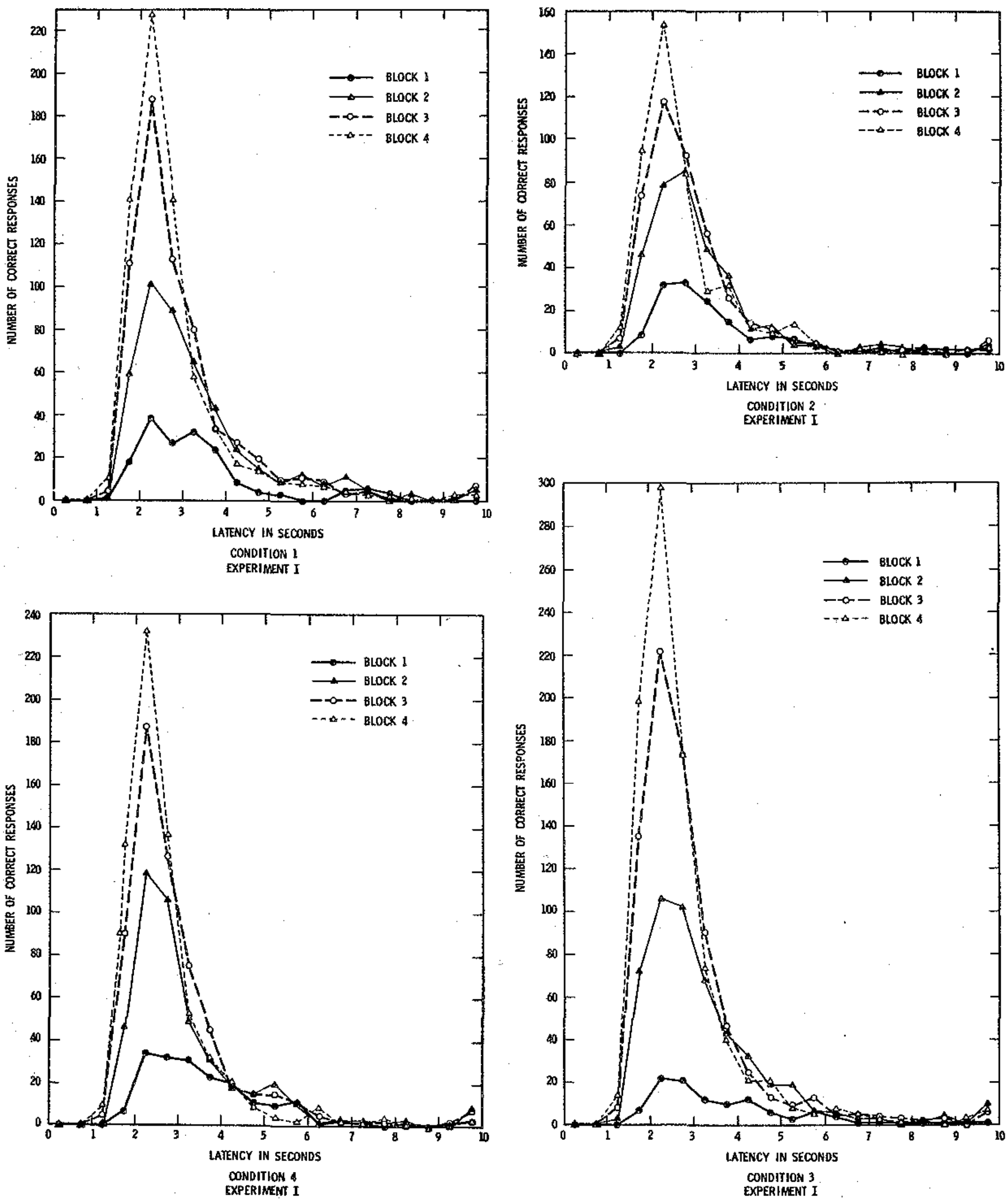

Fig. 5 Latency Distributions of Correct Responses.

