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THE EFFECTS OF TASK CHARACTERISTICS ON RESPONSE LATENCY AND LATENCY TRENDS DURING LEARNING AND OVERLEARNING.

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Even though response latency can vary greatly among subjects and from trial to trial for the same subject, latency as a measure of associate strength might be useful in connection with response frequency to measure degree of learning. The effects on latency and learning of two task variables--training procedure (anticipation vs. recall) and information transmission (amount of information required for errorless responding)--were investigated using a factorial design. Several aspects of latency as a possible basis for instructional decisions were studied: the "TLE," or trial of last error, i.e., the trial immediately preceding the correct criterion response of N successive errorless trials; the correctness of response; item difficulty, individual differences, and the TLE; maximum response latency on the TLE; and errors made subsequent to the first correct response. A series of eight stimuli that transmitted different amounts of information were presented to the 96 subjects on the display screen of an on-line computer. Subjects responded via a keyboard, which also gave them feedback. The main conclusion from many interesting results was that latency is not a sensitive measure of associative strength during the pre-TLE period, but it may well be an accurate measure during overlearning, after the TLE. (LH)

THE EFFECTS OF TASK CHARACTERISTICS ON RESPONSE LATENCY AND LATENCY TRENDS DURING LEARNING AND OVERLEARNING

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Abstract

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. Both pre- and post-TLE latencies were an increasing function of intrasubject differences in item difficulty. Pre-TLE latencies were an inverse function of subject learning rate. Post-TLE latencies were independent of subject 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 learning task, may be a sensitive measure of strength of learning during the overlearning phase, but not during initial learning.

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Origin and History of the Problem

Decision Processes in Instruction

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 essentially unknown. The 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 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 strength of the behavior. One approach--perhaps the most common in practical group instructional situations--is to simply give all students that amount of practice which past experience has shown to be sufficient for the average student. This is undesirable since it 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 response. Frequency is not, however, a completely adequate measure. If the initial probability of the response is fairly high or if the student is able to make use of a constructive guessing strategy based on the previous occurrence of some items, the frequency measure may be biased so as to cause the response strength to appear to be greater than it actually is.

Frequency measures also 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. One could continue instruction to a criterion of n successive errorless responses where n has been found to be a sufficient number of trials to attain the desired degree of retention on the average, but again this process does not satisfy the criterion of adaptive instruction in that it fails to adjust to individual differences. If a given number of reinforcements produces different degrees of response probability in different subjects during the early stages of learning, it seems reasonable to expect that a similar situation exists after frequency has reached asymptote.

Two other measures of response strength may be available at the time learning is taking place: response amplitude and latency. Response amplitude would not appear to be a particularly relevant measure within the area of verbal learning but there are several indications that latency may be quite useful as a supplement to frequency measures. Osgood (1953) points out that latency measures have the advantages of being applicable in a wide variety of situations, of providing a continuous trial-to-trial measure as opposed to the dichotomous measure of frequency and of retaining sensitivity after frequency measures have reached asymptote. The major disadvantage of latency measures is their extreme variability between subjects and from trial-to-trial for the same subject. This variability may be so severe as to render latency measurements useless as a basis for instructional decisions. The purpose of this study was to examine response latency behavior throughout the course of learning in a paired-associate learning task. A limited number of task variables which may influence the magnitude and variability of response latency were also investigated. Special consideration was given to the effects of these variables on the sensitivity of latency to changes in response strength.

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 promptings required to raise the strength of the association above threshold, i.e., 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 ten CC bigrams. Each subject received twenty trials but only those subjects who had ten successive errorless trials were evaluated. A significant decline in latency was found over the sequence of ten successive errorless trials.

If response frequency and latency are both indices of associative strength, we should expect to find reasonable correlations between the two measures. Beck, Phillips, and Bloodsworth (1962) and Johnson (1964) presented subjects with nonsense syllables previously scaled for association value by Archer (1960) and measured the latency of the subjects' first free associations. The obtained correlations ranged from -.19 to -.70. Johnson then constructed paired-associate lists in which the response items were the CVC trigrams for which first-response latencies had been obtained. The obtained correlation between learning rate and Archer's a value (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. The premise of two separate factors 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 one or four 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 0.75 or 2.85 seconds. After the subjects reached criterion, they were instructed to identify as many pairs as possible in two minutes, the next pair appearing immediately following the subject's response. Under these conditions, the fast practice group made significantly more responses than did the slow practice group.

It would appear that response strength is only one of several factors which influence latency, and if latency is to be a practical tool for evaluating associative strength, these other factors must be identified and subjected to experimental control. This experiment was therefore concerned with investigating both the relationship between learning and latency and factors other than learning which might influence latency.

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 Estes' one-trial learning models and from attempts to construct mathematical models of the associative learning process. As a result of the nature of the questions being asked, the data have been examined from new viewpoints which have revealed trends of considerable interest. These trends are discussed below.

A new and useful technique 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 to be discussed below.

Latency trends prior to the TLE. One of the first investigators to use the technique of aligning protocols on the basis of TLE was Millward (1964) who 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 the subjects 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 the subjects 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 subjects 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, Groen and Schlag-Rey (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 eighteen trials at which comparisons may be made, incorrect response latency was longer than correct response latency fourteen 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 subjects were given one practice trial during which they could examine the 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 one through twelve. 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, Groen and Schlag-Rey experiment, it did suggest that correct and incorrect response latencies may not always be equivalent.

<u>Latency as a function of learning rate</u>. 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 the subject 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 subjects 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, Groen and Schlag-Rey (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, both significant at the .01 level. 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, and the raw data were not made available. While it may well be that slow learners are slow responders, it must be noted that Simley found the same relationship between item difficulty and response latency within individual subjects.

Millward's results do offer the interesting suggestion 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, Groen and Schlag-Rey 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 the two sessions were .71 and .69.

Latency on the TLE. The trial of last error itself may have interesting properties. Suppes, Groen and Schlag-Rey (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. A paired-associate learning experiment reported by Williams (1962) used a list of 25 pairs of four letter words. His analysis of the latency data was based on the trial of the first correct response for a given item as opposed to the trial of last error. 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 the subject 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, we would expect the response latencies to be longer and we would also expect that there would be a higher probability of one or more subsequent incorrect responses.

This explanation is contradicted, however, by the previously discussed Eimas and Zeaman (1963) experiment. To test the hypothesis that correct response latency is indicative of response strength, Eimas and Zeaman classififed all items answered correctly on test trial one as either fast or slow. The slow items were not recalled particularly slowly on test trial two nor did they tend to be recalled incorrectly. Instead, they showed a significantly greater increment in speed on test trial two than did the items classified as fast on test trial one.

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?

Methods of Item Presentation and Response Measurement

The most troublesome problem in attempting to use latency measurements as predictors of single item response sequences for individual subjects may be latency's large trial-to-trial variability. 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 and Brackett, 1961; Battig and 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.

Disjunctive Reaction Time

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 the subject 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 point at which the frequency measure has reached asymptote, that is, 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 (1885), 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) drew an analogy between a DRT task and a model of a communications system. In this analogy, each alternative stimulus or signal is a message. The greater the number of alternative messages possible, the greater is the uncertainty as to which message will be transmitted. Thus, when a given message is transmitted, the reduction in uncertainty is a positive function of the number of possible alternative messages. The amount of information transmitted is defined as the amount by which the uncertainty is reduced. The information value (h_i) of a particular message (i) is given in units of "bits" as being equal to the $\log_2 \frac{1}{p_i}$ where p_i is the probability of occurrence of message i. When all messages or stimuli have an equal probability of occurrence, the formula may be simplified to $H = \log_2 n$, where n is the number of possible messages.

Hyman 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 the subjects 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 the subject per S-R event.

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, the findings have not been sufficiently consistent to allow one to state, with any degree of certainty, hypotheses concerning the factors which underlie these phenomena. 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. While this 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. 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. Within the context of the parametric investigation, several questions were asked concerning systematic changes in response latency as a function of learning in a paired-associate task.

Response Latency as a Function of Training Method

As was previously discussed, inter-response variability in response latencies presents a probem for any attempt to investigate the factors underlying latency behavior or to use latencies as a basis for instructional decisions. This is particularly true during the early stages of learning, prior to the TLE. Peterson (1965) suggested that the variability in pre-TLE response latencies in a paired-associate learning task may be at least partially due to interference effects deriving from the nature of the anticipation paradigm training method. It was further suggested that the interference effects might be eliminated or at least reduced by the use of a recall paradigm. 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 paradigms although in this case, no specific hypotheses were formed.

Response Latency as a Function of Information Transmission

As was pointed out in the introductory section on disjunctive reaction time, a subject's behavior during the overlearning phase of a paired-associate learning task is very similar to the behavior required of a subject in a DRT task. It was also shown that DRT is, in general, a positive linear function of the number of bits of information transmitted by the subject per S-R event. It seemed quite likely, therefore, that response latency after the TLE would be a positive function of the amount of information transmitted. Since the subject'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. Two, four, or eight equally probable response alternatives corresponded to the transmission of one, two, or three bits of information respectively.

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.

Response Latency as a Function of Learning

The recent studies of response latency during the course of paired-associate learning have several implications of relevance to instructional decisions based on response latency. Previous research has, however, resulted in conflict on several points, and it appeared that further investigation would prove to be fruitful. The current experiment attempted to answer a number of questions concerning systematic changes in latency during the course of learning. This was done within the context of the parametric investigation of task variables discussed above. The five points investigated are described below.

What is the nature of the function relating latency to practice prior to the TLE? Millward (1964) and Suppes, Groen and Schlag-Rey (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.

Do correct response latencies differ from incorrect response latencies prior to the TLE? Suppes, Groen and Schlag-Rey 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.

