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ABSTRACT

Response latency was studied as a measure of associative strength or degree of learning and possible basis for instructional decision making in computer-assisted instruction. Latency was investigated in a paired-associate task as a function of training procedure and information transmission requirements during acquisition and overlearning. The magnitude and variability of latency measurements were independent of training during acquisition, but both were reduced by the recall paradigm during overlearning. Latency was a function of number of response alternatives during acquisition and overlearning. During acquisition, prior to the trial of last error (TLE), latency remained constant and did not differ between correct and incorrect responses. There was a substantial drop in latency following TLE. Latency, as a rote verbal task, may be a sensitive measure of strength of learning during the overlearning phase, but not during initial learning. (Author)

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RESPONSE LATENCY AS A FUNCTION OF TRAINING METHOD, INFORMATION LEVEL, ACQUISITION, AND OVERLEARNING[1]

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Response latency was studied as a measure of associative strength or degree of learning and as a possible basis for instructional decision making in computer-assisted instruction. Latency was investigated in a paired-associate task as a function of training procedure (a comparison of the anticipation and recall paradigms) and information transmission requirements (a comparison of two, four, and eight response alternatives to an eight-item stimulus list) during both acquisition and overlearning. The magnitude and variability of latency measurements were independent of training method during acquisition, but both were reduced by the recall paradigm during overlearning. Latency was an increasing function of the number of response alternatives during both acquisition and overlearning. During acquisition, prior to the trial of last error (TLE) for each item, latency remained relatively constant and did not differ between correct and incorrect responses. There was a substantial drop in latency following the TLE. Pre-TLE latencies were independent of *S* learning rate, while post-TLE latencies were an increasing function of learning rate. The latency of the first correct response to an item was found to be shorter if there were no subsequent errors on that item. In general, the study suggests that latency, at least in a rote verbal task, may be a sensitive measure of strength of learning during the overlearning phase, but not during initial learning.

The development of instructional strategies is currently an area of considerable interest to educators and psychologists. With the availability of computer-based instructional systems, the educator now has the potential ability to construct instructional sequences which will adapt to the particular requirements of individual students. Such a sequence would vary the content and order of the instructional materials presented to the student as a function of the student's responses. The major problem facing the psychologist interested in this area is that the nature of the functions relating the student's responses to optimal presentation schemes is not well known. The computer engineer has provided the educator with the ability to make extremely fast, relatively sophisticated decisions concerning individual students, and the psychologist needs to be able

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to provide him with the basis for making such decisions.

A frequent requirement is simply to determine when a response has gained sufficient strength to allow the lesson to proceed to other material. Defining "sufficient strength" is of course a problem, but a more immediate problem is that of simply measuring the existing strength of the behavior. One approach—perhaps the most common in practical group instructional situations—is simply to give all students that amount of practice which past experience has shown to be sufficient for the average student. This, of course, ignores differences between individuals. One practical solution is to continue practice until the student reaches some behavioral criterion which is judged to be adequate. The common behavioral measure employed is response frequency. This is also the most reasonable measure in most cases since the goal of the instruction can usually be defined in terms of an increase in the frequency of the correct or appropriate response.

Frequency measures, however, may lose their sensitivity as response probability approaches asymptote. It is desirable that the student retain what he has learned, and it is known that retention is a function of the degree of learning. In this respect, experimental work suggests that response latency may be useful as a supplement to frequency measures, and latency is quite easily measured during computer-assisted instruction. A disadvantage of latency measures is their wide variability between *S*s and from trial to trial for the same *S*. The conditions contributing to this variability may need to be controlled in order to render latency measurements useful as a basis for instructional decisions. The purpose of the present study was to examine response-latency behavior throughout the course of learning in a paired-associate learning task and to investigate certain task variables which may influence the magnitude and variability of response latency.

Latency as a Measure of Response Strength

Hull, in his *Principles of Behavior* (1943), stated that habit strength manifests itself in the length of the time elapsing from the onset of the stimulus to the onset of the associated response. This statement was based on a study of paired-associate response latency done by Simley (1933). Simley's results indicated that latency decreased as a function of practice after the associative strength of the items had reached the "threshold of recall." It was further shown that during the sequence of correct responses, latency was a positive function of the number of trials before the first correct response. A similar experiment reported by Peterson (1965) obtained comparable results. Numerals were associated with a set of 10 consonant-consonant (CC) bigrams. Each *S* received 20 trials but only those *S*s who had 10 successive errorless trials were evaluated. A significant decline in latency was found over the sequence of 10 successive errorless trials.

If response frequency and latency are both indexes of associative strength, one should expect to find reasonable correlations between the two measures. Beck, Phillips, and Bloodsworth (1962) and Johnson (1964) presented *S*s with nonsense syllables previously scaled for association value by Archer (1960) and measured the latency of the *S*s' first free associations. The obtained correlations ranged from −.19 to −.70. Johnson then constructed paired-associate lists in which the response items were the consonant-vowel-consonant (CVC) trigrams for which first-response latencies had been obtained. The obtained correlation between learning rate and Archer's *a* (association) value was .41 while the correlation between learning rate and response latency was .36. The multiple correlation using both *a* and latency as predictors of learning rate was .57. It would appear that response frequency and latency may measure two relatively distinct factors, both of which are related to associative strength. Such a possibility is supported by a study by Williams (1962) in which paired-associate lists were learned by the anticipation method. Knowledge of results was presented for either 1 or 4 seconds. The longer knowledge-of-results exposure caused a significant reduction in the number of trials required to reach criterion but did not produce a comparable reduction in response latencies; that is, the response-frequency measure was altered but the latency measure was unchanged.

Shiffrin and Logan (1965) hold that latency is not a measure of associative strength but a defining property of different responses; that is, a fast response and a slow response to the same stimulus are actually two different responses, capable of being differentially reinforced. To demonstrate their point, the authors conducted a paired-associate learning experiment in which minimum response latency was limited to either .75 or 2.85 seconds. After *S*s reached criterion, they were instructed to identify as many pairs as possible in 2 minutes, the next pair appearing immediately following *S*'s response. Under these conditions, the fast-practice group made significantly more responses than did the slow-practice group.

Latency Trends during the Learning Process

In the past few years a number of studies have investigated response latencies throughout the course of paired-associate learning. The impetus for conducting most of these studies has come from questions derived from attempts to construct mathematical models of the associative learning process. The data obtained have been examined from new viewpoints which have revealed trends of considerable interest. A useful technique employed for investigating latency over the course of paired-associate learning is to align all item protocols on the basis of the trial of last error (TLE). The TLE for a particular item is defined as the last trial on which an incorrect response was made prior to the point at which that item reached a criterion of n successive errorless trials in which n is some predetermined value. Item records are aligned so that the TLE serves as a point of origin from which all trials, both prior to and after the TLE, are counted. When such TLE-based protocols are averaged, the result is analogous to a backward learning curve. All responses falling on a particular TLE relative trial are representative of a similar stage of learning in that each is equidistant from the point at which the criterion is attained.

Decrease in latency following the trial of last error. The manner in which Simley (1933) evaluated his data made his analysis very similar to the recent analyses which took the TLE as a point of origin. Simley's finding that latency declined rapidly after the TLE has been supported in all of the recent studies mentioned below.

Latency trends prior to the TLE. Millward (1964) used 12 two-digit numerals as stimuli in a 20-trial paired-associate learning task in which the required response was to press one of two buttons, six stimuli being associated with each button. The latencies on the first trial were relatively short, suggesting that *S*s simply guessed on that trial. Latencies increased rapidly over the next few trials and then remained relatively constant until the TLE. After the TLE there was a rapid decrease in latency which did not appear to have reached asymptote after nine successive errorless trials. Suppes, Groen, and Schlag-Rey (1966) measured latencies in a paired-associate task in which the stimulus items were a set of 12 CVC nonsense trigrams and the required response was to press one of three buttons. They found a very sharp rise in latency over the first few trials and concluded, as had Millward, that this was due to *S*s making random guesses on the initial trials. After this initial rise, both correct and incorrect response latencies were relatively constant up to the trial before the TLE. Kintsch (1965) ran *S*s in a paired-associate learning task in which stimulus items were 12 nonsense syllables with Glaze association values of .60, and the required response was to vocalize the numbers one or two. Kintsch's results differed from those of Millward and Suppes et al. in that after the sharp initial rise, latencies continued to increase somewhat as a function of trial number up to, and including, the TLE.

Latencies of correct and incorrect responses. Related to the question of response-latency stationarity prior to the TLE is the question of the relationship between correct and incorrect response latencies. Suppes et al. (1966) specifically investigated this point and found no significant difference between the response speeds of correct and incorrect responses. Millward (1964) presented a plot of the latencies of correct and incorrect responses prior to the TLE. Of the 18 trials at which comparisons may be made, incorrect response latency was longer than correct response latency 14 times but the variability of both curves was so great that one cannot draw any firm conclusions.

Eimas and Zeaman (1963) ran a "miniature experiment" in which *S*s were given one practice trial during which they could examine the stimulus-response (S-R) pair as long as they wished. They were then given two test trials during which only the stimulus item was presented and no knowledge of results was given. This was followed by a second practice trial and two more test trials. The stimuli consisted of 12 CCC trigrams of high association value and the response elements were the numbers 1–12. If the latencies of the response sequences consisting of four incorrect responses are examined, it is noted that these response speeds are much slower than the latencies of correct responses on the corresponding trials. While this experiment was not directly comparable with the Suppes et al. experiment, it did suggest that correct and incorrect response latencies may not always be equivalent.

Latency as a function of learning rate. The purpose of Simley's (1933) study was to demonstrate that the rate of learning below and above the "response threshold" is a function of the same factors. The rate of learning below threshold was measured by the number of promptings required before *S* could provide the correct response while learning rate above threshold was held to be indicated by the decrease in response latency as a function of practice following the point at which the correct response reached threshold. Simley concluded that he had demonstrated his point since the data for each of the three *S*s discussed clearly showed that response latency during overlearning was a positive function of the number of trials required to reach threshold. Items which were learned slowly had higher latencies during overlearning. This result was even more pronounced when the recent innovation of comparing trials equally distant from the TLE was applied to the data. The more difficult items, as defined by the number of trials required to reach the TLE, had longer response latencies even when the items were equated as to the number of trials of overlearning.

This same effect was found in the data presented by Suppes et al. (1966). When mean response times were correlated with item difficulty (measured in terms of the number of trials required to reach the TLE) the Spearman rank-difference correlation coefficients for the two experimental sessions discussed were .68 and .77. In contrast, mean response time after the TLE was unrelated to item difficulty in the data presented by Kintsch (1965). Millward (1964) noted that in his data, latency was in general a positive function of the number of trials required to reach the TLE throughout the learning task. He attributed this to the fact that slow learners would require more trials to reach the TLE and postulated that slow learners may have longer response latencies than fast learners. This hypothesis was not evaluated in the article. Millward's results suggest that latency may be a positive function of item difficulty prior to the TLE when level of learning is held constant by equating the number of subsequent trials required to reach the TLE. This suggestion was supported by the Suppes et al. study. When subgroups were ranked according to item difficulty and the subgroups' mean latencies for correct responses prior to the TLE were also ranked, the Spearman rank-difference correlation coefficients for two sessions were .71 and .69.

Latency on the trial of last error. The TLE itself may have interesting properties.

Suppes et al. (1966) found that, in general, response latency on the TLE was considerably longer than either the preceding error latencies or the preceding success latencies. The frequency with which the TLE latency was greater than either the immediately preceding or subsequent response latencies was significantly greater than chance. The authors pointed out that the same phenomenon was to be found in Kintsch's (1965) data and in an unpublished study by W. K. Estes and D. Horst.

First correct response latency and subsequent errors. The paired-associate learning experiment reported by Williams (1962) used a list of 25 pairs of four-letter words. Her analysis of the latency data was based on the trial of the first correct response for a given item as opposed to the TLE. Latency data were presented for the trial of the first correct response and for the ninth trial thereafter. Item sequences were classified into two groups on the basis of whether or not incorrect responses were made following the first correct response. Latency measures for item sequences containing incorrect responses declined from 2.02 to 1.50 seconds while the sequences of all correct items declined from 1.87 to 1.40 seconds. The decline in latency over the nine trials is in agreement with the data previously discussed. The more interesting finding was that first-correct-response latencies were longer if *S* made subsequent errors. This is in agreement with the conception of response latency as an index of associative strength. If the associative strength were relatively low at the time of the first correct response, the response latencies would be expected to be longer and it would also be expected that there would be a higher probability of one or more subsequent incorrect responses. This explanation is contradicted, however, by the Eimas and Zeaman (1963) experiment. To test the hypothesis that correct-response latency is indicative of response strength, Eimas and Zeaman classified all items answered correctly on Test Trial 1 as either fast or slow. The slow items were not recalled particularly slowly on Test Trial 2 nor did they tend to be recalled incorrectly. Instead, they showed a significantly greater increment in speed on Test Trial 2 than did the items classified as fast on Test Trial 1.