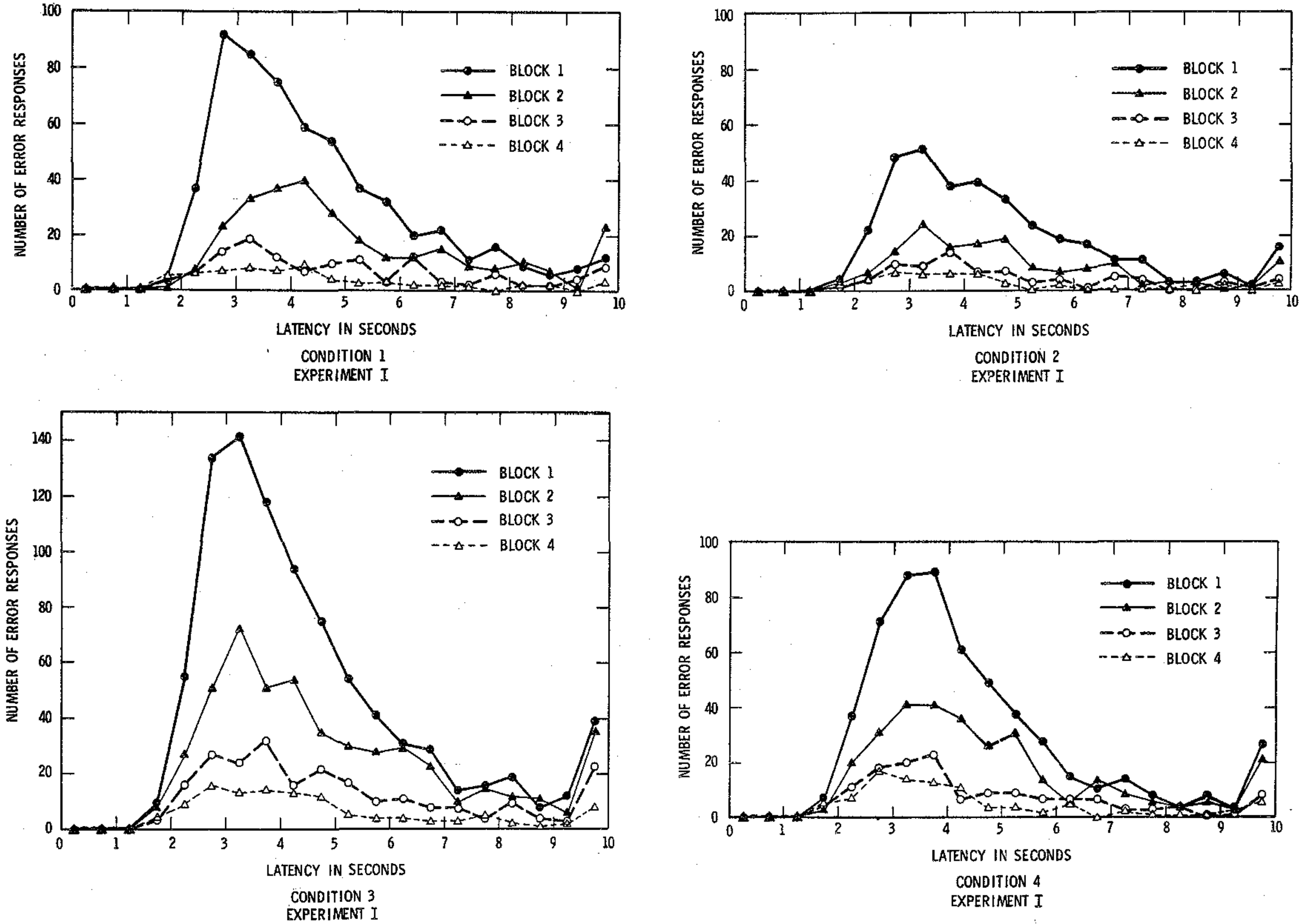

Fig. 6 Latency Distributions of Error Responses.

Chapter IV

Theoretical Analyses

One-Element Model

A number of purposes can be served by determining, first of all, the extent to which the present data conform to the simple one-element model for paired-associate learning (Bower, 1961; Estes, 1961). Interpreted in terms of the present situation, the assumptions of the model are: (1) Learning occurs only on R trials; on each such trial there is a constant probability c that the correct response will become associated with the stimulus for the given item; once an association is formed the correct response will thereafter occur with a probability of 1 when the given stimulus is presented on test trials. (2) For a given set of conditions there is some fixed probability g that a correct response will occur by guessing on trials prior to learning for a given item; in Experiment I, the value of g should be expected on a priori grounds to be equal to one over the number of admissible responses, i.e., 1/90. In Experiment II, since the list of response words was initially unknown to the subjects, for all practical purposes g should be equal to 0. As in most other applications of the model, the assumptions concerning guessing probabilities need some qualifications. The assumptions stated above should be expected to hold only if the subject continued throughout the experiment to follow the strategy of guessing on unlearned items by responding at random from the full set of possible response alternatives.

In Experiment II, the set of response alternatives was initially unknown so that on the first trial the guessing probability should be equal to 0; if, however, response learning, in some sense occurs, beyond the learning of associations between stimuli and the correct responses, then at an intermediate stage in the experiment the subjects may have learned some of the responses without having associated them with the proper stimuli and thus on test trials may have probability greater than 0 of successes by guessing. Further, even in Experiment I, it is possible that over the course of the experiment, subjects might improve their guessing strategy as, for example, by going over to the more efficient procedure of guessing on unlearned items by choosing responses only from those not belonging to already learned items. Nonetheless, on the early trials of an experiment one should expect that the simplest assumptions concerning guessing behavior would be recently well-approximated and thus we make our preliminary assessment of the applicability of the model by treating only the data of the first two test trials for each condition.

In Table 9 we present for each experiment and each condition the proportions of instances in which items were correct on both of the first two test trials, correct on the first and incorrect on the second, incorrect on the first and correct on the second, or incorrect on both, together with theoretical values for the one-element model. For each experiment computations of theoretical values have been made under two assumptions concerning guessing probabilities. In case of Experiment I, the first set of computations was conducted with g equal to .01, assuming that guessing responses were chosen from the full set of

Table 9

Joint Response Proportions for First Two Test Trials Compared with

Predictions from One-Element Model

	Experiment I			Experiment II		
	Theoretical g = .01	Observed	Theoretical g = .05	Theoretical g = 0	Observed	Theoretical g = .05
Condition 1						
CC	.07	.08	.04	.14	.14	.12
CI	.01	.02	.04	.00	.01	.02
IC	.16	.16	.20	.37	.37	.38
II	.76	.74	.72	.49	.48	.48
Condition 2						
CC	.17	.16	.16	.42	.38	.40
CI	.01	.01	.03	.00	.00	.01
IC	.24	.29	.30	.39	.36	.40
II	.58	.54	.51	.19	.26	.19
Condition 3						
CC	.07	.03	.03	.14	.11	.10
CI	.01	.03	.05	.00	.02	.04
IC	.01	.01	.05	.00	.03	.04
II	.91	.93	.87	.86	.84	.82
Condition 4						
CC	.17	.13	.14	.42	.36	.38
CI	.01	.07	.04	.00	.08	.03
IC	.01	.01	.04	.00	.04	.03
II	.81	.79	.78	.58	.52	.56

admissible alternatives. The second set of computations was done with g equal to .05, the value that would obtain if the subjects had learned the 20 responses belonging to the list and chosen from among these on guessing trials. In the case of Experiment II, the two assumptions used were $g = 0$ and $g = .05$. We expect that if the model is applicable, the observed values should fall between those computed under the two guessing assumptions in each experiment, since one would expect on psychological grounds that the guessing behavior might be moving from the lower level toward the higher over the course of the first few trials.