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 <u>after</u> the TLE in the data presented by Simley (1933), Millward, Kintsch and Suppes <u>et al</u>. It was found prior to the TLE in the data obtained by Millward, Kintsch, and Suppes, Groen and Schlag-Rey. Is this effect a between subjects variable (slow learners are slow responders) as suggested by Millward or a within subjects variable (difficult items have long response latencies) as suggested by Simley's data?

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, Groen and Schlag-Rey, and Kintsch. Millward did not find the phenomenon.

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

<u>Summary of Hypotheses and Experimental Questions</u>

It was hypothesized that an anticipation procedure, as compared with a recall procedure, would result in longer and more variable latencies.

(1) The variance of response latencies prior to the TLE would be greater under the anticipation procedure than under the recall procedure.

(2) Prior to the TLE, response latencies would be longer under an anticipation procedure than under a recall procedure.

(3) What are the relative effects of the anticipation and recall procedures on response latencies subsequent to the TLE?

It was hypothesized that latency would be a positive function of the number of bits of information which a subject is required to transmit.

(1) Response latency prior to the TLE would be an increasing function of the number of response alternatives.

(2) Response latencies subsequent to the TLE would be an increasing linear function of the $\log_2$ of the number of response alternatives.

The effects of learning on latency were studied by investigating the following questions under each of the experimental conditions.

(1) What is the general relationship of latency to practice prior to the TLE?

(2) Do the latencies of correct responses differ from the latencies of incorrect responses during practice prior to the TLE?

(3) Are the response latencies of individual subjects a positive function of item difficulty for those subjects? Is this effect found both prior to and after the TLE?

(4) Are the mean response latencies of different subjects an inverse function of the learning rate of those subjects? Is this effect found both prior to and after the TLE?

(5) Is response latency on the TLE greater than the latency of an immediately preceding incorrect response? Is response latency on the TLE greater than the latency of an immediately subsequent correct response?

(6) Is the latency of the first correct response to an item longer if subsequent errors are made to that item?

Method

The experiment consisted of 16 replications of a two by three 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 subjects were used in each of the six treatment groups.

Subjects

Subjects were drawn from the University of Pittsburgh's introductory psychology classes during the fall and winter trimesters of the 1966-1967 school year. Students in these classes were required to donate four hours of their time to being experimental subjects and were not paid for their services. A total of 103 subjects 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 the experimenter. The remaining 96 subjects were evenly divided between males and females. Eight males and eight females were assigned to each of the six treatment groups.

The subjects 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 subject experienced difficulty in correctly identifying the stimuli.

Materials

The stimuli used in the tasks were CVC trigrams of 20 to 30 per cent 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 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. As was previously discussed, subjects 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 a subject's responses were correct.

Apparatus

The experiment was controlled by the Learning Research and Development Center's Computer Facility. This is an on-line, time shared system using a Digital Equipment Corporation, PDP-7 digital computer. The system presented the stimuli and knowledge of results, processed the subject's responses, maintained records of each subject's progress and timed response latencies and interitem intervals. Response latencies were measured with an accuracy of $\pm$ 0.001 seconds. All other timing was controlled to within $\pm$ 0.02 seconds. A complete record of each subject'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 subject was being run. The output of this data reduction program was a printed summary of each subject's record.

The stimulus trigrams were presented on the screen of a cathode ray tube three inches high by four inches wide. The trigram letters were all upper case. Each letter was generated as a set of points selected in a seven by five point matrix. The letters were one-half inch high by three-eighths inch wide. The screen of the tube was positioned 20 inches in front of the subject, at eye level.

Subjects were required to indicate their responses by pressing buttons mounted on one of three response panels. The panels were 15 1/2 inches wide by 15 inches deep and sloped upwards on an angle of 20 degrees. They rested on a table in front of the subject 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 one-half inch diameter caps which extended one-half inch above the panel. A force of five ounces over a distance of one-eighth inch was required to actuate the switches.

On all the panels, the switches were mounted on a semicircular arc with a two inch radius. This allowed a center to center distance of three-quarters of an inch between the switch caps on the eight key panel. The switch caps were not numbered or otherwise identified for the subjects.

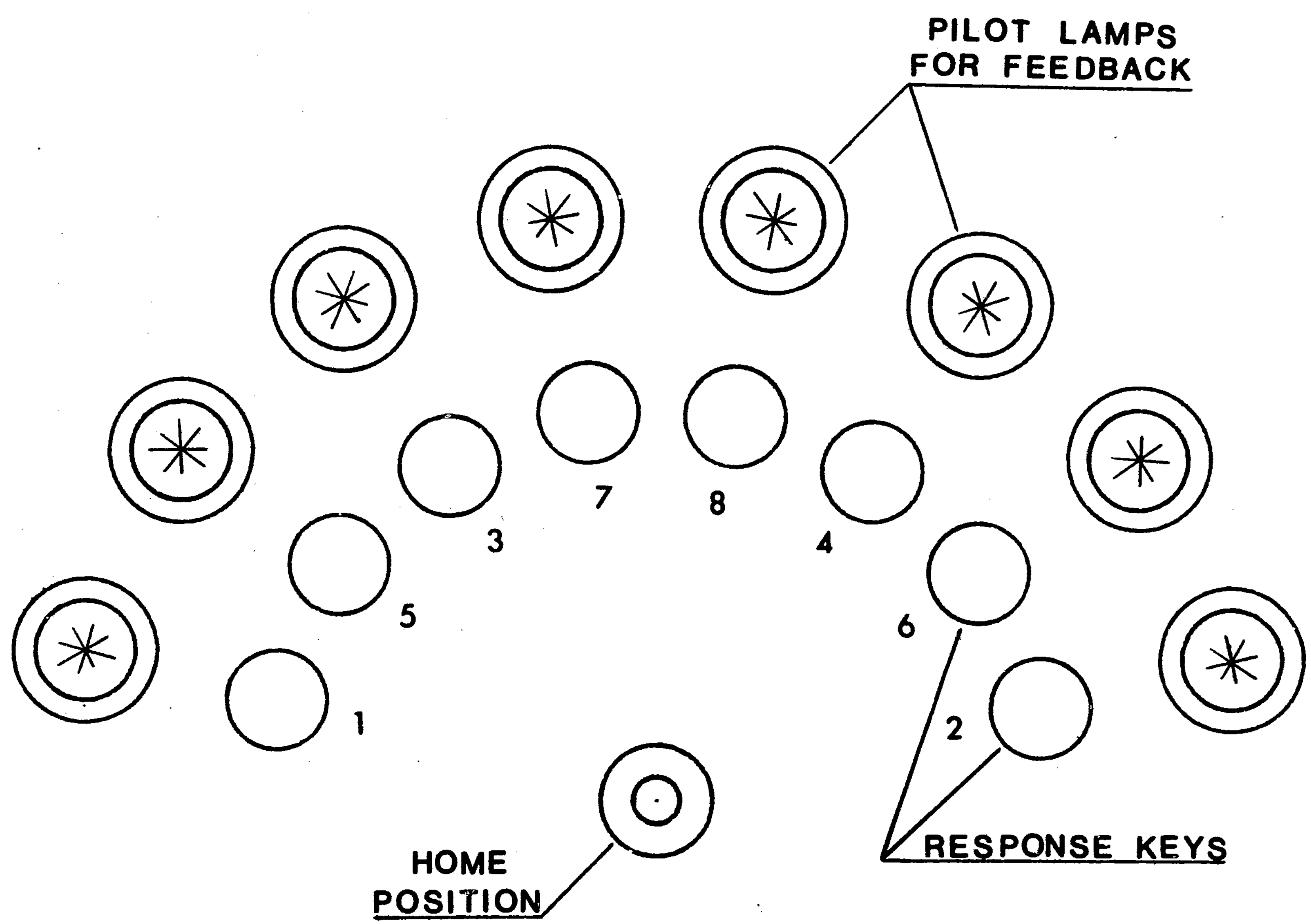

Fig. 1. Full Scale Diagram of Response Positions for Information Level Three.

The keys were assigned arbitrary numerical identities for the purpose of program control and response recording but the subjects 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 through 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 subjects 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 subjects at the start of a test trial and to indicate the end of a task. An inter-office telephone enabled the subject to contact the experimenter when the subject finished the experiment or in the case of unforseen problems.

Randomization Procedures

The experiment consisted of 16 replications of the three by two factorial design. The order in which the treatment conditions were administered within each replication was predetermined by reference to a random number table. When a subject 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. Within a single replication, an attempt was made to keep the stimulus-response assignments the same across the six treatment groups. Perfect correspondence was not possible since the different information level treatment groups had different numbers of response alternatives but as close a correspondence as possible was maintained. Table 1 illustrates a typical example of response assignments.

The order of item presentation during each trial was controlled by systematic reference to a table of randomly determined orders. The

TABLE 1

Example of Stimulus-Response Assignments

	Number of Response Alternatives		
	2	4	8
Stimuli	Responses	Responses	Responses
ZAB	1	1	1
ZAF	2	2	2
ZOX	1	3	3
ZEG	2	4	4
ZIK	1	1	5
ZOK	2	2	6
ZEF	1	3	7
ZIX	2	4	8

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 subjects responded to items in the same order under both the anticipation and recall procedures. The sequence of orders was repeated once every thirty trials.

Experimental Procedure

Subjects were run one at a time. After the instructions were given, the subject 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. Information concerning the particular experimental treatment which a subject was to receive was loaded into the computer and the system was placed in a waiting mode before the subject was brought into the laboratory. After the subject 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. The experimenter then started the experiment from the subject's console. He remained with the subject until he was sure that the subject understood what was required of him and then left the room.

All the experimental conditions included a warm-up period. During this period, the subjects were trained by the same method (anticipation or recall) that they would experience in the main task. They also used the same response panel with 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 the subject's response panel.