Summary of latency trends. These recent studies of latency trends during paired-associate learning have raised questions of interest in five different areas. First, what is the nature of the latency curve prior to the TLE? Is there always a sharp initial rise following the first, relatively fast responses? After the occurrence of such a rise, if any, do response latencies remain constant or do they continue to increase up to the TLE? Secondly, there is the question of whether or not response latency, on a given pre-TLE trial, is a function of the correctness of the response. Third, there are several questions concerning the relationship of response latency to item difficulty and/or individual differences in learning rate. Is latency during overlearning a function of the number of trials required to reach a criterion of errorless responding? Does this relationship hold during the early stages of learning, prior to the TLE? If these effects do exist, are they attributable solely to item difficulty or are they also a function of individual differences in learning rate? Fourth, is the occurrence of maximum response latency on the TLE a reliable phenomenon? Finally, does the response latency of the first correct response to a given item predict the probability of occurrence of subsequent errors on that item?

DEFINITION OF THE PROBLEM

While the recent studies concerning the attributes of response latency during the course of learning have interesting implications for latency as a basis for instructional decisions, it appears that the effects of associative strength on response latency are relatively complex and dependent on a number of task-related variables which are unrelated to learning per se. These task-related variables are related to performance rather than learning; during learning these variables act as parameters which influence the magnitude of the effect of learning variables. Hence, while the present experiment was concerned with systematic changes in latency during the course of learning, equal consideration was given to parametric investigation of task variables which were considered likely to influence the relationship of latency and learning. If the task variables which influence latency can be identified and brought under experimental control, the investigator will be in a much stronger position to evaluate the functions relating latency to associative strength. Two such task variables were investigated: training method and information transmission. The anticipation and recall paradigms were compared and the effects of information transmission were explored by varying the amount of information required for errorless responding.

Training Method

In his investigation of response latencies after the TLE, Peterson (1965), using an anticipation procedure, was unable to determine the presence of any systematic trends in the latency data prior to the TLE and suggested that the variability appeared to be so great as to render any attempt at analysis futile. He postulated that at least a partial cause of the high degree of variability might be interference effects due to incorrect responses and suggested that the interference might be alleviated by using a recall paradigm. Faster learning under a recall paradigm, as contrasted with an anticipation paradigm, has been demonstrated in a series of experiments conducted by Battig (Battig & Brackett, 1961; Battig & Wu, 1965). In general it was found that recall procedures resulted in a consistently higher percentage of correct responses per trial and required fewer trials to reach criterion. Battig and Brackett suggested that recall procedures may be superior due to their separation of the two behavioral processes of producing a previously learned correct response and learning new S-R associations. If the temporal contiguity of the associative- and response-production processes does produce interference effects which retard the rate of learning, it would appear quite likely that these effects would also tend to increase the magnitude and variability of response latencies. If the use of a recall paradigm does reduce these interference effects, the variability of response latency during the early stages of learning should be reduced.

In this study, the anticipation and recall paradigms were, therefore, contrasted and it was hypothesized that response latencies prior to the TLE would be shorter and less variable under the recall paradigm than under the anticipation paradigm. In addition, the magnitude and variability of response latencies after the TLE were contrasted under the two training paradigms.

Information Transmission

If one is interested in determining the variables which influence latency in a verbal learning task, one of the most fertile related areas of investigation would appear to be the study of choice or disjunctive reaction time (DRT). If viewed in the context of information theory, it becomes evident that the behaviors required in a paired-associate learning task and in a DRT task are similar forms of information processing. The major difference is that the S-R associations are well known to *S* in the DRT task while they must be learned in the paired-associate task. Once the strength of the S-R associations has risen above "threshold," the two tasks become quite similar. Since the latency of responses which occur after the TLE may be of special interest, it would appear to be worthwhile to examine the relevance of the findings of the DRT studies to paired-associate learning.

For almost 70 years following the work of Merkel (1953), the generalization was widely held that DRT was some positive function of the number of response alternatives. With the application of information theory to the study of reaction time, the proposition was refined to a quantitative statement. Hyman (1953) varied the amount of information in the stimulus display in a DRT task which had a one-to-one correspondence between stimuli and responses and concluded that DRT is a positive linear function of the number of bits of information in the stimulus display. A previous study by Hick (1952), however, had shown that this relationship did not hold if *S*s were allowed to make errors. Subsequent studies by Bricker (1955) and

Rabbitt (1959) supported Merkel's original contention that it is the number of the response alternatives and the relative probability of any particular response which influences DRT. The currently accepted function is DRT $= a + b\ H_t$, where H_t is the amount of information, expressed in bits, transmitted by S per S-R event.

In this study, it seemed quite likely, therefore, that response latency after the TLE would be a positive function of the amount of information transmitted. Since S's performance was essentially errorless during this period, the amount of information transmitted was equal to the $\log_2$ of the number of response alternatives. There was a possibility that response latency prior to the TLE would also be related to the amount of information transmitted. Due to the occurrence of errors, information transmission was not directly related to the number of response alternatives but it was considered that the relationship might be sufficient to have some influence. It was, therefore, hypothesized that response latencies prior to the TLE would increase as some function of the number of response alternatives.

Learning

The current experiment attempted to answer a number of questions concerning systematic changes in latency during the course of learning. The five points investigated were the following:

1. What is the nature of the function relating latency to practice prior to the TLE? Millward (1964) and Suppes et al. (1966) found a sharp initial rise on the first few trials but latency then remained relatively constant until the TLE. Kintsch (1965), on the other hand, found a steady increase in latency up to, and including, the TLE.

2. Do correct-response latencies differ from incorrect-response latencies prior to the TLE? Suppes et al. (1966) found no difference between these latencies but data from Eimas and Zeaman (1963) indicate that under some conditions, incorrect responses are slower than correct responses.

3. Is latency before and/or after the TLE a function of learning rate as defined by the number of trials required to reach the TLE? This effect was found *after* the TLE in the data presented by Simley (1933), Millward (1964), Kintsch (1965), and Suppes et al. (1966). It was found prior to the TLE in the data obtained by Millward, Kintsch, and Suppes et al. Is this effect a between-S variable (slow learners are slow responders) as suggested by Millward or a within-S variable (difficult items have long response latencies) as suggested by Simley's data?

4. Is response latency on the TLE reliably greater than the latency of immediately preceding incorrect responses or immediately subsequent correct responses? Abnormally long latencies on the TLE were found in the data presented by Suppes et al. and Kintsch. Millward did not find the phenomenon.

5. Is the latency of the first correct response to an item longer if S makes subsequent errors on that item? Williams (1962) reported that this was the case but her findings were contradicted to some extent by the data reported by Eimas and Zeaman (1963).

METHOD

The experiment consisted of 16 replications of a 2×3 factorial design. The two training methods, anticipation and recall, were contrasted and three levels of information transmission were investigated by pairing two, four, or eight response alternatives with the members of an eight-item stimulus list. Different Ss were used in each of the six treatment groups.

Subjects

The Ss were drawn from introductory psychology classes. A total of 103 Ss were run. Of these, six failed to complete the experiment as a result of equipment failures and one was rejected due to an error on the part of E. The remaining 96 Ss were evenly divided between males and females. Eight males and eight females were assigned to each of the six treatment groups. The Ss were not given a formal vision test but were required to read the stimuli aloud during the first trial of the warm-up task. No S experienced difficulty in correctly identifying the stimuli.

Materials

The stimuli used in the tasks were consonant-vowel-consonant (CVC) trigrams of 20–30% association value as determined by Archer (1960). The four trigrams VAH, VAQ, VEH, and VOZ were used in the warm-up task. The main task

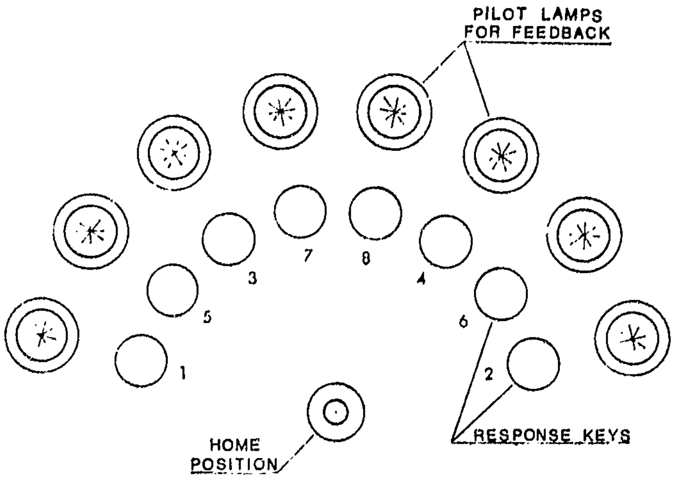

FIG. 1. Full-scale diagram of response positions for Information Level 3.

stimulus list was ZAB, ZAF, ZEF, ZEG, ZIK, ZIX, ZOK, and ZOX. These stimuli were selected so as to be highly similar in terms of the composition and placement of the letters. The responses to be associated with the above stimuli were key positions on a response panel. The *S*s were required to associate two, four, or eight key positions with the eight stimuli. This corresponded to the transmission of one, two, or three bits of information when all of an *S*'s responses were correct.

Apparatus

The experiment was controlled by an on-line PDP-7 digital computer. The system presented the stimuli and knowledge of results, processed *S*'s responses, maintained records of each *S*'s progress, and timed response latencies and interitem intervals. Response latencies were measured with an accuracy of ±.001 seconds. All other timing was controlled to within ±.02 seconds. A complete record of each *S*'s stimuli, responses, and response latencies was punched out on paper tape during the course of the experiment. These paper tapes were fed back into the computer, and a limited amount of data reduction was done while the next *S* was being run. The output of this data-reduction program was a printed summary of each *S*'s record.

The stimulus trigrams were presented on the screen of a cathode-ray tube 3 inches high × 4 inches wide. The trigram letters were all upper case. Each letter was generated as a set of points selected in a 7 × 5 point matrix. The letters were ½ inch high × ⅜ inch wide. The *S*s were required to indicate their responses by pressing buttons mounted on one of three response panels. The panels rested on a table in front of *S* and could be moved about to maximize ease of responding. Two, four, or eight push-button microswitches were mounted at the top of each panel to correspond to the three levels of information transmission. The pushbuttons had ½-inch diameter caps which extended ½ inch above the panel. A force of 5 ounces over a distance of ⅛ inch was required to actuate the switches.

On all the panels, the switches were mounted on a semicircular arc with a 2-inch radius. This allowed a center-to-center distance of ¾ inch between the switch caps on the eight-key panel. The switch caps were not numbered or otherwise identified for *S*s. The keys were assigned arbitrary numerical identities for the purpose of program control and response recording but *S*s had no access to this information. The identities of the keys are illustrated by the diagram of the eight-key panel in Figure 1. On the four-key response panel, Keys 1–4 were located in the same positions as the correspondingly numbered keys on the eight-key panel. Only Keys 1 and 2 were present on the two-key response panel. This arrangement assured that Keys 1 and 2 were in the same relative position on all three response panels and that Keys 3 and 4 were in the same positions on the two more complex panels. The correct response keys were indicated by illuminating a red pilot lamp next to the correct key. A white ring marked the center of the arc on which the switches were mounted. The *S*s were instructed to respond with the index finger of their preferred hand and to keep their finger on the ring between responses. A buzzer was used to warn *S*s at the start of a test trial and to indicate the end of a task.

Randomization Procedures

The experiment consisted of 16 replications of the 3 × 2 factorial design. The treatment conditions were administered in random order within each replication. When an *S* arrived at the laboratory, he was assigned to the next available treatment condition in the replication currently assigned to his sex. The assignment of responses to stimuli was varied randomly over the 16 replications, and the order of item presentation during each trial was randomized. The randomness of the orders was constrained to the extent that the same item was never presented twice in succession by being the last item on one trial and the first item on the next trial. All *S*s responded to items in the same order under both the anticipation and recall procedures. The sequence of orders was repeated once every 30 trials.