The remaining parameter that had to be evaluated for each experiment was the conditioning parameter c. If the effects of R trials were the same under all conditions, so also would be the value of c and a single estimate should serve for all conditions of a given experiment. On the basis of comparisons of learning curves for different conditions already discussed, however, we know that the effects of R trials differ under the different conditions and thus that a common estimate of c could not be expected to be adequate. Making use of the information already obtained concerning the differential effects of reinforcements under the different conditions, we have estimated three different c values for each experiment: the first, c_1, represents the effect of the first R trial; the second, c_2, represents the effect of any later R trial which is not preceded by a T trial; the third, c_3, represents the effect of any R trial preceded by a T trial. For Experiment I, the estimate of c_1, obtained from the pooled data of the first T trial for Conditions 1 and 3, was .07; the value for c_2, obtained from the pooled data of the first test trials of Conditions 2 and 4, was .10; and the value for c_3, obtained from the data of the second test trial of Condition 1, was .14. For Experiment II the corresponding estimates were $c_1 = .03$, $c_2 = .11$, and $c_3 = .18$. Using these estimates, the theoretical values were computed according to the standard procedure described in, e.g., Atkinson and Estes (1964), or Estes (1961). On the whole, the agreement between theoretical and observed values is relatively good, and especially so for the second two rows of each table, having to do with the probabilities of shifts from incorrect to correct responding (over an R trial in Conditions 1 and 2, or over two adjacent T trials, in Conditions 3 and 4). The only major disparities between theoretical and observed values occur in the case of the probability that a correct response on a T trial is followed by a correct response on a subsequent T trial in Conditions 3 and 4. In both experiments the retention loss from the first of two adjacent unreinforced T trials to the next is greater in the data than allowed for by the one-element model.

The results of this analysis, then, would seem to cast no doubt on the basic assumption of the one-element model that the acquisition of correct associations occurs on essentially an all-or-none basis on individual R trials, but with the effect of an R trial depending on the type of sequence in which it is imbedded, and in particular, an R trial being more effective if it follows a T trial. The perfect retention implied by the model is not observed, however, especially following a block of two adjacent R trials. A fully adequate model will evidently have to provide for discontinuous acquisition of correct responses, but imperfect retention, with the degree of retention of the effects of an effective learning trial depending upon the type of sequence.

According to the one-element model, the basic learning curves plotted in terms of error probability on the first T following each successive R trial should be described by functions of the form

$$q_n = A\, X^{n-1} , \tag{1}$$

where q_n denotes probability of an error following the n^{th} R trial, and A and X are constants. If the conditioning parameter c, representing the effect of an R, were constant throughout the series, then the parameter X, in Equation 1 would equal $1 - c$ and A would equal $q_0(1 - c)$, where q_0 is the error probability prior to the first R trial. However, we know on the basis of analyses discussed above that the effect of an R increases over the learning series in our situation, with the largest change occurring from the first to the second R under each condition. Nonetheless, if the conditioning parameter does not change greatly subsequent to the second R, a function of the form of Equation 1 should describe the learning curve for each condition. Letting c_1 denote the conditioning parameter on the first R trial, c_2 the conditioning parameter on the second and subsequent R trials, and g the probability of a correct response by guessing on unlearned items, Equation 1 becomes

$$q_n = (1 - g)(1 - c_1)(1 - c_2)^{n-1} ,$$

where $n = 1, 2, \ldots$ for Conditions 1 and 3, and $n = 2, 4, \ldots$ for Conditions 2 and 4.

With this interpretation in mind, the values of A and X in Equation 1 were determined by least-squares for each of the empirical learning curves of Fig. 1, and the corresponding empirical and theoretical values are compared for each condition of Experiments I and II in Fig. 7 and Fig. 8, respectively.

We take the close agreement of theoretical and observed values to support the general family of models which assume a constant learning effect (or constant learning probability) on R trials and no learning on T trials. Within this family, special support cannot be claimed for the one-element model over, for example, the linear model or various stimulus sampling models, all of which entail learning functions of the form of Equation 1. Thus the next step in a theoretical analysis is to determine which, if any, of these models can provide a rational interpretation of the differences in values of learning rate parameters (i.e., X values in Fig. 7 and Fig. 8) over the four conditions.

Stimulus Fluctuation Model

Of the extant models which can accommodate the forms of the learning curves, the obvious candidate for more detailed examination is the stimulus fluctuation model (Estes, 1955a, 1955b). On a priori grounds, it is clear that this model can account, at least qualitatively, for many of the empirical relationships that have emerged from our data.