The warm-up task was paced by allowing the subjects only three 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 the subjects 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, subjects 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 two trials long in the training task and ten trials in the main task. The trial prior to the first trial in the series of six successive errorless trials was designated the trial of last error (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, Groen and Schlag-Rey (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 0.5 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 the subject's response (or for a maximum of three seconds in the warm-up task). The pilot lamp next to the correct key was then illuminated. The word on the screen and the light stayed on together for two 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 four 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 two 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 0.5 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 the subject responded (or for a maximum of three seconds in the warm-up task). 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 four second intertrial interval. The warning buzzer was not used to signal the start of the training phase of the next trial since the purpose of the buzzer was to warn the subject to get set to respond.

Statistical Procedures

In general, the experiment was a factorial design with two levels of training procedure (anticipation and recall paradigms) and three levels of information transmission requirements (two, four, and eight response keys corresponding to one, two, and three bits of information). In addition, a third factor relating to a specific question such as the relative latencies of correct and incorrect responses, was usually involved. Training procedure and number of response alternatives were both between subjects variables. The third factor was either a between or within subjects variable, depending on the nature of the specific question.

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 considered likely 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. While this finding per se was not relevant to the points under investigation, it 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 relationship 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. For this reason, two subtasks were defined across the two information levels. Items for which the correct responses were keys 1 or 2 were considered to be analogous across all three information levels and likewise, items for which the correct responses were keys 3 or 4 were considered to be analogous across the two higher order information levels. The questions of interest could then be evaluated within these subtasks.

For each experimental hypothesis or question to which this problem was considered relevant, a preliminary analysis of variance (ANOVA) was conducted which included key position as an additional within subjects variable. Key positions 1 and 2 were contrasted with key positions 3 and 4. Since keys 3 and 4 were not present in the two response alternative task, this analysis considered only data which derived from the four and eight response alternative tasks. Data from keys 5 through 8 in the eight response task were not included in the analysis. The question of interest in this analysis 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. Such an interaction indicated that either the variable in question or some interaction of that variable with the information level or method variables was a function of key position.

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 ANOVA 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 high probability level of 0.10 was selected as a significance criterion for the preliminary, key position ANOVA.

Subjects were run until all items had received at least 10 trials after reaching the criterion of six successive errorless trials. This assured at least 16 observations for each item for each subject after the TLE but there was no way to control the number of observations prior to the TLE. For this reason, all the analyses which dealt with data prior to and including the TLE suffered from missing data. Rather than attempt to compensate for the missing data statistically, observations were discarded until the number of observations in each treatment group equalled the number of scores present in the treatment group containing the fewest observations. The use of such a procedure might not be considered completely legitimate since scores would be dropped on a random basis from those groups containing a larger number of observations but dropped selectively from the treatment groups with the smallest number of available scores. There appeared to be no obvious cases in which the data might be biased due to this selection, but the reader should remain cognizant of the fact that the procedure was technically questionable.

The latency scores were positively skewed but the normal procedure of using a reciprocal transformation (Edwards, 1962) was not completely satisfactory. In some cases, e.g., when the scores were means of large numbers of observations, reciprocally transformed scores tended to form a rectangular or bimodal distribution. Therefore, frequency histograms were plotted for the data in each analysis using several different transformations. The transformation which yielded the distribution most normal in appearance was used in the ANOVA for that problem. The square root, log, and reciprocal transformations were evaluated. The histograms were plotted on the University of Pittsburgh IBM 7090 computer using a modified version of the U.C.L.A. Bio-Medical statistics program BMD(05D) (Dixon, 1965). Transformed data were used only in the statistical tests. Data presented in tables and graphs are raw score means in units of milliseconds. Almost all of the statistical tests employed were anlayses of variance of either a straight factorial design or a factorial with split plot design. All ANOVAs were run on the above mentioned computer using the BMD(02V) program (Dixon, 1965). 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 0.05.

Results

The first and second sections of this chapter deal with general latency behavior over the course of learning. The third and fourth sections are concerned with the effects of the experimental variables of training method and information transmission requirements on response latency. The remaining sections present data relevant to several specific relationships between learning and response latency.

Data pertinent to each of the experimental hypotheses and questions are summarized in a series of tables. The tables contain the means, in milliseconds, of the relevant treatment groups and a summary of the relevant analysis of variance. Each of the different analyses had its own particular data reduction procedures and these are explained in the text accompanying each table.

Throughout the tables, the convention has been adopted of using the initials I and M to refer to the information level and method variables in notation representing interactions. Additional initials have been used where appropriate.

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 per cent 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 subjects at different points after this trial.

Figure 3 illustrates these same relationships with the protocols alligned on the basis of the TLE. Again, all experimental treatment conditions have been grouped together. Both the latency and response probability curves are unreliable in the extreme left-hand portion of the figure since relatively few protocols were available to determine the points on

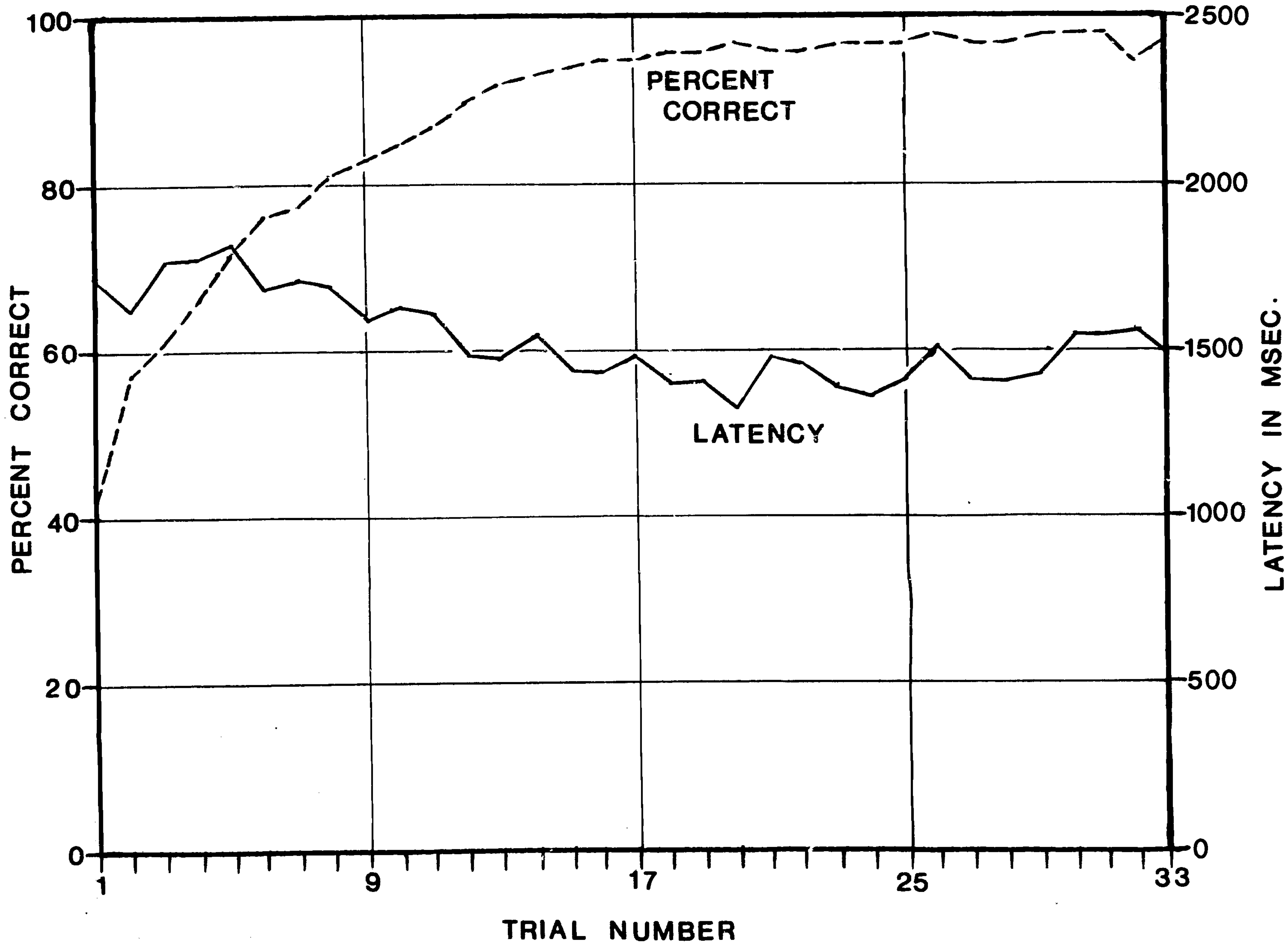

Fig. 2. Correct response probability and response latency as a function of trial number.