Experimental Procedure

The *S*s were run one at a time. After the instructions were given, *S* was alone in the room but could be observed through a one-way vision window. The computer control system was located in a separate room. After *S* was seated at the console, he was given typical paired-associate learning-task instructions which were varied as little as possible between the anticipation and recall procedures. All the experimental conditions included a warm-up period. During this period, *S*s were trained by the same method (anticipation or recall) and with the same response panel (two, four, or eight buttons) that they would use in the main task. The training list consisted of only four items which were always associated with Buttons 1 and 2 regardless of the number of buttons on *S*'s response panel. The warm-up task was paced by allowing *S*s only 3 seconds in which to respond following the presentation of the stimulus. Failure to respond was counted as an error. Response times were unlimited during the main task. This procedure was intended to deter *S*s from adopting a strategy of rehearsing each item a number of times before proceeding to the next item. Response times were unlimited in the main task to prevent the occurrence of a truncated latency distribution. As far as it was possible to determine, this strategy was successful.

In both the training task and the main task, *S*s were drilled until they reached a criterion. This was not the usual criterion for the entire list but a criterion for each of the items in the list. Response records were maintained for the individual items. When a series of six successive errorless trials was completed for a given item, the control program noted that that item had reached criterion. The program continued to present the item on subsequent trials but the occurrence of errors was irrelevant to how long the drill was continued. Drill on the list was terminated a set number of trials after the trial on which the last item reached criterion. This final drill period was 2 trials long in the training task and 10 trials in the main task. The trial prior to the first trial in the series of six successive errorless trials was designated the TLE for that item. This schedule for determining the point at which drill was terminated assured that all items would have at least 16 trials after the TLE. The procedure did not assure the absence of errors after the TLE, but Suppes et al. (1966) noted that the few incorrect responses which did occur after items had reached a similar criterion appeared to be careless mistakes, the latencies of which were consistent with the short latencies of well-learned responses.

The experimental conditions of the anticipation and recall procedures were equated as far as possible. Under the anticipation procedure, the onset of a .5 second auditory warning signal occurred 1.5 seconds before the beginning of a trial, where a trial was one presentation of the complete list. The stimulus item was presented and remained on the screen until the occurrence of *S*'s response. The pilot lamp next to the correct key was then illuminated. The word on the screen and the light stayed on together for 2 seconds. The screen was then erased and the light was turned off at the same time. After a 1.5-second interitem interval, the next word was presented on the screen. Successive list presentations were separated by a 4-second intertrial interval and the warning buzzer always preceded the first item of each trial by 1.5 seconds.

The recall procedure incorporated successive training and testing phases within each trial. During the training phase, each trigram-light pair was presented together for 2 seconds. Following each presentation, the screen was erased and the light was turned off for a 1.5 second interitem interval. At the time of the end of the presentation of the last trigram-light pair in the training phase of the trial, the warning buzzer was turned on for .5 second. The first trigram in the test phase was presented on the screen 1.5 seconds after the onset of the buzzer. During the test phase, the stimulus item remained on the screen until *S* responded. The screen was then erased and remained blank for a 1.5-second interitem interval. No knowledge of results was given during the test phase of the trial. Following the completion of the test phase, the screen remained blank for a 4-second intertrial interval.

The relative position of the keys on the response panel raised a problem of experimental control. It was considered a definite possibility that since they had relatively distinctive positions, the keys on the two-key response panel and the end keys on the four- and eight-key response panels might be subject to a serial position effect; that is, items for which these keys were the correct responses might be learned more quickly than the items for which the responses fell into the middle of the key array. In addition, it was possible that the perceptual-motor task of locating and pressing a key which was distinctive in that it was isolated or at the end of the line of keys might be faster than an equally well-learned response to one of the keys in the middle of the key array. It was in fact found that items for which the correct responses were the end keys in the four- and eight-key tasks had shorter latencies and required fewer trials to reach the TLE as compared with keys in the middle of the array. This finding suggested that the two-key task might be qualitatively different from the four- and eight-key tasks and that within the latter tasks, the different responses might not be analogous. If this were the case, the specific relationships under investigation might be a function of key position, and information derived from an analysis which treated the data from all keys as homogeneous might be misleading.

Hence, for each experimental hypothesis or question to which this problem was considered relevant, a preliminary analysis of variance was conducted which included key position as an additional within-*S* variable. The question of interest was not whether latency varied as a function of key position but whether there was any significant interaction between the key-position variable and the variable of interest in that particular analysis. When such an interaction was found, two separate analyses of the data were conducted: the first covering Keys 1 and 2 for all three information levels and the second covering Keys 3 and 4 for only the two higher order information levels. If no interaction was found, only one analysis, covering all key positions and all information levels, was conducted.

Since the failure to find a significant interaction in this preliminary analysis would result in ignoring possible differences between key positions, an alpha error was considered to be of smaller consequence than a beta error. For this reason, a

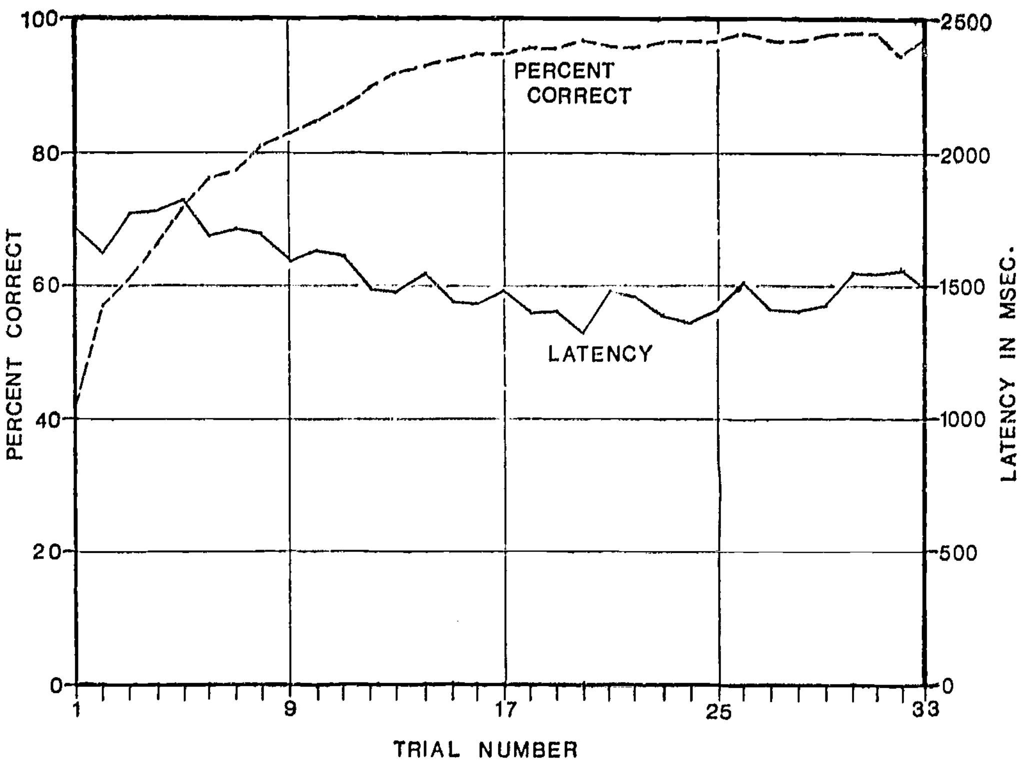

FIG. 2. Correct response probability and response latency as a function of trial number.

high probability level of .10 was selected as a significance criterion. Latency scores were positively skewed, and transformations which yielded the distribution most normal in appearance were used in the analysis for a particular problem. The square root, log, and reciprocal transformations were evaluated. Almost all of the statistical tests employed were analyses of variance of either a straight factorial design or a factorial with split plot design. For the statistical tests which were directly concerned with the experimental hypotheses and questions, as opposed to the key-position-variable tests, the significance criterion selected was .05. Latency data presented in tables and graphs in the results section are raw score means in units of milliseconds.

RESULTS

Changes in Latency over the Course of Learning

Figure 2 illustrates the relationship between correct response probability and response latency over the first 33 trials of the main task. All experimental treatment conditions have been grouped together. Correct response probability increased as the usual negatively accelerated function and approached an asymptote at about 98% correct. Over the same period, response latency rose slightly over the first few trials and then began a decline which continued through Trial 20. The reliability of the data points represented by the curves decreases after Trial 16 since the training period terminated for different *S*s at different points after this trial.

Figure 3 illustrates these same relationships with the protocols aligned on the basis of the TLE. Again, all experimental treatment conditions have been grouped together. Twenty-five percent of the data, or 192 responses, are represented on Trial TLE−8.[3] This percentage increases until all of the 768 responses are represented in the data points on Trial TLE+1 and all trials thereafter. Correct response probability increased from what would be expected by chance on Trial TLE−11 to 54% correct on Trial TLE−1. Correct response probability was, of course, zero on the TLE and one on Trials TLE+1–TLE+6 since the criterion for defining the TLE was six successive errorless trials. Error rate on Trials TLE+7–TLE+16 was never greater than 4%. In general, response latencies remained fairly constant prior to the TLE and then decreased in a negatively accelerated curve which did not appear to have reached an asymptote at the point at which training was terminated, at Trial TLE+16.

Latency prior to the TLE. Millward

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[3] Eight trials before the TLE.

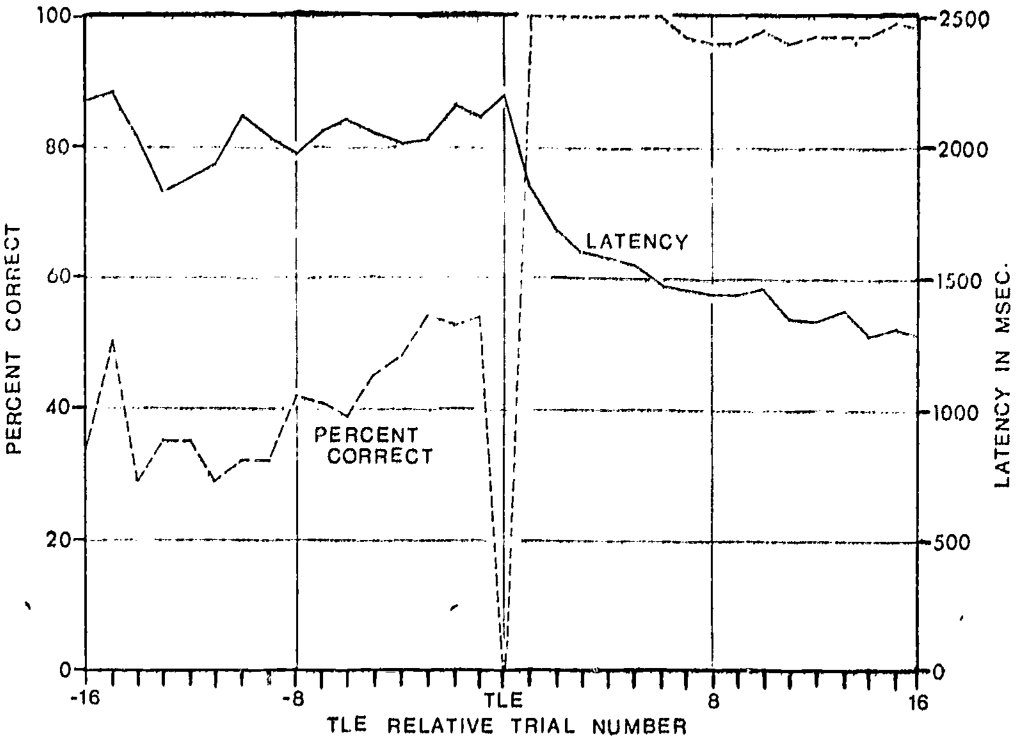

FIG. 3. Correct response probability and response latency as a function of TLE relative trial number.

(1964) and Suppes et al. (1966) noted that the latency of the first response to an item was short, relative to the next few trials. These observations were made under an anticipation paradigm in which *S*s were simply guessing on the first trial, and it was suggested that the short initial latencies reflected this guessing behavior. In the current experiment, the first response latencies of the anticipation *S*s were 146 milliseconds shorter than the corresponding responses of the recall-treatment *S*s who had already been shown one correct pairing of the items. This would appear to be indicative of the guessing behavior of the anticipation *S*s.