The principal assumptions of the fluctuation model, interpreted in terms of the present experimental situation, are as follows:

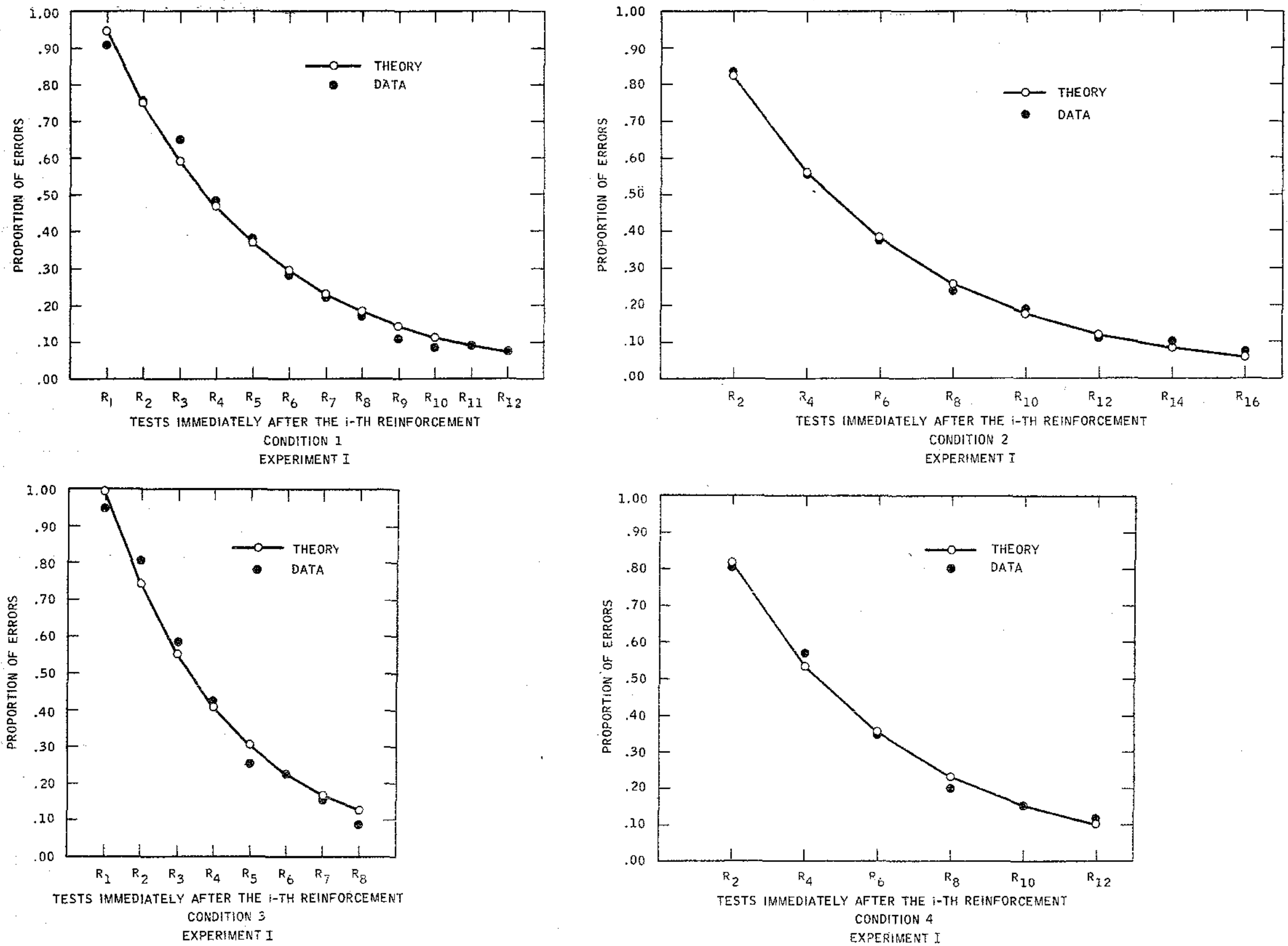

Fig. 7 Theoretical Functions Compared with Data of Experiment I.