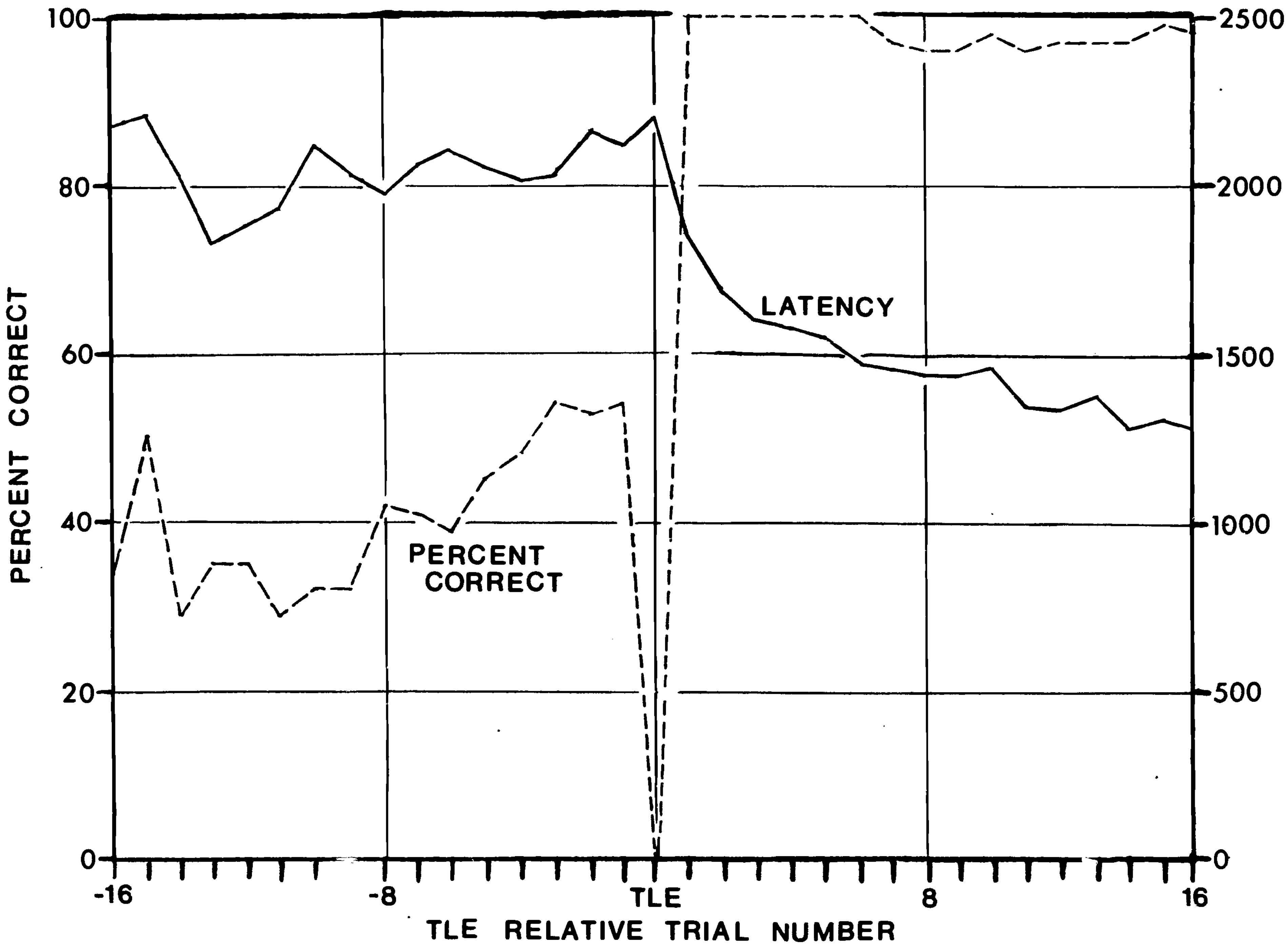

Fig. 3. Correct response probability and response latency as a function of TLE relative trial number.

the curves. Twenty five percent of the data or 192 responses are represented on trial TLE-8.[1] 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 percent correct on trial TLE-1. Correct response probability was, of course, zero on the TLE and one on trials TLE+1 through TLE+6 since the criterion for defining the TLE was six successive errorless trials. Error rate on trials TLE+7 through TLE+16 was never greater than four percent but this was still somewhat higher than had been expected and suggested that the criterion of six successive errorless trials may have been insufficient.

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 (1964) and Suppes, Groen and Schlag-Rey (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 the subjects 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 subjects were 146 msec. shorter than the corresponding responses of the recall treatment subjects who had already been shown one correct pairing of the items. This would appear to be indicative of the guessing behavior of the anticipation subjects.

Figure 4 illustrates changes in latency over the first eight trials of the experimental task. Millward and Suppes, Groen and Schlag-Rey also found that latencies increased sharply over the first few trials. This was not a consistent finding in the current experiment. Four of the six treatment groups had shorter latencies on trial two than on trial one. Only the two more difficult eight response tasks (information level 3) could be said to have demonstrated substantial increases in latency over the early trials. For information

[1] Eight trials before the TLE.

levels one and two, there was some tendency for the anticipation task latencies to increase but neither of the corresponding recall tasks demonstrated increasing response times 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. It was found that key position was not a relevant variable ($F < 1.0$) and all key positions were included in a single analysis. For each subject, 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 subjects 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 the subjects 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. In a series containing an odd number of trials, the middle trial was randomly assigned to the first or second half. A mean was determined for each half of the trial series and these means comprised the scores which were examined as a within subjects variable in the analysis.

The results of the analysis are presented in Table 2. 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

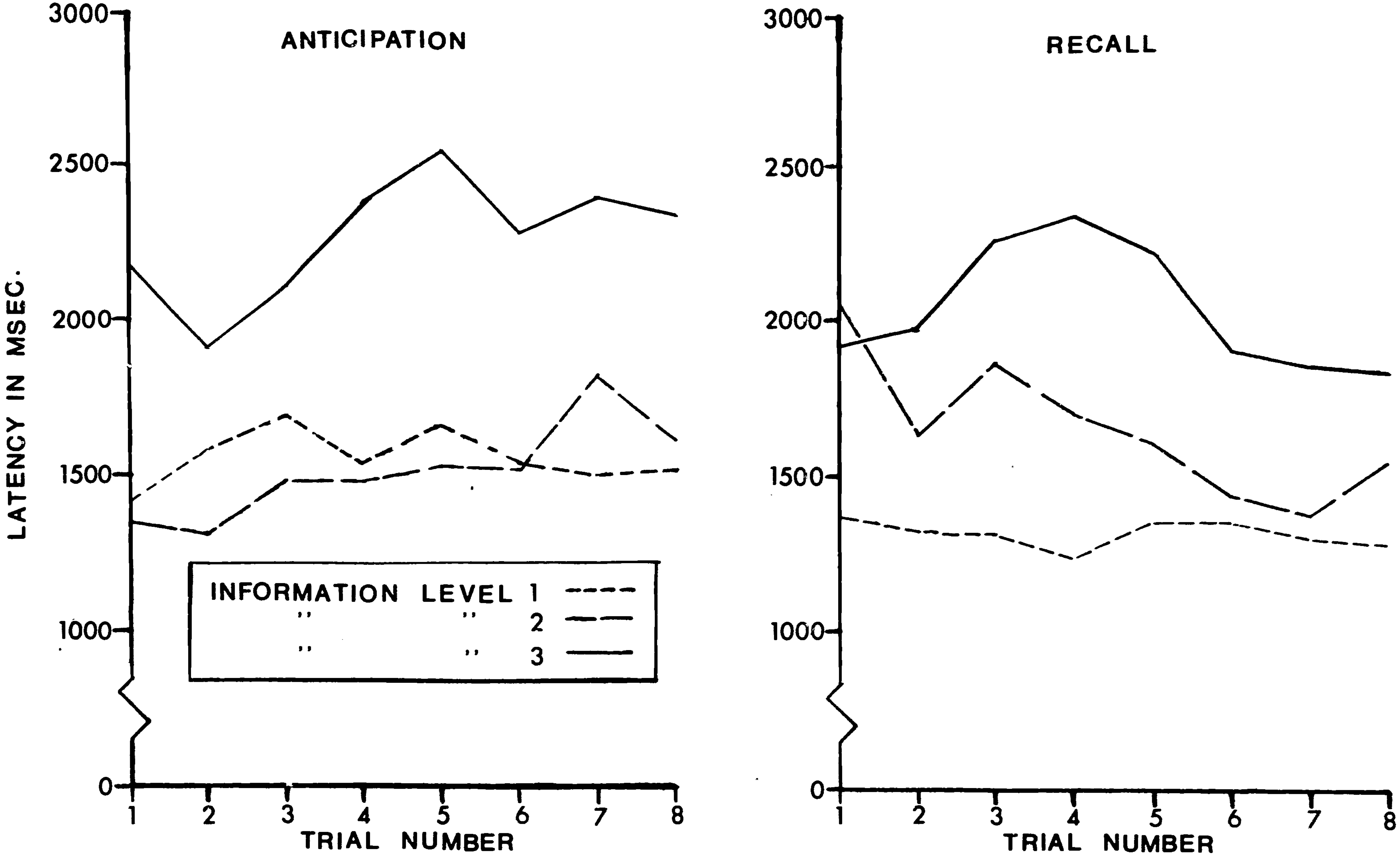

Fig. 4. Response latency of the six treatment groups over the first eight trials of the experimental task.

latencies to increase, but this tendency was apparently not consistent. We may conclude that, in general, response latencies remained constant or increased slightly. There was definitely no reduction in response latency prior to the TLE.

TABLE 2

Pre-TLE Response Latencies as a Function of Practice
Comparison of the First and Second Halves of the Pre-TLE Trial Series

All Key Positions

Treatment Group Means

Treatment	N	First Half	Second Half	Increase
Information Level				
1	12	1488	1673	185
2	12	1834	1999	165
3	12	2050	2522	472
Method				
Anticipation	18	1914	2277	363
Recall	18	1668	1853	185
Total	36	1791	2065	274

Analysis of Variance
(Reciprocal transformation)

Source	df	SS	MS	F
Between Ss Variance	35	21,094.08		
Practice	1	508.64	508.64	3.04
I x P	2	0.52	0.26	< 1.00
M x P	1	3.43	3.43	< 1.00
I x M x P	2	227.92	113.96	< 1.00
Within Ss Error	30	5,015.85	167.19	
Total	71	26,850.44		

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 subjects variable in an ANOVA in which information transmission level and training method were between subjects variables.

Key position did not interact with the trials variable ($F < 1.0$) and all key positions were included in a single analysis. The results of the analysis are presented in Table 3. Averaged across all treatment conditions, response latency decreased by 572 msec. from trial TLE+1 to trial TLE+16. This was a significant reduction.