Figure 4 illustrates changes in latency over the first eight trials of the experimental task. Millward and Suppes et al. also found that latencies increased sharply over the first few trials. This was not a consistent finding in the current experiment. Only the two more difficult eight-response tasks

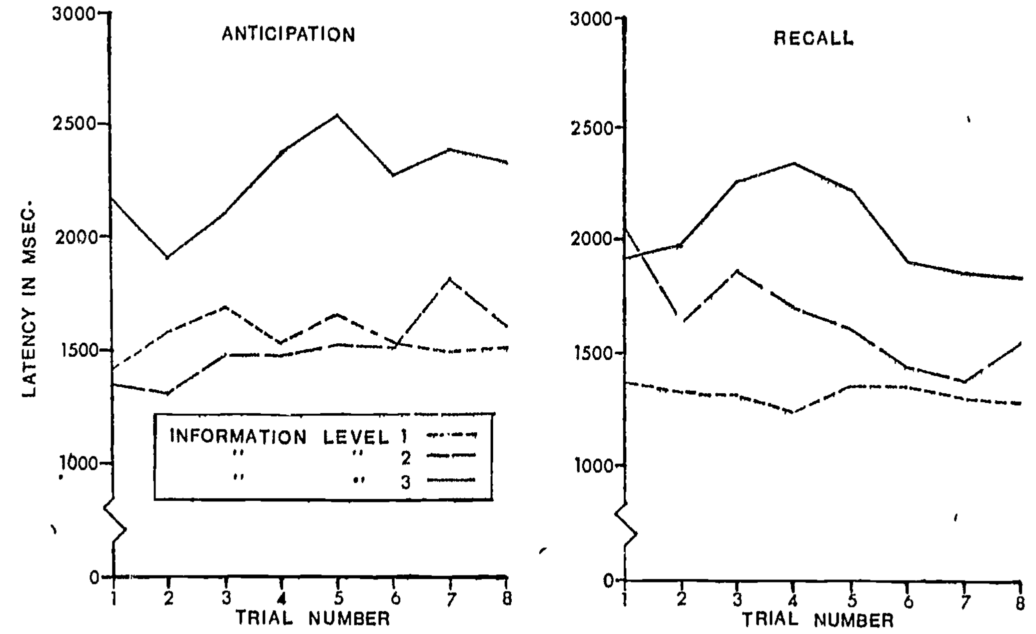

FIG. 4. Response latency of the six treatment groups over the first eight trials of the experimental task.

TABLE 1

TREATMENT GROUP MEANS FOR PRE-TLE RESPONSE LATENCIES (IN MILLISECONDS) FOR ALL KEY POSITIONS AS A FUNCTION OF PRACTICE—COMPARISON OF THE FIRST AND SECOND HALVES OF THE PRE-TLE TRIAL SERIES

Treatment	*n*	First half	Second half	Increase
Information Level				
1	12	1,488	1,673	185
2	12	1,834	1,999	165
3	12	2,050	2,522	472
Method				
Anticipation	18	1,914	2,277	363
Recall	18	1,668	1,853	185
Total	36	1,791	2,065	274

Note.—Abbreviated: TLE = trial of last error.

(Information Level 3) could be said to have demonstrated substantial increases in latency over the early trials. Reference to Figure 3 illustrates that, in general, response latency prior to the TLE remained relatively constant. The curve may be somewhat distorted, however, since as one moves from the left toward the TLE, an increasingly higher proportion of less difficult items is encountered and, as will be discussed later, the less difficult items tended to have shorter latencies. The curve, therefore, may not reflect the true relationship between latency and practice prior to the TLE.

To investigate this possibility, the following question was posed: Does response latency change as an item receives practice prior to the TLE? It appeared reasonable to expect that a change in response latency would be more likely to occur and would be more meaningful for those items which had a substantial number of trials prior to the TLE. For each *S*, the item which had the greatest number of trials prior to the TLE was selected. In the case of ties, the tied items were averaged together. Only items which had six or more trials prior to the TLE were considered and *S*s who had no items with at least six pre-TLE trials were excluded from the analysis. Since, for the anticipation-treatment groups, the initial response to each item was made before *S*s had observed the presentation of the correct S-R pair, the first trials of these groups were not included in the criterion-trial count nor in the analysis. The series of trials for each item was split into a first and second half. Shown in Table 1 are the means determined for each half of the trial series. These means comprised the scores which were examined as a within-*S* variable in the analysis. The results of the analysis indicated that response latencies during the two halves of practice did not differ significantly. The table of means indicates that there was some tendency for the response latencies to increase, but this tendency was apparently not consistent. It may be concluded that, in general, response latencies remained constant or increased slightly. There was clearly no reduction in response latency prior to the TLE.

Latency after the TLE. Figure 3 indicated that response latency declined following the TLE. To evaluate this finding, post-TLE trial number was incorporated as a within-*S* variable in an analysis of variance in which information-transmission level and training method were between-*S* variables. Group means are presented in Table 2. Averaged across all treatment conditions, response latency decreased by 572 milliseconds from Trial TLE+1 to Trial TLE+16. This was a significant reduction ($F = 33.62$, $df = 15/1{,}350$, $p < .001$).

Summarizing the changes in latency over the course of learning, it can be stated that following a possible increase on the first few trials (the probability and magnitude of which was dependent on the task characteristics) response latency remained relatively constant prior to the TLE and

TABLE 2

RESPONSE LATENCY (IN MILLISECONDS) FOR ALL KEY POSITIONS AFTER THE TRIAL OF LAST ERROR (TLE) AS A FUNCTION OF TRIAL NUMBER AND TRAINING METHOD

Method	*n*	Overall *M*	*M* for Trial TLE+1	*M* for Trial TLE+16	Decline
Anticipation	48	1,629	1,968	1,433	535
Recall	48	1,323	1,744	1,135	609
Total	96	1,476	1,856	1,284	572

then decreased substantially over the first 16 trials following the TLE.

Intratrial Variability in Response Latency

Variability in response latency was investigated under each of the experimental conditions and in the two major stages of learning, pre- and post-TLE. The scores obtained represent variability in response latency within individual trials. For each *S*, a variance was calculated for each trial prior to, and including, the TLE for the last item to reach criterion. These intratrial scores were then averaged together to obtain a mean pre-TLE variance for each *S*. The same procedure was followed for the first 16 trials *after* the TLE. A summary of the group mean standard deviations is presented in Table 3. The most striking feature of the scores in Table 3 is that the post-TLE standard deviations are consistently smaller than the pre-TLE scores. It will also be noted that the variability of the three information-level groups increased as a positive function of the amount of information which *S* was required to transmit both prior to and after the TLE.

TABLE 3

TREATMENT GROUP MEAN STANDARD DEVIATION SCORES (IN MILLISECONDS) REPRESENTING INTRATRIAL VARIABILITY IN RESPONSE LATENCIES FOR ALL KEY POSITIONS

Treatment	Pre-TLE trials		Post-TLE trials	
	n	*SD*	*n*	*SD*
Information Level 1 (A)				
Anticipation (B)	16	792	16	431
Recall (C)	15	716	16	351
Information Level 2 (D)				
Anticipation	16	1,322	16	642
Recall	16	1,078	16	440
Information Level 3 (E)				
Anticipation	16	1,339	16	927
Recall	16	1,769	16	782
A × BC	31	755	32	391
D × BC	32	1,200	32	541
E × BC	32	1,554	32	854
ADE × B	47	1,151	48	667
ADE × C	48	1,198	48	524
Total	95	1,174	96	595

Note.—Abbreviated: TLE = trial of last error.

TABLE 4

EFFECTS OF INFORMATION TRANSMISSION LEVELS AND PRESENTATION METHODS ON RESPONSE LATENCIES FOR ALL KEY POSITIONS PRIOR TO THE TRIAL OF LAST ERROR

Treatment	*n*	Latency *M* (in msec)
Information Level		
1	28	1,506
2	28	1,972
3	28	2,384
Method		
Anticipation	42	1,926
Recall	42	1,983
Total	84	1,954

It had been hypothesized that recall variance would be less than the variance of latencies obtained under the anticipation paradigm. To test this hypothesis, a Mann-Whitney *U* test (Siegel, 1956) was conducted which compared the standard deviation scores of the anticipation and recall treatment *S*s both prior to and after the TLE. Prior to the TLE, no difference was detected between the two treatments. After the TLE, a significant proportion of the recall-treatment scores were smaller than the anticipation scores ($z = 2.90$, $p < .004$). It may be concluded that prior to the TLE, intratrial response latency variability was not influenced by training method but after the TLE, variability was significantly less under the recall paradigm.

Response Latency as a Function of Training Method

Pre-TLE latency. All pre-TLE response latencies (with the exception of initial responses to anticipation items) were averaged together to obtain a mean pre-TLE latency for each *S* for whom pre-TLE data were available. Mean pre-TLE latency was treated as a between-*S* variable in a factorial analysis of variance which examined the effects of both training method and information level. The results of this analysis are given in Table 4. Pre-TLE latencies did not differ significantly as a function of training method. The two means representing the anticipation and recall treatments differed by less than 60 milliseconds. It may be concluded that re-

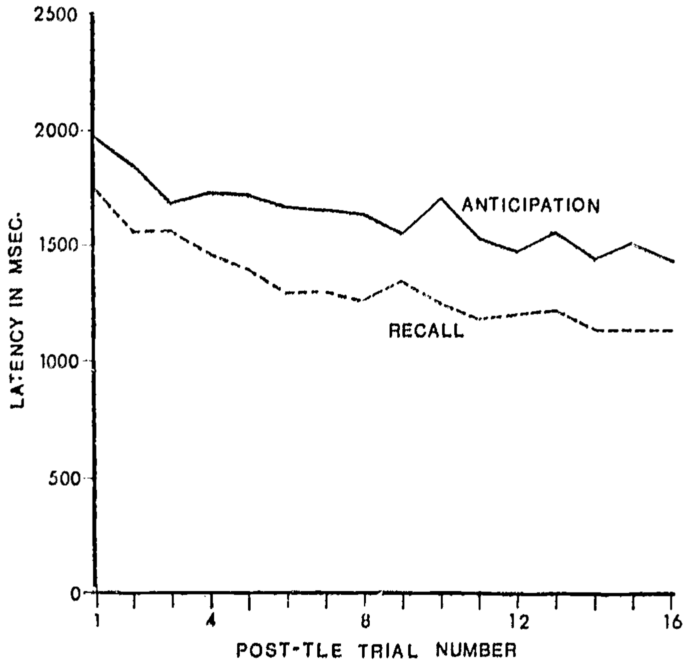

FIG. 5. Response latency of anticipation- and recall-method *S*s as a function of post-TLE trial number.

sponse latency prior to the TLE was independent of the training method.

Post-TLE latency. Rather than grouping all post-TLE data together, the effects of post-TLE practice were evaluated by treating the first 16 post-TLE trials as a within-*S* variable in a factorial analysis of variance in which information level and method were between-S variables. Since post-TLE practice was experimentally controlled, data were available from all of the 96 *S*s.

As shown in Table 2, mean post-TLE response latencies, averaged across the 16 trials, were 300 milliseconds faster under the recall paradigm than under the anticipation paradigm. This difference was statistically significant ($F = 22.23$, $df = 1/90$, $p < .001$). In addition, there was a significant interaction between the method and trials variables ($F = 4.03$, $df = 15/1{,}350$, $p < .001$). The effect of this interaction may be seen in Figure 5. While post-TLE latency declined under both paradigms, the magnitude of the reduction was slightly greater (74 milliseconds) for the recall paradigm than for the anticipation paradigm. It will be recalled that prior to the TLE, response latencies did not differ as a function of training method. On the TLE itself, the anticipation and recall treatment group means differed by only 10 milliseconds. It was only after the TLE that recall latencies became substantially faster than the comparable anticipation latencies, and the magnitude of this difference continued to increase during overlearning.

Response Latency as a Function of Information Transmission Requirements

Pre-TLE latency. Disregarding the initial response to anticipation items, the mean response latency prior to the TLE was calculated for each *S*. A factorial analysis of variance was conducted in which information level and training method were between-*S*s variables. Group means are presented in Table 4. Pre-TLE latency increased as a positive linear function of the number of bits of potential information involved in the task, that is, the amount of information which *S* was required to transmit for errorless responding. This relationship was statistically significant ($F = 13.48$, $df = 2/78$, $p < .001$). Since pre-TLE responding had a high error rate, *S*s were actually transmitting less than the potential information in the task, but latency did appear to be a linear function of potential information rather than transmitted information.