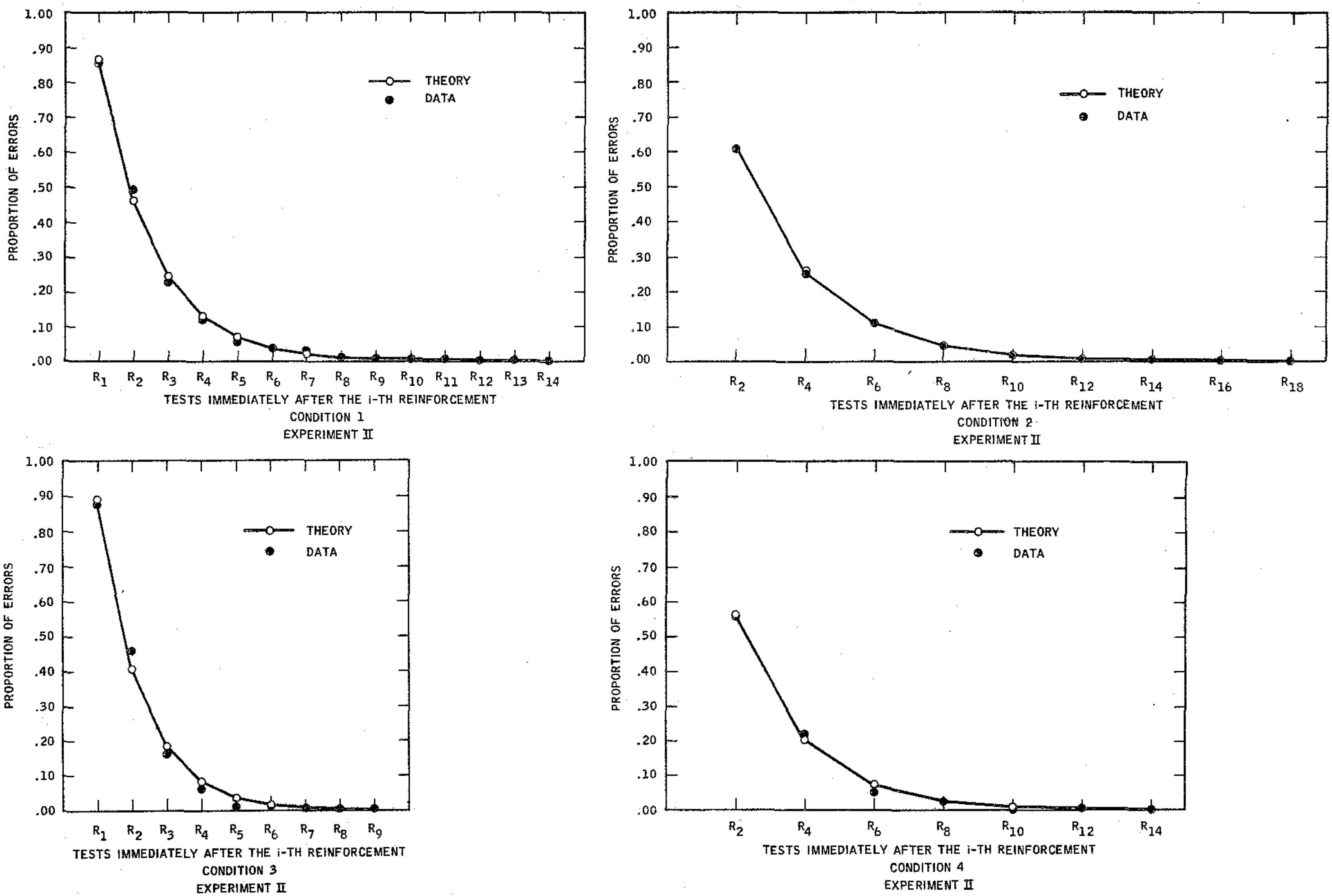

Fig. 8 Theoretical Functions Compared with Data of Experiment II.

1. The stimulus member of each item, together with the context in which it occurs, comprises a set of stimulus elements, or cues, N^* in number.

2. At any time some of these cues are in an active state, i.e., can be sampled by the subject if the item is presented, while the remainder are inactive.

3. Transitions between the active and inactive states occur randomly over time, there being some constant probability of a transition during any short interval of time Δt.

4. At any time, any given cue may be associated with ("conditioned to") the correct response, some specific incorrect response, or neither.

5. On each R trial, there is some fixed probability c that all cues in the sample will be conditioned to the correct response. On T trials, no changes in state of conditioning occur.

6. Probability of a correct response on any T trial is equal to the proportion of cues in the sample that are conditioned to the correct response.

It is easily seen that the observed pattern of joint response proportions over the T trials of an RTT or RRTT sequence (Table 9) is directly implied by the model. The expected proportion of shifts from incorrect on T_1 to correct on T_2 is very small, since nearly all instances of incorrect response on T_1 will be cases in which learning failed to occur on the preceding R trials (as in the one-element model). However, the retention loss from T_1 to T_2 for items with correct responses on T_1 should be somewhat greater than allowed for by the one-element model, for conditioned elements in the sample on T_1 may become unavailable for sampling on T_2 as a consequence of the random fluctuation process.

Similarly, the principal differences in rates of learning under the four conditions are readily interpretable in terms of the fluctuation model. Since the occurrence of T trials involves time, the occurrences of two successive R trials separated by a T trial in Condition 1 are, on the average, separated by a longer time interval than two successive Rs with no intervening T in Condition 2. The longer the interval between two R trials, the greater is the opportunity for cues unavailable for sampling on the first occasion to become available on the second. Thus, other things equal, the greater the temporal spacing between R trials, the greater will be the average number of cues newly conditioned per reinforcement. From this consideration, one could predict a priori that, on the average, R trials would be relatively most effective in Condition 3 and least effective in Condition 2. To predict the complete ordering of the learning curves, however, we shall have to derive the appropriate theoretical functions.

Our notation will largely follow that of Estes (1955a, 1955b)--

$p_n = 1 - q_n$: probability of a correct response on the first T after the n^{th} R

F_n : probability that any one cue is conditioned to the correct response after the n^{th} R (with $F_0 = g$, where g is, again, the guessing probability)

$J = \frac{N}{N^*}$: proportion of cues in the active state (assumed, for simplicity, to be the same for all items and constant over trials)

a : parameter representing rate of interchange of cues between the active and inactive states.

Although the time between occurrences of an item on successive cycles must vary owing to variations in the order of item presentation, and variations in response times on T trials, we shall simplify our derivations by utilizing a single, average interval $\underline{t}$. This quantity will be treated as a constant when we have occasion to use the two basic theorems

$$f_t = J(1 - a^t)$$

and

$$f'_t = J + (1 - J)a^t ,$$

where f_t and f'_t denote the probabilities that a cue in the inactive or active state, respectively, during presentation of an item on one cycle is active at the time of presentation of that item on the next cycle (Estes, 1955a, 1955b).

Now, to obtain the learning function for Condition 1, we proceed as follows.

Firstly, we require the probability that any cue is conditioned to the correct response after n R-occurrences. By the assumptions given above,

$$F_0 = g ,$$

$$F_1 = (1 - J)g + J ,$$

$$F_2 = F_1 + J(1 - a^{2t})(1 - F_1)$$

$$= 1 - (1 - J)(1 - g)[1 - J(1 - a^{2t})] ,$$

and, by induction

$$F_n = 1 - (1 - J)(1 - g)[1 - J(1 - a^{2t})]^{n-1} . \qquad (2)$$

In deriving Equation 2, we have set the conditioning parameter c equal to unity; also, we have assumed that the parameter J applies from the very first trial, although in the general theory the proportion of cues in the active state on the first trial would be only of the order of $J(1 - a^{t/2})$. The increase in expected proportion of active cues over the early trials which is implied by the model may serve to account for the observed increase in effectiveness of R trials over the first few trial cycles in both experiments.