TABLE 3

Response Latency after the TLE
as a Function of
Trial Number and Training Method

All Key Positions

Treatment Group Means

Method	N	Mean	Trial TLE+1	Trial TLE+16	Decline
Anticipation	48	1629	1968	1433	535
Recall	48	1323	1744	1135	609
Total	96	1476	1856	1284	572

Analysis of Variance
(Reciprocal transformation)

Source	df	SS	MS	F	
Information	2	156,354.69			
Method	1	78,791.26	78,791.26	22.23	***
I x M	2	4,376.86	2,188.43	< 1.00	
Between Ss Error	90	318,996.79	3,544.41		
Trials	15	58,715.13	3,914.34	33.62	***
I x T	30	3,851.17			
M x T	15	7,035.26	469.02	4.03	***
I x M x T	30	3,128.95	104.30	< 1.00	
Within Ss Error	1350	157,190.73	116.44		
Total	1535	788,440.84			

*** $p < .001$

Summarizing the changes in latency over the course of learning, we may state 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 then decreased substantially over the first 16 trials following the TLE.

Intratrial Variability in Response Latency

Since variability in response latency has proven to be a problem in obtaining reliable latency measures (Peterson, 1965), variability 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 subject, a standard deviation 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 standard deviation for each subject. The same procedure was followed for the first 16 trials after the TLE. A summary of the group means is presented in Table 4. One subject in the second treatment group (information level 1, recall method) responded correctly to all the items on the first trial and had no subsequent errors. Consequently, no pre-TLE data was available for this subject.

The most striking feature of the scores in Table 4 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 the subject was required to transmit both prior to and after the TLE.

The relationship of the standard deviation scores obtained under the two training methods was of special interest since 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 subjects both prior to and after the TLE. Prior to the TLE, the test yielded a U that equaled the mean of the distribution. Absolutely no difference was detected between the two treatments. After the TLE, the majority of the recall treatment scores were smaller than the anticipation scores. The test resulted in a z score of 2.90. A score of this magnitude would occur by chance with a probability of only .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.

TABLE 4

Standard Deviation Scores
Representing Intratrial Variability
in Response Latencies

All Key Positions

Treatment Group Means

Treatment		Pre-TLE Trials		Post-TLE Trials	
Information Level	Method	N	σ	N	σ
1	Anticipation	16	792	16	431
1	Recall	15	716	16	351
2	Anticipation	16	1,322	16	642
2	Recall	16	1,078	16	440
3	Anticipation	16	1,339	16	927
3	Recall	16	1,769	16	782
1	•	31	755	32	391
2	•	32	1,200	32	541
3	•	32	1,554	32	854
•	Anticipation	47	1,151	48	667
•	Recall	48	1,198	48	524
Total		95	1,174	96	595

Response Latency as a Function of Training Method

The magnitude of response latency scores obtained under the anticipation and recall paradigms was contrasted both prior to and after the TLE. It was anticipated that latency scores obtained under the recall paradigm would be smaller than the comparable scores obtained under the anticipation paradigm.

Pre-TLE latency as a function of method. Key position was not a relevant variable ($F=1.33$, $df=1, 40$) and all key positions were included in a single analysis. 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 subject for whom pre-TLE data were available. At least 14 subjects were available in each of the experimental treatment groups. Mean pre-TLE latency was treated as a between subjects variable in a factorial ANOVA which examined the effects of both training method and information level. The results of this analysis are given in Table 5.

TABLE 5

The Effects of Information Transmission Levels and Presentation Methods on Response Latencies Prior to the TLE

All Key Positions

Treatment Group Means

Treatment		N	Latency
Information Level	1	28	1506
	2	28	1972
	3	28	2384
Method			
Anticipation		42	1926
Recall		42	1983
Total		84	1954

Analysis of Variance

(Reciprocal Transformation)

Source	df	SS	MS	F	
Information	2	7,600.80	3,800.40	13.48	***
Method	1	0.25	0.25	<1.00	
I x M	2	810.88	405.44	1.44	
Error	78	21,986.67	281.88		
Total	83	30,398.60			

*** $p < .001$

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 msec. It may be concluded that response latency prior to the TLE was independent of the training method.

Post-TLE latency as a function of method. Key position was not a relevant variable (F=1.64, df=1, 1960) and all key positions were included in a single analysis. 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 subjects variable in a factorial ANOVA in which information level and method were between subjects variables. Since post-TLE practice was experimentally controlled, data were available from all of the 96 subjects. The results of this analysis are presented in Table 3 on page 33.

Mean post-TLE response latencies, averaged across the 16 trials, were 300 msec. faster under the recall paradigm than under the anticipation paradigm. This difference was significant. In addition, there was a significant interaction between the method and trials variables. 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 msec.) 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 msec. 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

It was predicted that response latency would be a positive, linear function of the number of bits of information which the subject was required to transmit.

Pre-TLE latency as a function of information level. Key position did not interact with the information level variable prior to the TLE ($F < 1.0$) and all response keys were therefore included in this analysis. Disregarding the initial response to anticipation items, the mean response latency prior to the TLE was calculated for each subject. A factorial ANOVA was conducted in which information level and training method were between subjects variables. A summary of the results of this analysis is presented in Table 5 on page 36.

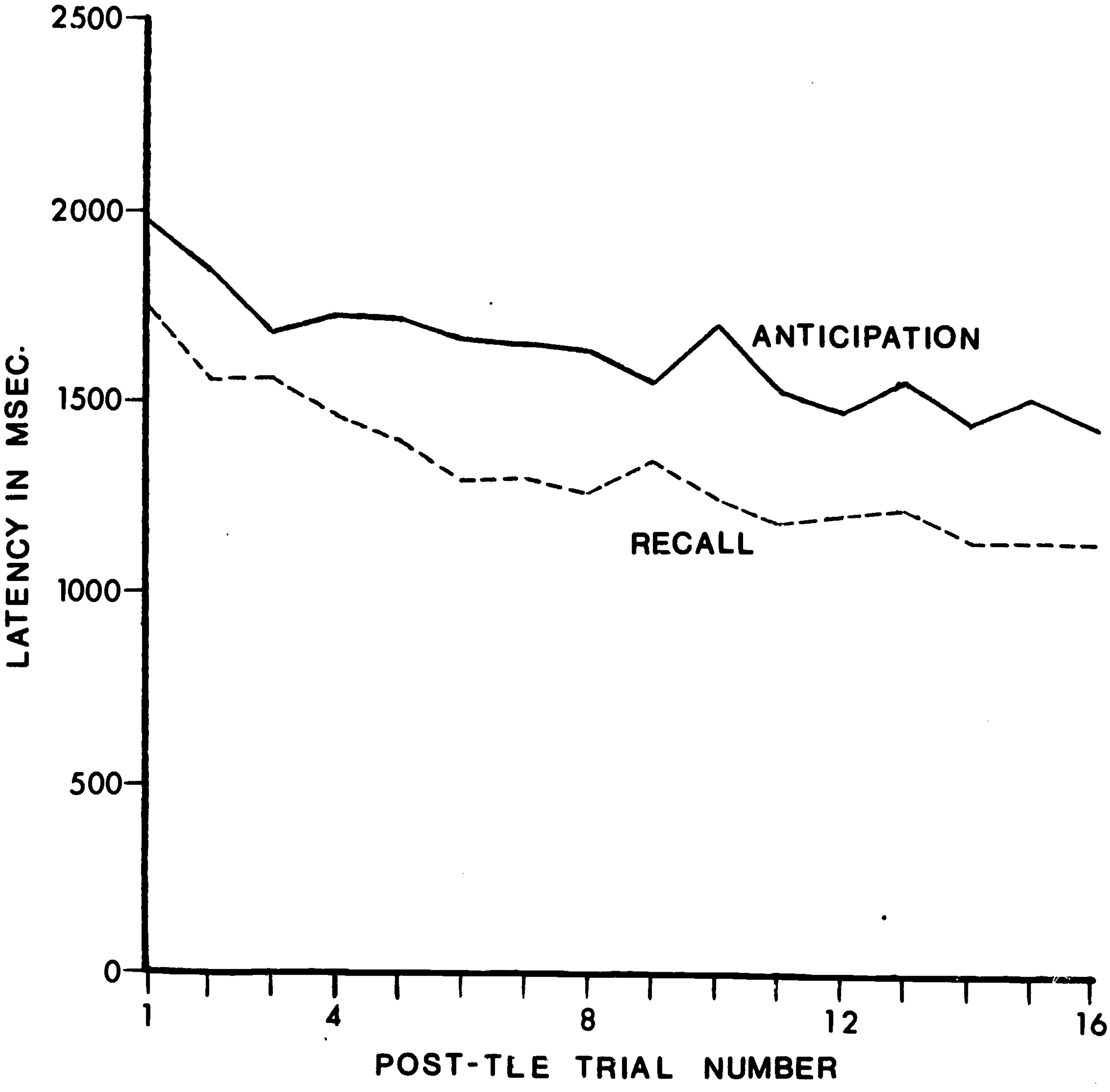

Fig. 5. Response Latency of anticipation and recall method subjects as a function of post-TLE trial number.

Pre-TLE latency increased as a positive linear function of the number of bits of potential information involved in the task, i.e., the amount of information which the subject was required to transmit for errorless responding. This relationship was significant. Since pre-TLE responding had a high error rate, the subjects 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 ANOVA 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 corresponding to the transmission requirements of one, two and three bits of information are 1528, 2079, and 2323 msec., respectively.

<u>Post-TLE latency as a function of information level</u>. The preliminary ANOVA 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 ($F = 36.28$, $df = 1, 1860$). 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. Data from keys 5 through 8 in the three bit, eight response task were discarded. Information level and method were between subjects variables in the factorial ANOVAs. Latency scores for each subject on each of the first 16 post-TLE trials formed a within subjects, trials variable. Summaries of the results of these analyses are presented in Tables 6 and 7 and curves representing changes in latency over trials are illustrated in Figures 6 and 7.