Since all key positions were included in this analysis, the question arises as to whether this trend was not simply the result of the higher order information levels having keys which resulted in longer latencies because of their position in the middle of the keyboard array. That this was not the case was demonstrated by the failure of the preliminary key-position analysis to find a significant interaction between the key-position and information-level variables. In addition, if the data from the end key positions (Keys 1 and 2) are examined, the three latency means for the three information levels are 1,528, 2,079, and 2,323 milliseconds, respectively.

Post-TLE latency. The preliminary analysis which incorporated key position as an additional variable found that after the TLE there was a significant interaction between the information-level and key-position variables ($F = 36.28$, $df = 1/1{,}860$, $p < .001$). For the two-bit, four-response task, response latency was independent of key position but for the three-bit, eight-response task, the inner key positions (Keys 3 and 4) had longer latencies than the outer key positions (Keys 1 and 2). One analysis was, therefore, conducted for only Keys 1 and 2 across all three information levels and a second analysis treated only Keys 3 and 4 in the two higher order information levels. Information level and method were between-*S* variables in the factorial analyses. Latency scores for each *S* on each of the first 16 post-TLE trials formed a within-*S* trials variable. Means of these data are presented in Table 5, and curves representing changes in latency over trials are illustrated in Figures 6 and 7.

Response latency increased as a function of information level for both sets of key positions, and in both cases the analyses indicate that these increases were significant (Key Positions 1 and 2: $F = 7.60$, $df = 2/90$, $p < .001$; Key Positions 3 and 4: $F = 21.58$, $df = 1/60$, $p < .001$). If the mean latencies for Keys 1 and 2 are examined, the function relating latency to the number of bits of information transmitted does not appear to be linear. The increase in latency as a result of moving from one to two bits of information is less than half the increase resulting from moving from two to three bits.

TABLE 5

Treatment Group Means for Response Latency (in Milliseconds) after the Trial of Last Error (TLE) as a Function of Information Transmission Levels

Information level	*n*	Overall *M*	*M* for Trial TLE+1	*M* for Trial TLE+16	Decline
Key Positions 1 and 2					
1	32	1,244	1,496	1,057	439
2	32	1,369	1,555	1,261	294
3	32	1,653	2,426	1,302	1,124
Total	96	1,422	1,826	1,207	619
Key Positions 3 and 4					
2	32	1,377	1,686	1,181	505
3	32	1,927	2,860	1,698	1,162
Total	64	1,652	2,273	1,440	833

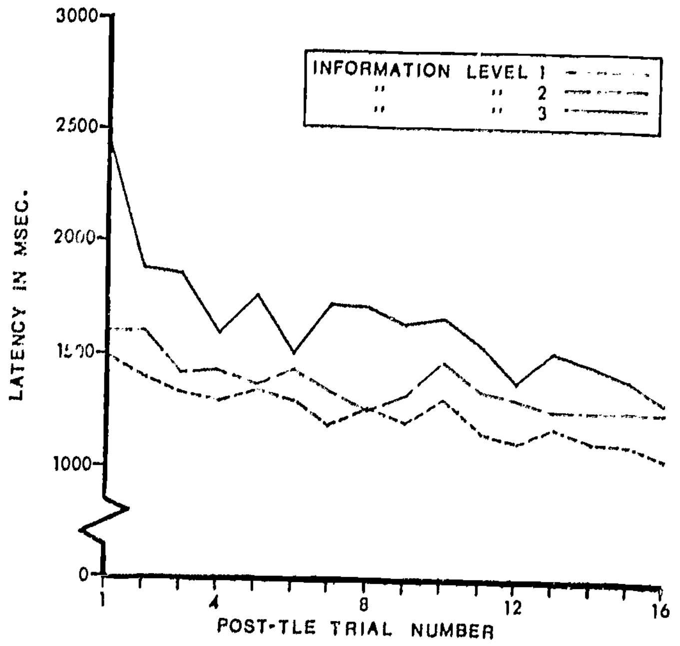

Fig. 6. Post-TLE response latencies of Information Levels 1, 2, and 3. (Key Positions 1 and 2 only.)

The manner in which the function relating latency to information level differed for the two different sets of key positions may be seen by contrasting the magnitude of the increase in response latency from Information Level 2 to Level 3 in the two analyses. For the end key positions, Keys 1 and 2, the effect of changing from four to eight response alternatives was to increase mean latency by 284 milliseconds. For Keys 3 and 4, which were internal components of the key array, the comparable effect was to increase the mean latency by 550 milliseconds. The effect is also evident in the distance separating the curves representing Information Levels 2 and 3 in Figures 6 and 7.

These figures also indicate that the decline in response latency over the first few post-TLE trials was much greater for Information Level 3 than for the two lower order levels. This difference did not persist over the full 16 trials, however. The Information × Trials interaction was not significant in either of the two analyses.

Pre-TLE Latency of Correct and Incorrect Responses

Prior to the TLE, 45% of the responses were correct. For each *S*, the mean pre-TLE latencies of correct and incorrect responses were determined for each item. The preliminary analysis incorporating

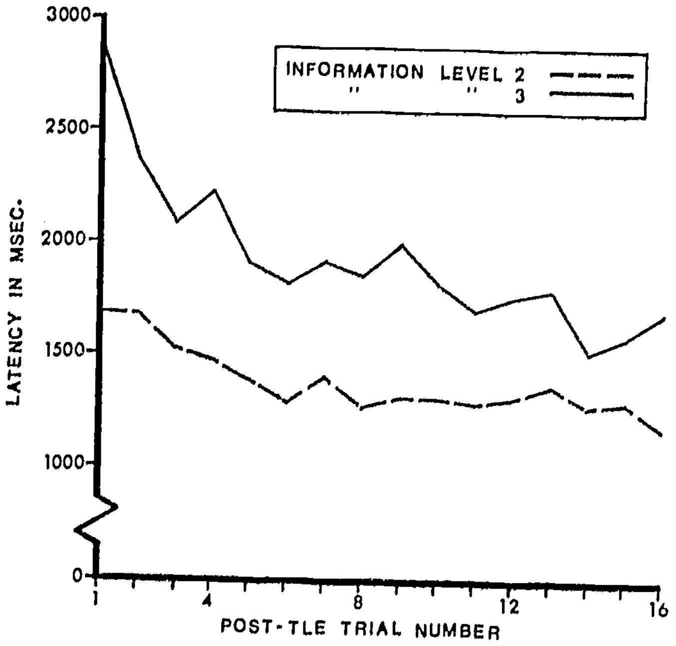

FIG. 7. Post-TLE response latencies of Information Levels 2 and 3. (Key Positions 3 and 4 only.)

key position as a variable found a significant interaction between the key position and correctness variables ($F = 3.15$, $df = 1/96, p < .10$). Therefore, one analysis treated only Key Positions 1 and 2, and a second analysis treated only Key Positions 3 and 4. Means are presented in Table 6. Correct and incorrect responses prior to the TLE were not significantly different. This finding was independent of key position and the effects of the experimental variables of training method and information level.

Since the scores on which these analyses were based were the means of all the pre-TLE responses, it was possible that while the pre-TLE averages might not differ, the relationship between correct and incorrect response latencies may have changed as a function of practice. For example, correct responses might have become faster as an item approached the TLE while incorrect responses became slower at approximately the same rate. If the correct and incorrect latency curves crossed, this could cause the mean value of the curves to be approximately the same. To evaluate this possibility, the latencies of correct and incorrect responses were plotted over the pre-TLE practice period. The average curve for all treatment groups and key positions is shown in Figure 8. It is evident from this plot that the relationship between correct and incorrect response latencies did not change systematically over trials. Both curves tended to approximate a constant latency of about 2 seconds. It may be concluded that prior to the TLE, correct response latencies did not differ from the latencies of incorrect responses.

Response Latency as a Function of Item Difficulty

On the basis of Simley's (1933) study, it was expected that for a given *S*, the more difficult items would have longer latencies than that *S*'s less difficult items. Response latencies prior to and after the TLE were investigated separately with respect to this question. In general, it was found that those items which were associated with the middle key positions had longer latencies and also required a greater number of trials to reach criterion than did the items associated with the end keys. While this relationship was in the direction anticipated by the contention that the more difficult

TABLE 6

TREATMENT GROUP MEANS FOR CORRECT AND INCORRECT RESPONSE LATENCIES (IN MILLISECONDS) PRIOR TO THE TRIAL OF LAST ERROR

Treatment	*n*	Response latencies		
		Correct	Incorrect	Incorrect-correct
Key Positions 1 and 2				
Information Level				
1	22	1,587	1,625	38
2	22	2,051	2,296	245
3	22	2,156	2,638	482
Method				
Anticipation	33	1,852	1,862	10
Recall	33	2,012	2,511	499
Total	66	1,932	2,187	255
Key Positions 3 and 4				
Information Level				
2	24	1,812	2,134	322
3	24	2,601	2,167	−434
Method				
Anticipation	24	2,127	1,947	−180
Recall	24	2,287	2,354	67
Total	48	2,207	2,151	−56

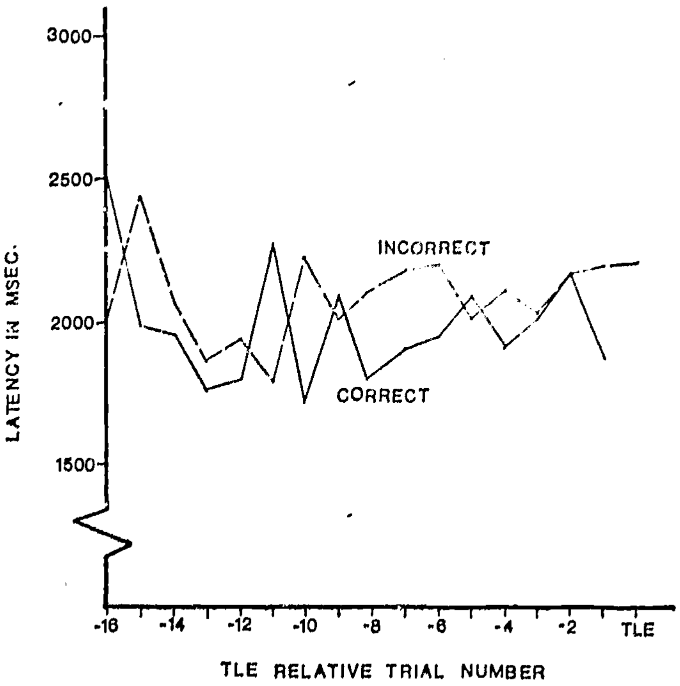

Fig. 8. Correct and incorrect response latencies prior to the TLE.

items would have longer latencies, it is likely that the positive correlation was simply an artifact. That is, items which had responses assigned to the end keys were probably learned more quickly because of the distinctive position of the keys, and this distinctive position may have also made the perceptual-motor task of locating and pressing a key easier and hence faster for an end key. Any analysis of the relationship between item difficulty and response latency which treated all key positions as analogous would be biased by having a greater number of inner key position items in the difficult-item group and a majority of items associated with Keys 1 and 2 in the less-difficult-item group. Two separate analyses were therefore conducted which treated Key Positions 1 and 2 and Positions 3 and 4 separately.

Item difficulty was measured by counting the number of trials required for an item to reach Trial TLE+1. The most difficult item and the least difficult item were selected for each pair of key positions for each *S* on this basis. Scores were calculated for these items by computing the mean latency for all responses prior to the TLE for the pre-TLE analysis and for the first 16 trials after the TLE for the post-TLE analysis. In the case of ties for the most or least difficult item, the tied items were averaged into a single score. Thus, for each set of analyses, each *S* for whom data were available was represented by a pair of latency scores for his most difficult item and his least difficult item for the key positions relevant to that particular analysis.

Pre-TLE latency. Latency data prior to the TLE and the number of trials required to reach Trial TLE+1 are shown in Table 7. For the pre-TLE analysis, only those items were considered which had at least one trial after the first presentation of the S-R pair and prior to the TLE. Relatively few *S*s were available for this analysis since, in some cases, all of an *S's* items had the same number of pre-TLE trials and more often, an *S* had an inadequate amount of pre-TLE data on the appropriate key positions. The amount of data available was not sufficient for a complete factorial test including all treatment conditions. Only 21 of the 48 recall-treatment *S*s had pre-TLE data on Keys 1 and 2. Since the method factor did not appear to alter the relationship between the latencies of the most and least difficult items, anticipation and recall *S*s were grouped together. Analysis of the data shown in Table 7 indicated that pre-TLE response latency did not differ as a systematic function of item difficulty for Key Positions 1 and 2.