With the simplifications just mentioned, F_1 is simply the probability g that the given cue was initially (by "chance") associated with the correct response plus the probability $(1 - g)J$ that the cue was initially unassociated but was available for sampling on the first R trial. The expression for F_2 is obtained similarly, the factor $J(1 - a^{2t})$ being the probability that a cue inactive on the first R trial would be active on the second (the interval being $2t$ since a T trial intervenes).

Now, the proportions of conditioned cues available for sampling on the T following the n^{th} R trial will be $1/N$ times the expected number of cues carried over from the R trial, $N[J + (1 - J)a^t]$, plus $1/N$ times the expected number of conditioned cues which were inactive on the R trial but became active by the time of the T trial, $(N^*F_n - N)J(1 - a^t)$, thus

$$p_n = \frac{1}{N} [N\{J + (1 - J)a^t\} + (N^*F_n - N)J(1 - a^t)]$$

$$= 1 - (1 - a^t)(1 - F_n)$$

$$= 1 - (1 - a^t)(1 - J)(1 - g)[1 - J(1 - a^{2t})]^{n-1} \ . \qquad (3)$$

The function for Condition 3 is derivable in exactly the same fashion, and differs only in that the interval between R occurrences is $3t$, so that the term $(1 - a^{2t})$ is replaced by $(1 - a^{3t})$,

$$p_n = 1 - (1 - a^t)(1 - J)(1 - g)[1 - J(1 - a^{3t})]^{n-1} \ . \qquad (4)$$

It might be remarked at this point that the curve for probability of a correct response on the second T following each R in Condition 3 differs from that of Equation 4 only in the replacement of the factor $(1 - a^t)$ by $(1 - a^{2t})$. Thus it is predicted that this curve should be displaced slightly below that of Equation 4 on early trials, but should converge to it on later trials. This prediction seems to be nicely borne out by the data of Experiment I, but the difference between T_1 and T_2 trials early in learning does not appear in Experiment II (Table 2).

Similar derivations yield for Conditions 2 and 4, respectively,

$$p_n = 1 - (1 - a^t)(1 - g)[\{1 - J(1 - a^{2t})\}\{1 - J(1 - a^t)\}]^{\frac{n-2}{2}} , \quad (5)$$

and

$$p_n = 1 - (1 - a^t)(1 - g)[\{1 - J(1 - a^{3t})\}\{1 - J(1 - a^t)\}]^{\frac{n-2}{2}} . \quad (6)$$

Now, using Equations 3 - 6, we can express the parameter X of Equation 1 in terms of parameters of the fluctuation model--

Condition 1: $X = 1 - J(1 - a^{2t})$

Condition 2: $X = [\{1 - J(1 - a^{2t})\}\{1 - J(1 - a^t)\}]^{\frac{1}{2}}$

Condition 3: $X = 1 - J(1 - a^{3t})$

Condition 4: $X = [\{1 - J(1 - a^{3t})\}\{1 - J(1 - a^t)\}]^{\frac{1}{2}}$.

On the assumption that the parameters a and J are constant over conditions within an experiment, one can easily prove the general set of inequalities

$$X_3 \leq X_1 \leq X_4 \leq X_2 ,$$

where the subscripts denote conditions; strict inequalities obtain except for the degenerate cases when $t = 0$ or when a or J equal 0 or 1. Reference to Fig. 7 and Fig. 8 shows that the predicted ordering of slope parameters is borne out exactly in both experiments.

For a still more rigorous test of the model, we can estimate a and J from some of X values determined by least-squares and compute numerical predictions of the remaining X's. Using the values from the fitted curves of Conditions 1 and 3 in Experiment I, we set

$$1 - J(1 - a^{2t}) = .791$$

and

$$1 - J(1 - a^{3t}) = .742 .$$

Solving these numerically, we obtain the estimates

$$a^t = .615$$

$$J = .336 ,$$

from which, in turn, we compute the predicted values

$$X_1 = .791$$

$$X_2 = .830$$

$$X_3 = .742$$

$$X_4 = .804 ,$$

corresponding to the least-squares estimates of .791, .824, .742, and .811, respectively, a result which leaves little to be desired.

Following the same procedure for Experiment II, we obtain estimates

$$a^t = .493$$

$$J = .617$$

and predicted values

$$X_1 = .533$$

$$X_2 = .605$$

$$X_3 = .457$$

$$X_4 = .560 ,$$

corresponding to least-squares estimates of .533, .646, .457, and .598, respectively.

The initial value parameter, A, in Equation 1 involves rather complex combinations of the model parameters, and owing to the uncertainty concerning the value of g (discussed above in connection with Table 9) and changes in parameters over the first couple of trials, we have not attempted to predict numerical values of A across conditions. Simply from inspection of Equations 3 - 6, however, it is clear that the values of A should be equal for Conditions 1 and 3 and for Conditions 2 and 4 within each experiment, the common value for Conditions 2 and 4 being the smaller. These predicted relationships are quite well approximated in the least-squares estimates for both experiments-- Experiment I: $\hat{A}$ = .945, .824, .999, .817, for Conditions 1, 2, 3, and 4, respectively; Experiment II: $\hat{A}$ = .863, .613, .891, .563.