TABLE 6

Response Latency After the TLE
as a Function of
Information Transmission Levels

Key Positions 1 and 2 Only

Treatment Group Means

Information Level	N	Mean	Trial TLE+1	Trial TLE+16	Decline
1	32	1244	1496	1057	439
2	32	1369	1555	1261	294
3	32	1653	2426	1302	1124
Total	96	1422	1826	1207	619

Analysis of Variance

(Reciprocal transformation)

Source	df	SS	MS	F	
Information	2	58,478.42	29,239.21	7.60	***
Method	1	68,184.29			
I x M	2	3,063.56	1,531.78	<1.00	
Between Ss Error	90	346,325.38	3,848.06		
Trials	15	47,754.86	3,183.66	14.35	***
I x T	30	6,612.62	220.42	<1.00	
M x T	15	6,073.85			
I x M x T	30	6,588.81	219.63	<1.00	
Within Ss Error	1350	299,558.71	221.90		
Total	1535	842,640.50			

*** $p < .001$

Response latency increased as a function of information level for both sets of key positions and in both cases the ANOVAs indicate that these increases were significant. 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 7

Response Latency After the TLE
as a Function of
Information Transmission Levels

Key Positions 3 and 4 Only

Treatment Group Means

Information Level	N	Mean	Trial TLE+1	Trial TLE+16	Decline
2	32	1377	1686	1181	505
3	32	1927	2860	1698	1162
Total	64	1652	2273	1440	833

Analysis of Variance
(Reciprocal transformation)

Source	df	SS	MS	F	
Information	1	65,491.02	65,491.02	21.58	***
Method	1	69,439.47			
I x M	1	1,735.52	1,735.52	<1.00	
Between Ss Error	60	182,100.10	3,035.00		
Trials	15	48,036.99	3,202.47	11.71	***
I x T	15	3,360.00	224.00	<1.00	
M x T	15	9,733.34			
I x M x T	15	2,112.73	140.85	<1.00	
Within Ss Error	900	246,132.96	273.48		
Total	1023	628,144.13			

*** $p < .001$

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 two to level three 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 msec. For keys 3 and 4, which were internal components of the key array, the comparable effect was to increase the mean latency

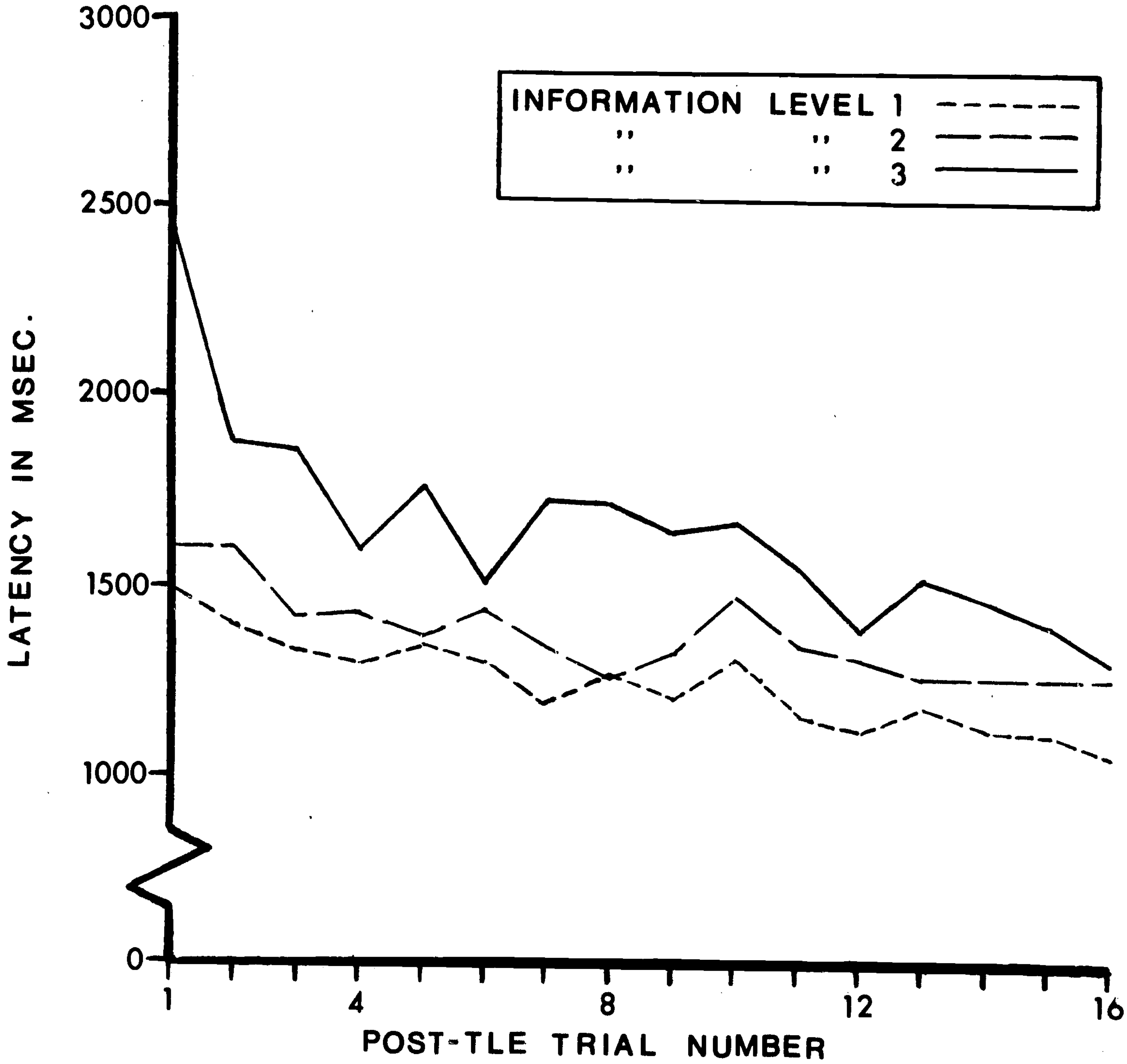

Fig. 6. Post-TLE response latencies of information levels 1, 2, and 3. Key positions 1 and 2 only.

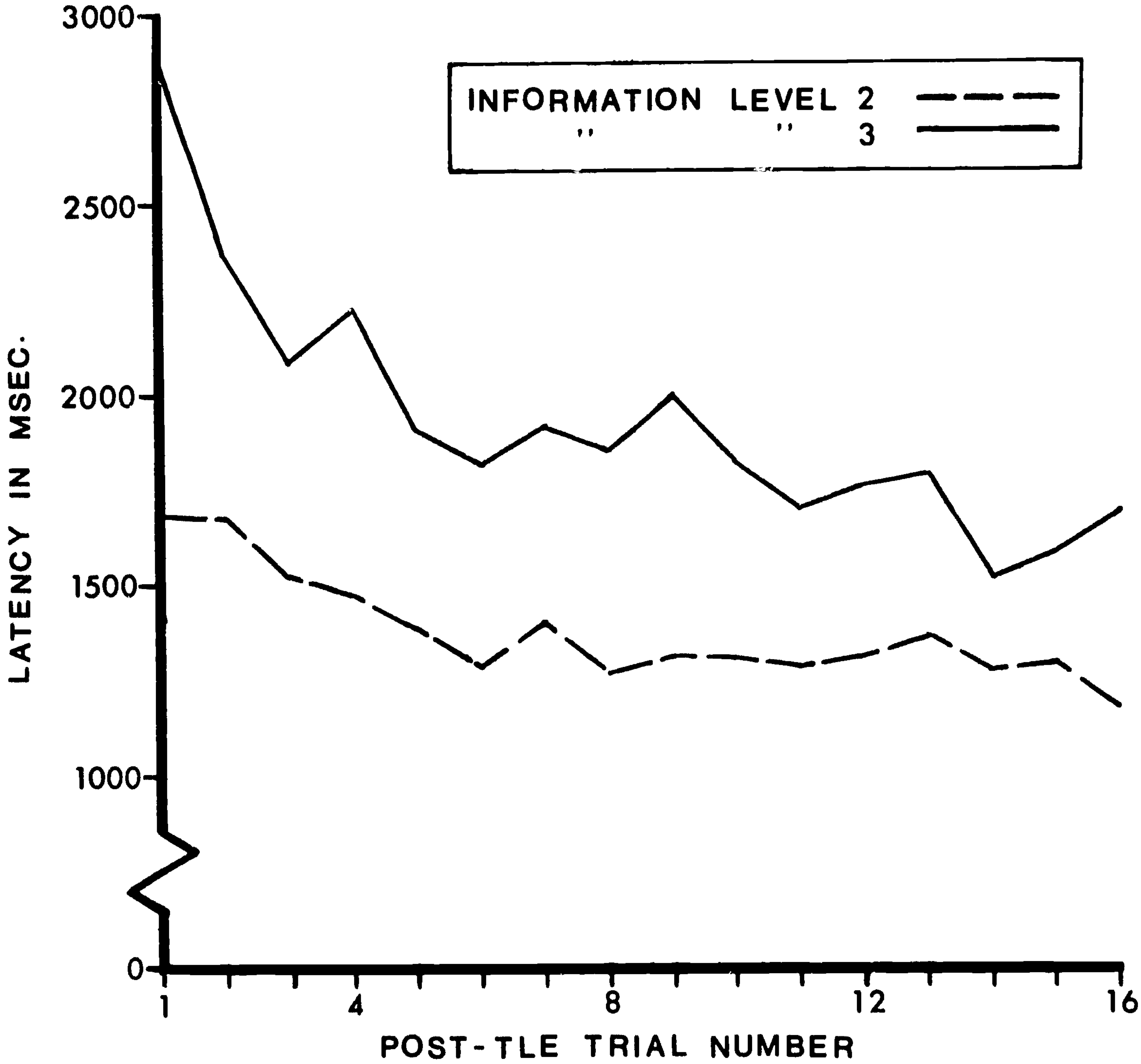

Fig. 7. Post-TLE response latencies of information levels 2 and 3. Key positions 3 and 4 only.

by 550 msec. The effect is also evident in the distance separating the curves representing information levels two and three in Figures 6 and 7.