There were at least 8 *S*s available in each experimental condition for the inside Key Positions 3 and 4 and this was considered to be sufficient for a complete factorial analysis. Analysis of the data in Table 7 indicated that the response latencies of the difficult items were significantly longer than the latencies of the responses to those items which *S*s found to be least difficult ($F = 13.41$, $df = 1/28$, $p < .001$). In addition, this difference was more pronounced for the four-response, two-bit task than for the eight-response, three-bit task. This resulted in a significant two-way interaction ($F = 7.97$, $df = 1/28$, $p < .01$).

Post-TLE latency. After the TLE, data were available for all items over at least 16 trials. The most and least difficult items for each key position were selected for each *S* by the procedure described above.

TABLE 7
TREATMENT GROUP MEANS FOR PRE-TLE RESPONSE LATENCIES OF MOST AND LEAST DIFFICULT ITEMS FOR EACH SUBJECT

Treatment	*n*	Most difficult item		Least difficult item		Most-least difficult item	
		Latency[a]	Trials	Latency[a]	Trials	Latency[a]	Trials
Key Positions 1 and 2							
Information Level							
1	13	1,817	11.1	1,586	2.3	231	8.8
2	13	1,808	13.3	2,060	3.6	−252	9.7
3	13	2,369	8.8	2,138	4.4	231	4.4
Total	39	1,998	11.1	1,928	3.4	70	7.7
Key Positions 3 and 4							
Information Level							
2	16	2,046	10.4	1,516	3.4	530	7.0
3	16	2,116	10.6	2,034	6.4	82	4.2
Method							
Anticipation	16	2,150	12.9	1,716	5.6	434	7.3
Recall	16	2,013	8.1	1,834	4.2	179	3.9
Total	32	2,081	10.5	1,775	4.9	306	5.6

[a] Latency *M*s given in milliseconds.

A small number of *S*s were lost because all their items had the same number of pre-TLE trials. Data for Key Positions 1 and 2 and Positions 3 and 4 are presented in Table 8. In the case of both analyses, the most difficult items had longer latencies than did the least difficult items. The differences were small, on the order of 100 to 200 milliseconds, but significant in both cases (Key Positions 1 and 2: $F = 5.03$, $df = 1/72, p < .05$; Key Positions 3 and 4: $F = 6.59$, $df = 1/52$, $p < .05$). In neither case was there any significant interaction with the information-level or method variables.

Response Latency as a Function of Subject Learning Rate

In the previous section, variation in response latency was investigated as a within-*S* function of item difficulty. The analyses discussed in this section dealt with variation in response latency as a function of individual differences in *S* learning rate. Responses prior to and after the TLE were treated separately. The measure of *S* learning rate employed was the total number of item presentations across all items and all key positions prior to and including the TLE. From each treatment group of 16 *S*s, the 4 *S*s who had the highest such scores were classified as slow learners and the 4 *S*s who had the lowest scores were classified as fast learners. In the pre-TLE analysis, 3 of the fast learners had no data prior to the TLE and had to be replaced with *S*s who were slightly slower learners.

Pre-TLE latency. A single pre-TLE response-latency score was calculated for each key position for each *S*. This score was the mean of all response latencies after the first presentation of the S-R pair and prior to the TLE. It was found that key position was not a significant variable in this context, and a single analysis including all key positions was conducted. The mean response latencies and the mean number of pre-TLE trials per item for each treatment group are presented in Table 9. Analysis of variance indicated that the slow and fast learners differed only slightly in their pre-TLE response latencies. Neither the learning-rate variable nor any interaction between learning rate and the information-level or method variables was significant. It may be concluded that slow and fast learners did not differ in response latency prior to the TLE.

TABLE 8

TREATMENT GROUP MEANS FOR POST-TLE RESPONSE LATENCIES OF MOST AND LEAST DIFFICULT ITEMS FOR EACH SUBJECT

Treatment	*n*	Most difficult item		Least difficult item		Most-least difficult item	
		Latency[a]	Trials	Latency[a]	Trials	Latency[a]	Trials
Key Positions 1 and 2							
Information Level							
1	26	1,251	10.0	1,162	0.4	89	9.6
2	26	1,420	10.0	1,356	2.3	64	7.7
3	26	1,732	7.7	1,550	3.3	182	4.4
Method							
Anticipation	39	1,611	13.1	1,455	3.5	156	9.6
Recall	39	1,325	5.4	1,258	0.5	67	4.9
Total	78	1,464	9.2	1,356	2.0	108	7.2
Key Positions 3 and 4							
Information Level							
2	28	1,429	10.8	1,266	2.4	163	8.4
3	28	1,963	10.9	1,817	6.1	146	4.8
Method							
Anticipation	28	1,890	13.8	1,656	5.7	234	8.1
Recall	28	1,502	7.9	1,428	2.8	74	5.1
Total	56	1,696	10.8	1,542	4.3	154	6.5

[a] Latency *Ms* given in milliseconds.

Post-TLE latency. A single post-TLE response-latency score was calculated for each key position for each *S*. This score was the mean of the first 16 post-TLE responses. The preliminary key-position analysis of variance indicated a significant interaction between key position and the learning-rate variable ($F = 3.37$, $df = 1/24$, $p < .10$). Therefore, two separate analyses for Key Positions 1 and 2 and Positions 3 and 4 were conducted. The mean response latencies and the mean number of pre-TLE trials per item for each treatment group are presented in Table 10. The treatment-group latency means in these tables indicate that for both sets of key positions, slow learners had slightly longer response latencies during the post-TLE trials but this difference was significant only for the outside key positions, Keys 1 and 2 ($F = 6.79$, $df = 1/36$, $p < .05$). There were no significant interactions between the variables of *S* learning rate and information level or method in either analysis.

TABLE 9

TREATMENT GROUP MEANS FOR PRE-TLE RESPONSE LATENCIES OF SLOWEST AND FASTEST LEARNERS FOR ALL KEY POSITIONS

Treatment	Slow learners		Fast learners		Slow-fast learners	
	Latency	Trials	Latency	Trials	Latency	Trials
Information Level						
1	1,500	7.1	1,525	1.1	−25	6.0
2	1,878	11.4	1,527	2.3	351	9.1
3	2,318	11.7	2,604	4.1	−286	7.6
Method						
Anticipation	1,866	12.9	2,000	3.5	−134	9.4
Recall	1,932	7.3	1,771	1.5	161	5.8
Total	1,899	10.1	1,885	2.5	14	7.6

Response Latency in the Area of the TLE

Response latency in the area of the TLE itself is of special interest. Suppes et al. (1966) found response latencies on the TLE to be consistently longer than the latencies of the immediately preceding and following trials. In addition, preceding sections have shown that while latencies prior to the TLE remained constant and independent of practice, post-TLE latencies decreased rapidly as a function of practice.

TABLE 10

TREATMENT GROUP MEANS FOR POST-TLE RESPONSE LATENCIES OF SLOWEST AND FASTEST LEARNERS

Treatment	Slow learners		Fast learners		Slow-fast learners	
	Latency	Trials	Latency	Trials	Latency	Trials
Key Positions 1 and 2						
Information Level						
1	1,245	7.1	1,049	1.0	196	6.1
2	1,547	11.4	1,227	2.0	320	9.4
3	1,732	11.7	1,867	3.8	−135	7.9
Method						
Anticipation	1,673	12.9	1,486	3.5	187	9.4
Recall	1,344	7.3	1,276	1.0	68	6.3
Total	1,508	10.1	1,381	2.3	127	7.8
Key Positions 3 and 4						
Information Level						
2	1,521	11.4	1,264	2.0	257	9.4
3	1,971	11.7	1,883	3.8	88	7.9
Method						
Anticipation	1,934	14.3	1,805	4.4	129	9.9
Recall	1,558	8.8	1,342	1.4	216	7.4
Total	1,746	11.6	1,574	2.9	172	8.7

The TLE thus appears to be a point of some importance in the systematic changes in latency over learning.

Changes in latency from Trial TLE−1 to the TLE. Only those items were considered which had an incorrect response on Trial TLE−1 which also were not an initial anticipation response. All such items which were available were averaged together to yield two mean scores for each *S*, one representing the latency of an error response on trial TLE−1 and the other representing the TLE latency. These scores were treated as a within-*S* variable in a factorial analysis of variance in which information level and method were between-*S* variables. The group-mean data of this analysis are presented in Table 11. The increase in incorrect response latency from Trial TLE−1 to the TLE, averaged over all experimental conditions was only 102 milliseconds. This difference was not significant nor were there any significant interactions with the experimental variables. It may be concluded that the latency of the TLE response was not substantially greater than the latency of immediately preceding incorrect responses.

Changes in latency from the TLE to Trial TLE+1. This analysis investigated the question of whether or not there was a significant drop in latency from the TLE to the first trial past the TLE. A pair of scores representing Trials TLE and TLE+1 were computed for each *S* who had at least one available protocol by taking the mean of all available response pairs. These scores were treated as a within-*S* variable in a factorial analysis of variance in which information level and method were between-*S* variables. The group-mean data of this analysis are presented in Table 12. Responses on Trial TLE+1 were, on the average, 251 milliseconds faster than responses on the TLE. This was a significant reduction ($F = 13.38$, $df = 1/84$, $p < .001$). The magnitude of the reduction in latency was a significant function of the information levels with the middle, two-bit task demonstrating the greatest change ($F = 4.38$, $df = 2/84$, $p < .05$). There was, in addition, a significant three-way interaction between information level, method, and trial relative to the TLE ($F = 5.25$, $df = 2/84$, $p < .01$). This may be attributed to the finding that while the decline was greater for the anticipation than for the recall treatments on the one- and three-bit tasks, the two-bit, recall-treatment group demonstrated a reduction in latency of 925 milliseconds that was much greater than that of the comparable anticipation group. Examination of the scores of the individual *S*s in two-bit recall condition indicated that this was a consistent trend. Of the 15 *S*s, 13 demonstrated a reduction in

TABLE 11

TREATMENT GROUP MEANS FOR COMPARISON OF INCORRECT RESPONSE LATENCIES ON TRIALS TLE-1 AND TLE FOR ALL KEY POSITIONS

Treatment	*n*	Trial TLE−1	Trial TLE	TLE−TLE−1
Information Level				
1	16	1,605	1,770	165
2	16	2,323	2,525	202
3	16	2,516	2,455	−61
Method				
Anticipation	24	2,163	2,214	51
Recall	24	2,134	2,287	153
Total	48	2,148	2,250	102

Note.—Abbreviated: TLE= trial of last error.

latency from the TLE to the next trial and of these 13, 5 had a reduction in latency that was greater than 1 second. It may be concluded that while, in general, responses were faster on Trial TLE+1 than on the TLE, this effect was negligible for the eight-response, three-bit task. Furthermore, the particular combination of conditions present in the two-bit recall task resulted in an unusually large decrement in response latency.

TABLE 12

TREATMENT GROUP MEANS FOR COMPARISON OF RESPONSE LATENCIES ON TRIALS TLE AND TLE+1 FOR ALL KEY POSITIONS

Treatment	*n*	Trial TLE	Trial TLE+1	TLE—TLE+1
Information Level 1 (A)				
Anticipation (B)	15	1,914	1,652	262
Recall (C)	15	1,547	1,470	77
Information Level 2 (D)				
Anticipation	15	1,890	1,608	282
Recall	15	2,508	1,580	925
Information Level 3 (E)				
Anticipation	15	2,877	2,826	51
Recall	15	2,224	2,321	−97
A × BC	30	1,730	1,561	169
D × BC	30	2,199	1,594	605
E × BC	30	2,550	2,573	−23
ADE × B	45	2,227	2,029	198
ADE × C	45	2,093	1,790	303
Total	90	2,160	1,909	251

Note.—Abbreviated: TLE = trial of last error.