In principle the fluctuation model could also be applied to the joint response proportions for T_1 and T_2, as done for the one-element model in Table 9. However, the theoretical expressions implied by the general form of the model prove too complex to make such an analysis attractive. As a substitute measure, we have utilized a simpler variant of the model developed by Atkinson and Estes (1964, pp. 219-223) for this situation. This special case assumes a set of only two cues associated with the stimulus member of an item. Exactly one of these cues is sampled on any trial; and the fluctuation process is such that the cue sampled on one trial is replaced by the other cue on the next trial with some constant probability j.

To avoid having to deal with the excessive number of free parameters required to allow for changing effectiveness of R occurrences over early trials, we used for this analysis the joint response proportions over pairs of successive Ts for data pooled over all replications of the basic sequence (RTRT, RRTRRT, RTT, or RRTT) after the second in Experiment I and all replications after the first in Experiment II. The three free parameters of the special case of the model (the guessing probability, g; the conditioning parameter, c; and the exchange parameter, j) were estimated simultaneously for all four conditions of each experiment by a minimum X^2 procedure. Using the three parameter estimates, theoretical values for the joint response proportions were computed, following the method illustrated by Atkinson and Estes (1964, pp. 221-222), with the result shown in Table 10. The agreement of theoretical and observed values is rather close for Experiment I, the X^2 of 13.34 not approaching significance for 9 df. For Experiment II the fit is less satisfactory, the X^2 of 30.22 being significant at the .01 level.

Table 10

The Two-Element Fluctuation Model vs. Joint Response Proportions for Data Pooled over Replications

	Experiment I		Experiment II	
	Observed	Predicted	Observed	Predicted
Condition 1				
CC	.242	.215	.497	.467
CI	.077	.070	.045	.048
IC	.206	.206	.239	.250
II	.474	.510	.219	.235
Condition 2				
CC	.347	.347	.600	.687
CI	.028	.083	.057	.034
IC	.264	.252	.257	.202
II	.361	.318	.086	.077
Condition 3				
CC	.241	.213	.506	.442
CI	.063	.071	.017	.073
IC	.053	.055	.077	.065
II	.642	.661	.401	.420
Condition 4				
CC	.282	.358	.614	.671
CI	.082	.072	.033	.049
IC	.053	.046	.065	.037
II	.584	.524	.288	.242
		$g = .075$ $j = .084$ $c = .247$		$g = .133$ $j = .021$ $c = .450$

Discussion

With regard to learning on test trials, in the sense of systematic changes in correct response probability, our results are essentially negative. There were no significant increases in frequency of correct responding over pairs of adjacent T trials without intervening Rs, and there were only small and transient retention losses over such pairs (these being limited to the early trials of Experiment I).

On the whole, these results are in accord with those of numerous studies involving only one or two replications of various R-T sequences ("miniature experiments"). A study by Estes, Hopkins, and Crothers (1960, Experiment II) exhibited rather striking constancy of correct response proportions over successive unreinforced tests in RTT, RTTTT, and RRTTT sequences. In the case of several experiments reported by Jones (1962), our computation of correct response proportions from the published data yield values of .53 and .48 for the two tests of an RTT sequence (Experiment I), .48, .44, .44, .44, and .55, .57, .56, .50 for the four tests of RTTTT sequences (Experiments II and III). In the case of two replications of an RTT sequence reported by Eimas and Zeaman (1963), proportions correct (read from their Figure 1) are .57 and .56, .76 and .73 for the two pairs of tests. In Seidel's (1963) investigation of test response as a function of number of reinforcements, proportions correct on TT pairs were .39 and .42, .57 and .60, .71 and .72, .74 and .78, .72 and .77, following 1, 2, 3, 4, or 5 Rs in Experiment I; .39 and .38, .57 and .58 following 1 and 2 Rs in Experiment II.

A design used by Neimark (1963a) is similar to Condition 3 of the present study in that her subjects learned 5 pairs of items to a criterion of one perfect trial over a series of repeated RTT sequences. For the present purpose her Table 1 (p. 6) is reconstructed. Three replications of the RTT sequence are available for Groups A, B, and C. The proportions correct on T_1 and T_2 for these three replications for Group A were .36, .30; .52, .56; and .82, .82. The corresponding values for Group B were .48, .42; .70, .74; and .88, .74. For Group C the proportions were .40, .36; .62, .64; and .70, .72. There do not seem to be any significant differences within the pairs of Ts. Another study by Neimark (1963b), however, showed some decrease in proportion correct (P(C)) from T_1 to T_2. The P(C)'s of the first two Ts of the RTTTTTT sequences for three different groups were .32, .24; .64, .56; and .64, .58 (reconstructed from Table 1, Neimark, 1963b). Unfortunately a significant test for these pairs is not available. An experiment by Estes, Hopkins, and Crothers (1960, Experiment I) involving single replications of RTT and RRTT sequences did yield a significant decrease in proportion correct from the first to the second tests.

Studies reporting increases in correct response probability over successive unreinforced tests have all involved designs or procedures differing in major respects from those summarized above. Landauer (1962), for example, reported a significant increase from the first to the second of a pair of tests; however, in Landauer's study, there was an unreinforced recognition task between the two tests, on which the subject was provided all the responses except those correct on T_1 from which to choose his answers. Peak and Deese (1937), Richardson (1958, 1960), Goss, Morgan, and Golin (1959), and Goss, Nodine, Gregory, Taub, and Kennedy (1962) have all been primarily interested in the function of extinction trials given after subjects reached a criterion of paired-associate acquisition under an anticipation procedure. The common result is that the drop in level of correct responding which almost inevitably occurs after a criterion run is followed by some recovery over a subsequent series of unreinforced tests.