Figures 6 and 7 also indicate that the decline in response latency over the first few post-TLE trials was much greater for information level three than for the two lower order levels. This difference did not persist over the full 16 trials however. The information by trials interaction was not significant in either of the two analyses.

Pre-TLE Latency of Correct and Incorrect Responses

Prior to the TLE, 45 percent of the responses were correct. For each subject, the mean pre-TLE latencies of correct and incorrect responses were determined for each item. Initial responses to anticipation items were not included. The preliminary ANOVA incorporating key position as a variable found a significant interaction between the key position and correctness variables ($F = 3.15$, $df = 1, 96$). Therefore, one analysis treated only key positions 1 and 2 and a second analysis treated only key positions 3 and 4. These analyses are summarized in Tables 8 and 9.

Correct and incorrect responses prior to the TLE had essentially the same mean latency values. 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 illustrated 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 two seconds. It may be concluded that prior to the TLE, correct response latencies did not differ from the latencies of incorrect responses.

TABLE 8

Correct and Incorrect Response Latencies
Prior to the TLE

Key Positions 1 and 2 Only

Treatment Group Means

Treatment		N	Correct	Incorrect	Incorrect-Correct
Information Level	1	22	1587	1625	38
	2	22	2051	2296	245
	3	22	2156	2638	482
Method					
Anticipation		33	1852	1862	10
Recall		33	2012	2511	499
Total		66	1932	2187	255

Analysis of Variance
(Log transformation)

Source	df	SS	MS	F
Between Ss Variance	65	3,776.12		
Correctness	1	22.99	22.99	1.90
I x C	2	20.36	10.18	<1.00
M x C	1	14.20	14.20	1.18
I x M x C	2	24.11	12.05	<1.00
Within Ss Error	60	724.13	12.07	
Total	131	4,581.91		

TABLE 9

Correct and Incorrect Response Latencies
Prior to the TLE

Key Positions 3 and 4 Only

Treatment Group Means

Treatment		N	Correct	Incorrect	Incorrect-Correct
Information Level					
	2	24	1812	2134	322
	3	24	2601	2167	-434
Method					
Anticipation		24	2127	1947	-180
Recall		24	2287	2354	67
Total		48	2207	2151	-56

Analysis of Variance

(Log transformation)

Source	df	SS	MS	F
Between Ss Variance	47	2,306.16		
Correctness	1	7.86	7.86	<1.00
I x C	1	28.87	28.87	2.30
M x C	1	0.00	0.00	<1.00
I x M x C	1	1.88	1.88	<1.00
Within Ss Error	44	552.61	12.56	
Total	95	2,897.38		

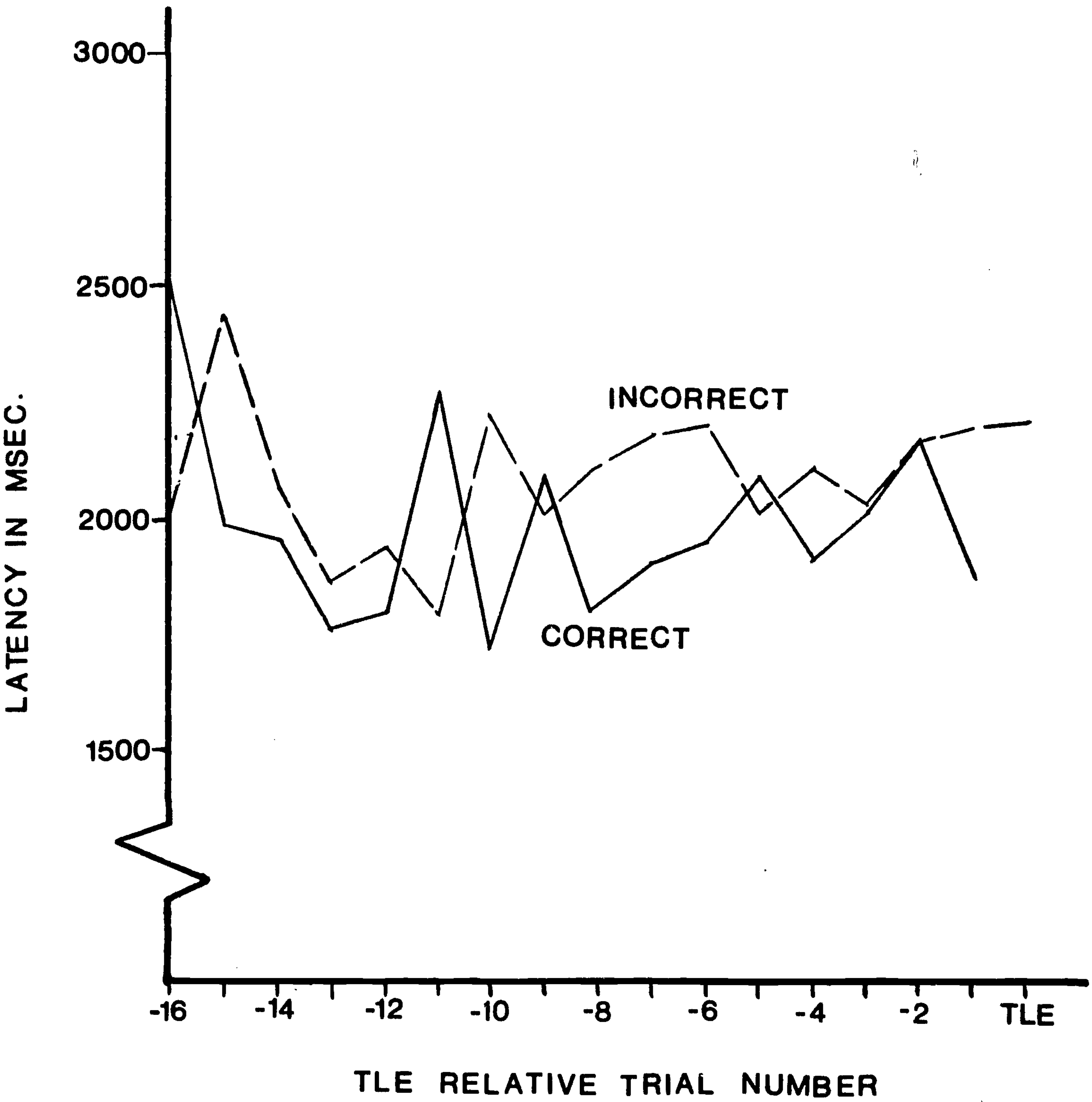

Fig. 8. Correct and incorrect response latencies prior to the TLE.

Response Latency as a Function of Item Difficulty

On the basis of Simley's study, it was expected that for a given subject, the more difficult items would have longer latencies than that subject'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 key positions within the key array had longer latencies and also required a greater number of trials to reach criterion than did the items associated with the end keys 1 and 2. While this relationship was in the direction anticipated by the contention that the more difficult 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. No ANOVA treating key position as a variable was conducted.

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 subject on this basis. Scores were calculated for these items by computing the mean latency for all responses (with the exception of initial anticipation 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 subject 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 as a function of item difficulty. Latency data prior to the TLE and the number of trials required to reach trial TLE+1 are shown in Tables 10 and 11. For some very easy items, no data were available prior to the TLE. For the pre-TLE analysis, therefore, the least difficult items were selected from that group of items which had at least one trial after the first presentation of the S-R pair and prior to the TLE.

TABLE 10

Pre-TLE Response Latencies of
Most and Least Difficult Items for Each Subject

Key Positions 1 and 2 Only

Treatment Group Means

Treatment	N	Most Difficult Item		Least Difficult Item		Most - Least Difficult Item	
		Latency	Trials	Latency	Trials	Latency	Trials
Information Level							
1	13	1817	11.1	1586	2.3	231	8.8
2	13	1808	13.3	2060	3.6	-252	9.7
3	13	2369	8.8	2138	4.4	231	4.4
Total	39	1998	11.1	1928	3.4	70	7.7

Analysis of Variance
(Log transformation)

Source	df	SS	MS	F
Between Ss Variance	38	1,317.93		
Item Difficulty	1	17.73	17.73	1.56
I x D	2	37.66	18.83	1.65
Within Ss Error	36	410.20	11.39	
Total	77	1,783.52		

TABLE 11

Pre-TLE Response Latencies of
Most and Least Difficult Items for Each Subject

Key Positions 3 and 4 Only

Treatment Group Means

Treatment	N	Most Difficult Item		Least Difficult Item		Most - Least Difficult Item	
		Latency	Trials	Latency	Trials	Latency	Trials
Information Level							
2	16	2046	10.4	1516	3.4	530	7.0
3	16	2116	10.6	2034	6.4	82	4.2
Method							
Anticipation	16	2150	12.9	1716	5.6	434	7.3
Recall	16	2013	8.1	1834	4.2	179	3.9
Total	32	2081	10.5	1775	4.9	306	5.6

Analysis of Variance
(Log transformation)

Source	df	SS	MS	F	
Between Ss Variance	31	1,139.86			
Item Difficulty	1	91.48	91.48	13.41	***
I x D	1	54.36	54.36	7.97	**
M x D	1	11.92	11.92	1.75	
I x M x D	1	5.61	5.61	<1.00	
Within Ss Error	28	190.90	6.82		
Total	63	1,494.13			

** $p < .01$
*** $p < .001$

Relatively few subjects were available for this analysis. In some cases, all of a subject's items had the same number of pre-TLE trials but more often, a subject had an inadequate amount of pre-TLE data. The amount of data available was not sufficient for a complete factorial test including all treatment conditions. Only 21 of the 48 recall treatment subjects 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 subjects were grouped together. An equal ratio of anticipation to recall subjects was maintained in each of the three information levels. As is shown in Table 10, pre-TLE response latency did not differ as a systematic function of item difficulty for key positions 1 and 2.