Latency trends in the area of the TLE. Following the completion of the previous two analyses it was felt that a more adequate description of changes in latency in the area of the TLE was needed. All item protocols which had at least three pre-TLE trials were selected. Approximately 50% of the items met this criterion. Mean correct and incorrect response latencies for Trials TLE−3–TLE+3 were calculated for each *S* who had at least one item protocol which met the criterion. The scores of all the available *S*s were then averaged together to obtain treatment-group means. The resulting data for each treatment group are presented in Table 13. Although no statistical tests were made on these data,

TABLE 13

CORRECT AND INCORRECT RESPONSE LATENCIES IN THE AREA OF THE TRIAL OF LAST ERROR FOR ALL KEY POSITIONS

Treatment	*n*	Correct-Incorrect	TLE−3	TLE−2	TLE−1	TLE	TLE+1	TLE+2	TLE+3
Information Level 1 (A)									
Anticipation (B)	14	C	1,813	2,269	1,655		1,439	1,569	1,414
		I	1,806	1,334	2,092	1,990			
Recall (C)	14	C	1,542	1,309	1,616		1,565	1,405	1,260
		I	1,723	1,955	1,625	1,621			
Information Level 2 (D)									
Anticipation	16	C	1,683	1,941	1,511		1,660	1,883	1,521
		I	1,521	2,127	2,013	1,907			
Recall	13	C	2,685	2,047	2,297		1,755	1,590	1,359
		I	1,843	2,736	3,172	2,425			
Information Level 3 (E)									
Anticipation	16	C	2,672	2,923	2,641		2,692	2,337	2,117
		I	2,893	2,379	2,642	2,897			
Recall	15	C	2,435	2,249	1,882		1,916	1,839	1,721
		I	2,193	2,031	2,485	2,120			
A × BC	28	C	1,689	1,852	1,636		1,502	1,487	1,337
		I	1,769	1,595	1,920	1,805			
D × BC	29	C	2,107	1,987	1,848		1,703	1,752	1,448
		I	1,642	2,371	2,510	2,144			
E × BC	31	C	2,561	2,608	2,287		2,317	2,096	1,925
		I	2,579	2,224	2,567	2,521			
ADE × B	46	C	2,081	2,417	1,954		1,952	1,945	1,696
		I	2,126	2,006	2,260	2,277			
ADE × C	42	C	2,239	1,913	1,929		1,749	1,617	1,455
		I	1,963	2,246	2,491	2,051			
Total	88	C	2,152	2,191	1,943		1,855	1,789	1,581
		I	2,057	2,108	2,359	2,169			

there do appear to be several trends which may be promising for future investigation. First, it will be noted that for this particular selection of data, the latency of the TLE response was, in general, shorter than the latency of an immediately preceding incorrect response. This trend held for five of the six treatment groups but was more pronounced for the recall training method conditions. The most accurate descriptive statement that can be made based on this data is that incorrect response latencies tended to reach a peak during the last few trials prior to and including the TLE. There did not appear to be any reliable sharp division points.

Secondly, it will be recalled that it was previously demonstrated that, in general, the latency of correct and incorrect responses prior to the TLE did not differ. For the sample of data shown in Table 13, there were no systematic differences between correct and incorrect response latencies on Trials TLE−3 and TLE−2, but on Trial TLE−1, correct response latencies were consistently shorter than the latencies of the corresponding incorrect responses. While the two-bit recall and three-bit anticipation tasks had only negligible differences between correct and incorrect response latencies, the other four task conditions demonstrated substantial differences. It may be the case that response latencies do become indicative of the correctness of the response as the item approaches the point at which it is finally learned.

Finally, the data represented in Table 13 suggest that the decline in correct response latency evident after the TLE may begin prior to the TLE. Under each of the three anticipation training method conditions, mean correct response latency declined from Trial TLE−2 to Trial TLE−1. Under the recall paradigm, only the three-bit task demonstrated a reduction in latency across these trials but for all three information levels, latency on Trial TLE−2 was less than the latency of the preceding trial.

Since these trends were postulated a posteriori with reference to a particular sample of data, the use of statistical tests to evaluate the frequency of their occurrence would not appear to be justified. They are presented only as an attempt to clarify for future study the nature of latency behavior during an important phase of the learning process.

First Correct Response Latency as a Function of Subsequent Errors

This final analysis reverses past procedure by examining latency on the trial of the first correct response rather than on trials relative to the TLE. The latency of the first correct response was determined for each item for each *S*. All such first correct responses were then divided into two groups on the basis of whether or not *S* made any errors after the first correct response and prior to reaching the criterion of six successive errorless trials. To remain consistent with the terminology suggested by Williams (1962), those items on which subsequent errors did occur were termed break items. Items for which there was no subsequent error were termed nonbreak items. For each *S*, a pair of scores was computed which consisted of the mean latencies of the first correct responses of all the break and nonbreak items for that *S*. These scores were treated as a within-*S* variable in a factorial analysis of variance in which information level and training method were between-*S* variables. The *S*s whose data did not include both break and nonbreak items were excluded from consideration. At least 12 *S*s were available in each treatment group. A summary of the group-mean data is presented in Table 14.

First correct responses to break items had longer latencies than the corresponding nonbreak items for five of the six treatment groups. This difference was significant ($F = 19.44$, $df = 1/66$, $p < .001$). The magnitude of the difference increased as a positive function of information level for the anticipation-procedure groups but was a nonlinear, **U**-shaped function of information level for the recall-procedure groups. These varying relationships, shown in Table 14, resulted in a significant three-way interaction ($F = 3.29$, $df = 2/66$, $p < .05$). To relate the findings of this analysis to the previously discussed analyses taking their point of origin from the TLE, it may be pointed out that the first correct responses of break items occurred prior to the TLE while the first correct responses of nonbreak items occurred on Trial TLE+1. The results of this analysis are, therefore, consistent with the previous findings that correct responses remain relatively slow on the trials prior to the TLE and are then considerably faster on Trial TLE+1. In addition, however, this analysis does suggest that when a nonbreak item was learned, as indicated by the fact that no more errors were made on that item, the latency of the response was immediately shortened. Although all the preceding responses had been in error, *S*'s very first production of the correct response was substantially faster than the preceding responses.

TABLE 14

TREATMENT GROUP MEANS FOR LATENCIES OF FIRST CORRECT RESPONSES FOR ALL KEY POSITIONS DIVIDED ON THE BASIS OF THE OCCURRENCE OF SUBSEQUENT ERRORS

Treatment	*n*	Break items	Non-break items	Break-nonbreak
Information Level 1 (A)				
Anticipation (B)	12	1,746	1,647	99
Recall (C)	12	1,544	1,248	296
Information Level 2 (D)				
Anticipation	12	1,436	1,285	151
Recall	12	2,707	1,589	1,118
Information Level 3 (E)				
Anticipation	12	2,774	2,367	407
Recall	12	1,846	2,119	−273
A × BC	24	1,645	1,447	198
D × BC	24	2,071	1,437	634
E × BC	24	2,310	2,243	67
ADE × B	36	1,985	1,766	219
ADE × C	36	2,032	1,652	380
Total	72	2,009	1,709	300

CONCLUSIONS AND DISCUSSION

Training Method

It was expected that the recall paradigm would result in shorter and less variable latencies prior to the TLE than would the anticipation method, following through the suggestion made in previous work by Peterson (1965). The present investigators found, however, that pre-TLE response latencies did not differ between the two paradigms in either duration or variability. The recall paradigm did result in faster learning and a lower postcriterion error rate—a finding which is in agreement with previous research (Battig & Brackett, 1961; Battig & Wu, 1965). The recall paradigm did, therefore, have some instructional advantage and this finding in itself might lead one to expect that pre-TLE latencies would be shorter under the recall paradigm. If the recall training method was more efficient because interference effects were reduced under this paradigm, the response-latency measures must have not been sensitive to the interference effects.

After the TLE, the recall paradigm resulted in shorter and less variable latencies than did the anticipation paradigm. The reduced variability was probably not meaningful in itself, but a function of the shorter mean latency for recall. Averaged over all post-TLE latencies, the ratio of the standard deviation to the mean was .40 for both the anticipation and recall paradigms. The smaller magnitude of the recall-method latencies could have been the result of one or both of two separate factors. First, responses may have been effectively paced at a higher rate in the recall paradigm than in the anticipation paradigm. The minimum possible elapsed time between recall responses was 1.5 seconds. Due to the knowledge-of-results presentation, the minimum time between anticipation responses was 3.5 seconds. The different rates at which the items were presented may be analogous to the situation discussed by Williams (1962). Williams' *S*s learned word pairs by the anticipation method, and knowledge of results was exposed for either 1 or 4 seconds. The longer exposure time resulted in a significant reduction in the number of trials required to reach criterion but did not produce the expected reduction in latencies. Williams suggested that the slower presentation rate resulting from the longer knowledge-of-results exposure may have specifically increased latencies. The anticipation-paradigm latencies may have been increased for the same reason in the post-TLE period of the current experiment but if this were the case, it might be expected that the effect would have also been present in the data prior to the TLE. If, on the other hand, response latencies after the TLE are indicative of the degree of overlearning and if the recall paradigm is a more efficient training method during overlearning as well as during early learning, the shorter post-TLE latencies may reflect the higher response strengths of the items learned under the recall paradigm. It will be recalled that the difference between the post-TLE recall and anticipation latencies increased as a function of practice. This would be expected if the anticipation-recall difference were due to suprathreshold response strength increasing at a faster rate under the recall paradigm. However, the same effect might be expected if the difference were due to a discrepancy in the rate at which the two tasks were paced. A comparison of the two methods in which interresponse interval was held constant across the two paradigms should differentiate between hypotheses.

In summary, the recall paradigm was the more efficient training procedure in terms of response probability. Response latency prior to the TLE was independent of the training method. As practice was continued after the TLE, recall-treatment latencies became increasingly shorter than the corresponding anticipation response latencies. If post-TLE latencies are indeed indicative of suprathreshold response strength, recall may also be the more efficient training procedure during overlearning.

Information Transmission Requirements

As was anticipated from the reaction-time literature, response latency increased as the number of response alternatives increased. These results support the findings of Bricker (1955) and Rabbitt (1959) that variation in the number of response alternatives rather than the number of stimuli is sufficient to alter the information characteristics of the task. In the current experiment, all three information-level groups had eight-item stimulus lists. Only the number of response alternatives differed. The latencies of the different information-level groups became ordered on the basis of the number of response alternatives very soon after the start of the main task. Pre-TLE response latencies, averaged across training methods, closely approximated a linear function of the amount of potential information in the task, that is, a $\log_2$ function of the number of response alternatives. Since *S*s were making errors during this period, however, the amount of information actually being transmitted was much smaller. The average amount of information transmitted per response in the two-, four-, and eight-response-alternative tasks was approximately .01, .13, and .36 bits, respectively. It would be expected from the reaction-time literature that response latencies would be a linear function of the amount of information actually being transmitted but the latency data appeared to be more a linear function of the amount of potential information in the task.

On the TLE itself, latency was approximately a linear function of the potential information in each task. There was a slight tendency toward concavity but this should probably be discounted in view of the subsequent results. Following the TLE, the amount of transmitted information approximated the potential information in each task. Immediately after the TLE, the function became positively accelerated in that the eight-response task had excessively long latencies. As post-TLE practice continued, however, the function became more linear. This was true for both the outside key positions (Keys 1 and 2 alone) and for all key positions taken together. Response latencies on the eight-key task decreased more quickly for the outside keys and for these keys, the function was essentially linear for the post-TLE Trials 8–16. There is no reason to expect that the function would not have become linear for all keys if practice had been continued.

Several summarizing conclusions may be drawn. Response latency increased as the number of response alternatives was increased. The *S*'s latency behavior reflected the different numbers of response alternatives very soon after the beginning of the task. During the early stages of learning, prior to and including the TLE, latency was a linear function of the potential information in the task. Immediately following the TLE, when the transmitted information approximated the potential information, latency became a positively accelerated function of the amount of information in the task but as practice continued, the function became more linear.

Response Latency Prior to the TLE

An *S*'s first response to an item was slightly faster under the anticipation paradigm than under the recall paradigm. This probably reflected the fact that the anticipation *S*s were simply guessing on the first trial while the recall *S*s, having once viewed the correct pairs, had some basis for making a decision. There was a tendency for the latency of difficult items to increase over practice prior to the TLE. This increase was more pronounced under the anticipation paradigm and for the eight-response tasks but the trend was not significant for any of the treatment groups. There was no evidence of a reduction in latency as a function of pre-TLE practice until the last one or two trials prior to the TLE. During the period in which correct response probability increased from 30% to 54%, response latencies remained essentially constant. It would appear that latency was not indicative of response strength during the pre-TLE period.