Artifacts associated with acquisition criteria were avoided in the recent investigation by Butler and Peterson (1965). Over a block of 30 test trials given following 10, 20, or 30 anticipation trials with a six item list of CCC pairs, the proportion of correct responses increased significantly. However, so also did the proportion of overt errors; and the increase in correct responding was shown to be primarily a matter of an increasing tendency to repeat previously correct responses.

It is of special interest to note that in Butler and Peterson's study the duration of a recall test, whether given as the first phase of an anticipation trial or as an "extinction" trial, was only 2 sec., whereas in Experiment I of the present study subjects had unlimited time to respond on tests, and in Experiment II the duration of a test trial was 5 sec. In the present Experiment I, latencies of correct responses were observed to decrease appreciably over a series of postcriterion trials. Thus the possibility is suggested that once an association has formed between the stimulus and response members of an item, so that the subject recognizes the appropriate pairing, latency of the correct recall response decreases over successive tests. If the duration of a test trial is such as to be exceeded by many response latencies early in the series (which would be the case with a 2 sec. duration), then decreasing latencies over a sequence of tests will necessarily be accompanied by an increase in the relative frequency of recorded correct responses. However, when the duration of a test trial is greater than all or nearly all of the initial latencies, decreases in correct response latency entail no concomitant change in frequency measures.

On the whole it seems reasonable to conclude that learning, in the sense of a systematic increase in correct response probability, does not occur on unreinforced test trials except under special circumstances. Substantial effects of this type evidently occur only when training on a list of items is discontinued after associative learning has occurred but before response latencies have approached asymptotic levels, and then only if the time allowed for responding on test trials is relatively short. When test trials are imbedded in more complex training programs, there appear to be no appreciable increases in correct response probability over successive tests which occur without intervening reinforced trials. Neither, under these conditions, does there seem to be any substantial evidence of learning in the sense of increased stereotypy of whatever responses happen to occur on test trials.

By all odds the most significant result, both practically and theoretically, of the present study is the clear demonstration that interspersed test trials in some manner potentiate the effects of reinforced trials. Since the ordering of the four R-T conditions with respect to various performance measures in both experiments is well interpreted by the fluctuation model, we are inclined to conclude that the function of interspersed T trials is primarily to modify the probabilities that various components, or aspects, of a stimulus will be sampled on R trials.

According to the stimulus fluctuation model, the interposition of T trials could produce such effects simply by virtue of the increased temporal spacing of the R trials (Estes, 1955b). On the assumption that cues (or, more accurately, the subject's dispositions to perceive, or sample, particular cues) fluctuate between active and inactive states over time, increased time intervals between R trials provide increased opportunities for conditioning of new cues. Within the design of the present study, it is not possible to separate sharply the effects of the increased temporal spacing of R trials entailed by intervening Ts from the effects, if any, of processes or activities occurring on the T trials.

In view of the excellent quantitative account of the learning rates in Experiment I by the fluctuation model, it seems reasonable to assume that the function of T trials in that situation was primarily to modify the spacing of R trials. However, in Experiment II there were some appreciable quantitative deviations from the pattern of parameter values implied by the model. Considering also the increased opportunities for such activity as rehearsal of correct responses resulting from the substitution of spoken words for key-presses as responses, we are led to surmise that under the conditions of Experiment II, T trials provide opportunity for activities (as, for example, searching for mnemonic aids) which modify stimulus sampling probabilities in other ways than those expected simply as a function of time. Thus, although the manner in which T trials influence the course of paired-associate acquisition has been clarified by this study, full understanding of the mechanisms involved will require further experimental analysis.

Appendix

Error Proportions after the i-th Reinforcement in Conditions 1 and 2

	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}	R_{11}	R_{12}	R_{13}	R_{14}	R_{15}	R_{16}
Experiment I																
Condition 1 (RT)	.908	.756	.652	.480	.380	.280	.224	.168	.108	.088	.096	.076				
Condition 2 (RRT)		.832		.556		.372		.236		.188		.116		.100		.072
Experiment II																
Condition 1 (RT)	.852	.496	.224	.120	.056	.036	.032	.012	.008	.004	.004	.004				
Condition 2 (RRT)		.612		.260		.104		.044		.016		.004		.000		.000

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13. ABSTRACT

Learning of paired-associate items was studied in relation to different repetitive sequences of reinforced (R) trials and test (T) trials. One purpose was to obtain evidence as to whether either learning or forgetting occurs on unreinforced T trials; a second was to adduce principles bearing on the problem of optimal programming of R and T trials. The four training conditions were: (1) R T R T ...; (2) R R T R R T ...; (3) R T T R T T ...; (4) R R T T R R T T ... . Five items were assigned to each condition and the sequences were repeated till a criterion of learning was reached. Two groups of 50 subjects were run; one with nonsense syllable-number pairs and one with nonsense syllable-word pairs.

Performance on tests given successively without intervening reinforcement showed no significant change in correct response probability--suggesting that neither learning nor forgetting occurred on T trials per se. The course of learning was, however, affected to a major extent by the ratio of Ts to Rs and by their arrangement in the various repetitive sequences. Learning curves plotted in terms of error proportion on the first T following the n^{th} R trial lined up in the order: Condition 3 (lowest), 1, 4, 2. Thus, some process of importance to the course of acquisition clearly occurs on test trials, and results in increased effectiveness of subsequent R trials. When acquisition is considered in relation to the total amount of experimental time, the conditions with highest densities of R trials are most efficient on early trials, but this relation tends to reverse on later trials, and over all Condition 1 (RTRT...) appears to be nearly optimal.

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