Correct response probability averaged across all treatment groups would be expected to be .25 by chance alone. The obtained probability, averaged over the entire pre-TLE period, was .45. Therefore, roughly half of the correct responses observed during this period could have been due to factors other than chance. If these factors had any effects on the latency of correct responses, they were effectively masked by chance responding. In the eight-response tasks, the observed correct response probability was .40 while the probability expected by chance alone would be only .125. Thus, approximately 70% of the correct responses could have been due to factors other than chance and it would be expected that this higher proportion of responses might override any masking effects due to chance responding. On the eight-response task, the relationship of correct to incorrect response latency was a function of key position. For items assigned to outside keys, correct responses were 482 milliseconds faster than incorrect responses. For items assigned to inside keys, correct responses were 434 milliseconds slower than incorrect responses. A portion of this discrepancy may be attributed to differences in average response speed between the keys. In general, responses to outside keys were faster than responses to inside keys. For items assigned to outside keys, all the correct responses would be to the faster, outside keys but some portion of the incorrect responses would be to the slower, inside keys. The situation would be reversed for the items assigned to the inside keys. When allowance is made for this influence, there would not appear to be any strong systematic difference between correct and incorrect responses in even the eight-response tasks. It seems most parsimonious to conclude that the influence of the learning factors evident in correct response probability prior to the TLE could not be detected on the basis of the latencies of correct and incorrect responses.

The latency data were quite variable during the pre-TLE period and the hypothesized stabilizing effects of the recall-paradigm training method did not occur. It may be the case that the variability in response latency is inherent in the response-production process in the early stages of learning and is not attributable to the postulated interference effects of the anticipation paradigm. As was discussed in the previous section, one of the few factors which did have a significant influence on latency during the pre-TLE period was the number of response alternatives.

The effects of variation in item difficulty are rather difficult to assess during the pre-TLE period. On the outside keys, there was a considerable range of difficulty as measured by the number of trials required to reach the TLE but the corresponding difference in latency was negligible. There was a comparable range of difficulty for the inside keys and in that case the corresponding difference in latency was highly significant with the most difficult items being 306 milliseconds slower than the easiest items. There was also a significant interaction with information level for these keys, and the Item Latency × Difficulty relationship was almost solely due to the data from the four-response tasks. There is no obvious reason why this particular situation should have resulted in a significant relationship. The latency differences between hard and easy items, ambiguous as they were, do suggest that there was some increase in latency if an item continued over a considerable number of trials without being learned. It may be that *S*s were able to recognize the stimulus component as being a member of a difficult item before they were able to supply the correct response member.

Response Latency in the Area of the TLE

It was anticipated that the TLE would be a point at which sharp, systematic changes in latency measurements would occur. This anticipation was supported by the finding in the current experiment, as well as in previous studies, that response latencies remained fairly constant prior to the TLE and then began to decrease immediately following the TLE. The results of the current experiment suggest that the change in latency associated with the TLE may not be as discrete as was suggested by the findings of Suppes et al. It was found that latency on the TLE was not significantly greater than the latency of the immediately preceding incorrect responses. For items which had a number of trials prior to the TLE, there did appear to be some increase in incorrect response latency as items approached the TLE but the maximum latency tended to occur one or two trials prior to the TLE as often as it occurred on the TLE itself. This was true for the two- and four-response anticipation tasks, the tasks which were most similar to the conditions employed by Suppes et al., and it is not apparent why the results differed between the two experiments.

There was a large and significant drop in latency from the TLE to Trial TLE+1 although the significant interaction between information level, method, and trial number is difficult to explain. Since response latencies were, in general, constant prior to the TLE, the significant reduction in latency immediately following the TLE suggests that the post-TLE decline began on Trial TLE+1. For some items, the decline did not begin until a few trials after the TLE but since correct responses could have occurred by chance alone after the TLE, correct response probability may not have reached asymptote for these items until one or two trials after the TLE. If latencies did begin to drop only after correct response probability reached asymptote, the implication is that probability and latency are both measures of the same process but latency only becomes a sensitive measure when the probability measure has reached asymptote. Closer examination of the data, however, suggests a lower correlation between correct response probability and response latency. By definition, correct response probability did not reach asymptote until after the TLE but the decline in latency appeared to begin prior to the TLE for some items. Although the conclusions are speculative, it appeared to be the case that in some instances, correct response latencies became shorter while incorrect response latencies remained constant, or increased slightly, on the last one or two trials prior to the TLE. No such trends are evident in the data available from previous studies but if the tendencies detected in this experiment are indicative of the underlying processes, latency may become a sensitive measure before the point at which correct response probability reaches asymptote. It might further be inferred that response probability and latency are measuring two different factors.

Rather than viewing the TLE as a point at which distinct changes occur in both correct response probability and response latency, it may be more fruitful to consider the trials immediately prior to and after the TLE as an area of transition. The area may be analogous to a psychophysical threshold in that while distinctly different situations hold on either side of the threshold, the behavior in question is highly variable and probabilistic in the area of the threshold itself. The most accurate statement that can be made at this time is that latency begins to decline one or two trials before or after the point at which the probability of a correct response reaches asymptote.

Response Latency during Overlearning

Response latency after the TLE was a negatively accelerated, inverse function of practice. The decrement curves could have been the result of an increasingly large proportion of items undergoing a sudden, discrete reduction in latency, but examination of the response curves of individual items indicated that the observed decline resulted from a gradual decrement in latency for all items. The major portion of the decline occurred on the first few trials after the TLE but there was no indication that the curve had reached asymptote at the point at which practice was terminated. It is difficult to predict at what point the latencies would have reached asymptote. None of the previous studies continued practice beyond 10 trials past the TLE. As indicated, both the information-level and method variables had significant effects during overlearning. Post-TLE interitem variability was considerably smaller than pre-TLE variability. The mean standard deviation, over all treatment conditions, was approximately half as large after the TLE as it was prior to the TLE. Part of this reduction may be attributed to shorter post-TLE latencies but the ratio of the standard deviation to the mean was .53 prior to the TLE and .40 after the TLE.

It was found that post-TLE response latencies were a significant positive function of item difficulty as defined by the number of trials required to reach the TLE. While the data obtained by Millward (1964) and Suppes et al. (1966) indicate that longer pre-TLE response protocols had slower post-TLE responses, it was not possible to determine from the available data whether this effect was due to item difficulty or individual differences in learning rate. Post-TLE latency differences between the most and least difficult items were not large but it must be remembered that these differences were derived from mean latency scores averaged over the first 16 post-TLE trials; it may be the case that the differences are more pronounced immediately after the TLE. The interesting aspect of this relationship between item difficulty and post-TLE latency is that during the post-TLE period, the response strengths of the most and least difficult items would have been defined as equivalent on the basis of correct response probability and the number of trials of overlearning which each item had received. An obvious area for future research would be to attempt to determine if some indicant of response strength such as retention or transfer would confirm the latency measure suggestion that the response strengths of the two types of items still differed. It is possible, the work of Shiffrin and Logan (1965) suggests, that post-TLE differences in response latency between the most and least difficult items were not an indicant of response strength but simply due to the items being practiced with different response speeds during the pre-TLE period. The current study did find that difficult items had longer latencies prior to the TLE and the practice effect alone could account for the post-TLE difference.

In addition to intra-*S* differences in latency as the result of item difficulty, post-TLE latencies were demonstrated to be related to *S* learning rate. Slow learners tended to be slow responders during the post-TLE period. The difference between fast and slow learners was significant on only the outside positions, Keys 1 and 2. The mean scores on the inside keys, although not significantly different, demonstrated a tendency toward the same relationship. It does not appear that the slower, post-TLE latencies were a function of slow response practice prior to the TLE since the mean latencies of the slow and fast learners were essentially equal prior to the TLE. If the post-TLE differences were a function of *S* learning rate and if post-TLE latencies are indeed a measure of overlearning, this suggests that the number of trials required for an *S* to reach a response probability criterion may be correlated with the rate at which the associations are strengthened during overlearning. To achieve the same degree of retention, a slow learner may require more overlearning practice than a fast learner. Post-TLE response latencies may provide a means of determining the amount of overlearning practice which would be required for a particular *S* to assure a given degree of retention.

Some Suggestions concerning Measurement of the Learning Process

With respect to the measures of correct response probability and response latency, the learning process appears to have two very distinct periods: early learning, the period prior to the point at which response probability reaches asymptote, and overlearning, the period during which latency undergoes its greatest systematic variation. The bulk of experimentation in verbal learning has dealt with only one measure, response probability, and only the first phase of the learning process.

It would appear that latency is not a sensitive measure of associative strength during the pre-TLE period. During this period, response probability seems to be the most accurate measure available. Response probability was sensitive to differences in the training method in that recall *S*s reached a response probability criterion with fewer trials than did the anticipation-method *S*s. Pre-TLE response latencies were insensitive to the training method. Latencies did not reflect the increase in associative strength indicated by the increase in correct response probability from a chance level to .54 just prior to the TLE. Finally, latencies did not differentiate between correct and incorrect responses during this period.

Response latencies were indicative of the complexity of the task during the pre-TLE period in that latency was a function of the number of response alternatives. This might imply that latency would be useful as a measure of other task parameters which influence learning. Latency may be a more sensitive measure of the early stages of learning in more complex tasks. The learning task in the current experiment was intentionally kept very simple in that response learning was minimized. If the task had required an appreciable amount of response integration, the results obtained might have been quite different in that pre-TLE latencies might well vary systematically as a function of response learning. In such a learning situation, latency may be a useful supplement to response probability measures.

During overlearning, after the TLE, the relative utility of the response probability and latency measures is reversed. The response probability measure becomes insensitive because it has reached asymptote and at about the same time, response latency seems to become a sensitive measure of associative strength. One cannot be sure that latency is measuring associative strength during this period until latency measures are checked against some other measure such as retention but there are several indications that this is the case. The rapid post-TLE decline in latency, of course, suggests the continued development of associative strength. Just as response probability was sensitive to differences in training method prior to the TLE, the post-TLE reduction in latency was more pronounced under the recall paradigm than under the anticipation paradigm. Post-TLE latencies appeared to be sensitive to differences in learning rate which were determined by response probability measures earlier in learning. This was true for both individual differences in *S* learning rate and differences in item difficulty. Latencies were a positive function of the number of response alternatives throughout the post-TLE period, as well as prior to the TLE, but the rate at which latency declined did not differ significantly between the different information levels.

While it is evident that response-probability measures are more useful than latency measures prior to the TLE and that latency may well be a useful measure after the TLE, the utility of latency measures in the transition area around the TLE is not at all clear. Is there an abrupt change in latency at the point at which response probability reaches asymptote or are the two transition points only roughly equivalent? The situation might be clarified by using more precise measurement techniques such as using a greater number of response alternatives to reduce chance effects. If this were done, the TLE would be a more accurate indication of the point at which correct response probability reached asymptote. An extensive investigation of individual item protocols should also prove to be useful. It may well be the case, however, that response measures in this area demonstrate the instability characteristic of other thresholds.

In summary, the following statements can be made about latency measures in the task used in the current experiment: (*a*) prior to the TLE, latency was a measure of task complexity but did not measure the development of associative strength; (*b*) during overlearning, response latency did appear to measure the continued development of associative strength. These results concerning latency measures provide a host of experimental questions for future research. The most obvious of these is whether or not the post-TLE decline in latency is actually indicative of the growth of associative strength. Can the degree of retention be controlled by training to a latency criterion? Do response latencies reach a stable asymptote and if so, does this asymptote have any implications for retention? How does latency change over the course of learning in more complex tasks such as concept formation? Do latency measures have utility for instructional decisions in the early stages of such tasks?

Latency Measurement in Instruction

Since this experiment concerned a rote drill situation, the generality of the results and conclusions are somewhat limited with respect to other types of instructional situations but one broad statement may be made. It would appear that response latencies can be accurate measures of the learning process and hence can form an adequate basis for instructional decisions but their applicability may be limited to specific stages of learning. In a rote drill context, latencies early in learning, prior to the TLE, appear to contain little information of value for instructional decisions. Latencies may be quite useful in a situation in which instructional materials have been carefully programmed so that correct response probability is always relatively high but they would seem to be least useful in situations in which probability of a correct response is very low.

After the TLE, on the other hand, at the time when response probability measures have reached asymptote in a rote drill situation, response latencies demonstrate their largest and most systematic variation. Interresponse variability also decreases during this period and this would increase the reliability of latency measures. These findings may have definite implications for instructional decision making. In a spelling drill, for example, the goal of the instruction is not only that the student learn the association but also that the associations be retained. While it is known that overlearning increases retention, the amount of overlearning to be provided has always been a relatively arbitrary decision. The capability of measuring response latency may provide a means of determining the optimal amount of overlearning practice for a particular student and a particular group of words. If it were found that response latencies were not shortened by an instructional program designed to bring a student to a high level of proficiency in a certain skill, the utility of the instructional procedures might be questionable.

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