There were at least eight subjects 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. Table 11 illustrates that in this case, the response latencies of the difficult items were significantly longer than the latencies of the responses to those items which the subjects found to be least difficult. In addition, this difference was more pronounced for the four response, two bit task than for the eight response, three bit task.

Post-TLE latency as a function of item difficulty. 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 subject by the procedure described above. A small number of subjects 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 Tables 12 and 13 respectively. In the case of both analyses, the most difficult items had longer latencies than did the least difficult items. Although the differences were small, on the order of 100 to 200 msec., they were significant in both cases. In neither case was there any significant interaction with the information level or method variables.

Response Latency as a Function of Subject Learning Rate

Whereas the previous section investigated variation in response latency as a within subjects function of item difficulty, the analyses discussed in this section examined variation in response latency as a function of individual differences in subject learning rate. Responses prior to and after the TLE were treated separately. The measure of subject learning rate employed was the total number of item presentations across all items and all key positions

TABLE 12

Post-TLE Response Latencies of
Most and Least Difficult Items for Each Subject

Key Positions 1 and 2 Only

Treatment Group Means

Treatment	N	Most Difficult Item		Least Difficult Item		Most - Least Difficult Item	
Information Level		Latency	Trials	Latency	Trials	Latency	Trials
1	26	1251	10.0	1162	0.4	89	9.6
2	26	1420	10.0	1356	2.3	64	7.7
3	26	1732	7.7	1550	3.3	182	4.4
Method							
Anticipation	39	1611	13.1	1455	3.5	156	9.6
Recall	39	1325	5.4	1258	0.5	67	4.9
Total	78	1464	9.2	1356	2.0	108	7.2

Analysis of Variance
(Log transformation)

Source	df	SS	MS	F
Between Ss Variance	77	1,792.46		
Item Difficulty	1	25.89	25.89	5.03 *
I x D	2	6.77	3.38	<1.00
M x D	1	6.91	6.91	1.34
I x M x D	2	4.98	2.49	<1.00
Within Ss Error	72	370.92	5.15	
Total	155	2,207.93		

* $p < .05$

prior to and including the TLE. From each treatment group of 16 subjects, the four subjects who had the highest such scores were classified as slow learners. The four subjects who had the lowest scores in each treatment group were classified as fast learners. In the pre-TLE analysis, three of the fast learners had no data prior to the TLE and had to be replaced with subjects who were slightly slower learners.

TABLE 13

Post-TLE Response Latencies of
Most and Least Difficult Items for Each Subject

Key Positions 3 and 4 Only

Treatment Group Means

Treatment	N	Most Difficult Item		Least Difficult Item		Most - Least Difficult Item	
Information Level		Latency	Trials	Latency	Trials	Latency	Trials
2	28	1429	10.8	1266	2.4	163	8.4
3	28	1963	10.9	1817	6.1	146	4.8
Method							
Anticipation	28	1890	13.8	1656	5.7	234	8.1
Recall	28	1502	7.9	1428	2.8	74	5.1
Total	56	1696	10.8	1542	4.3	154	6.5

Analysis of Variance
(Log Transformation)

Source	df	SS	MS	F
Between Ss Variance	55	1,669.99		
Item Difficulty	1	37.51	37.51	6.59 *
I x D	1	1.74	1.74	< 1.00
M x D	1	12.72	12.72	2.24
I x M x D	1	1.17	1.17	< 1.00
Within Ss Error	52	296.06	5.69	
Total	111	2,019.19		

* $p < .05$

<u>Pre-TLE latency as a function of subject learning rate</u>. A single pre-TLE response latency score was calculated for each key position for each subject. 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 relevant variable ($F < 1.0$) and a single analysis including all key positions was conducted. The results of this analysis are presented in Table 14 together with the mean response latencies and the mean number of pre-TLE trials per item for each treatment group.

TABLE 14

Pre-TLE Response Latencies of Slowest and Fastest Learners

All Key Positions

Treatment Group Means

Treatment	Slow Learners		Fast Learners		Slow-Fast Learners	
	Latency	Trials	Latency	Trials	Latency	Trials
Information Level						
1	1500	7.1	1525	1.1	-25	6.0
2	1878	11.4	1527	2.3	351	9.1
3	2318	11.7	2604	4.1	-286	7.6
Method						
Anticipation	1866	12.9	2000	3.5	-134	9.4
Recall	1932	7.3	1771	1.5	161	5.8
Total	1899	10.1	1885	2.5	14	7.6

Analysis of Variance
(Reciprocal transformation)

Source	df	SS	MS	F
Variance due to Information and Method Variables	5	5,335.05		
Subject Learning Rate	1	275.82	275.82	< 1.00
I x R	2	64.25	32.12	< 1.00
M x R	1	1.68	1.68	< 1.00
I x M x R	2	363.95	181.97	< 1.00
Error	36	13,376.71	371.58	
Total	47	19,417.46		

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.

Post-TLE latency as a function of subject learning rate. A single post-TLE response latency score was calculated for each key position for each subject. This score was the mean of the first 16 post-TLE responses. The preliminary key position ANOVA indicated a significant interaction between key position and the learning rate variable (F = 3.37, df = 1, 24). Therefore, two separate analyses for key positions 1 and 2 and positions 3 and 4 were conducted. The results of these analyses are summarized in Tables 15 and 16 together with the mean response latencies and the mean number of pre-TLE trials per item for each treatment group.

TABLE 15

Post-TLE Response Latencies of
Slowest and Fastest Learners

Key Positions 1 and 2 Only

Treatment Group Means

Treatment	Slow Learners		Fast Learners		Slow-Fast Learners	
	Latency	Trials	Latency	Trials	Latency	Trials
Information Level						
1	1245	7.1	1049	1.0	196	6.1
2	1547	11.4	1227	2.0	320	9.4
3	1732	11.7	1867	3.8	-135	7.9
Method						
Anticipation	1673	12.9	1486	3.5	187	9.4
Recall	1344	7.3	1276	1.0	68	6.3
Total	1508	10.1	1381	2.3	127	7.8

Analysis of Variance
(Reciprocal transformation)

Source	df	SS	MS	F
Variance due to Information and Method Variables	5	101,635.26		
Subject Learning Rate	1	31,243.48	31,243.48	6.79 *
I x R	2	3,545.46	1,772.73	< 1.00
M x R	1	526.15	526.15	< 1.00
I x M x R	2	785.40	392.70	< 1.00
Error	36	165,703.26	4,602.87	
Total	47	303,439.01		

* $p < .05$

TABLE 16

Post-TLE Response Latencies of Slowest and Fastest Learners

Key Positions 3 and 4 Only

Treatment Group Means

Treatment	Slow Learners		Fast Learners		Slow-Fast Learners	
	Latency	Trials	Latency	Trials	Latency	Trials
Information Level						
2	1521	11.4	1264	2.0	257	9.4
3	1971	11.7	1883	3.8	88	7.9
Method						
Anticipation	1934	14.3	1805	4.4	129	9.9
Recall	1558	8.8	1342	1.4	216	7.4
Total	1746	11.6	1574	2.9	172	8.7

Analysis of Variance (Reciprocal transformation)

Source	df	SS	MS	F
Variance due to Information and Method Variables	3	85,634.94		
Subject Learning Rate	1	4,852.48	4,852.48	1.20
I x R	1	4,754.56	4,754.56	1.18
M x R	1	847.34	847.34	< 1.00
I x M x R	1	1,884.06	1,884.06	< 1.00
Error	24	96,821.52	4,034.23	
Total	31	194,794.90		

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. This difference was, however, significant for only the outer key positions, keys 1 and 2. There were no significant interactions between the variables of subject learning rate and information level or method in either analysis.

Response Latency in the Area of the TLE

Response latency in the area of the TLE itself is of special interest. Suppes, Groen and Schlag-Rey (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. The TLE thus appears to be a point of some importance in the systematic changes in latency over learning. It was reasoned that the investigations of greatest interest would compare the TLE latency to the latencies of the immediately preceding and subsequent trials. As will be discussed below, these two comparisons involved different criteria for including data in the analysis. Separate analyses were, therefore, conducted to contrast TLE latency with response latencies on trials TLE-1 and TLE+1.

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 was not an initial anticipation response. All such items which were available were averaged together to yield two mean scores for each subject, 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 subjects variable in a factorial ANOVA in which information level and method were between subjects variables. Key position had no effect on the trials variable ($F = 1.27$, $df = 1, 60$) and therefore, a single analysis treating all key positions was conducted. The results of this analysis are summarized in Table 17.

The increase in incorrect response latency from trial TLE-1 to the TLE, averaged over all experimental conditions was only 102 msec. 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. All item protocols were considered which had a TLE trial which was not an initial anticipation response.

TABLE 17

Comparison of Incorrect Response Latencies on Trials TLE-1 and TLE

All Key Positions

Treatment Group Means

Treatment	N	Trial TLE-1	Trial TLE	TLE - TLE-1
Information Level				
1	16	1605	1770	165
2	16	2323	2525	202
3	16	2516	2455	-61
Method				
Anticipation	24	2163	2214	51
Recall	24	2134	2287	153
Total	48	2148	2250	102

Analysis of Variance

(Reciprocal transformation)

Source	df	SS	MS	F
Between Ss Variance	59	62,522.42		
TEL-1 vs. TLE	1	131.92	131.92	< 1.00
I x T	2	460.38	230.19	1.21
M x T	1	42.49	42.49	< 1.00
I x M x T	2	219.80	109.90	< 1.00
Within Ss Error	54	10,232.28	189.49	
Total	119	73,609.29		

A pair of scores representing trials TLE and TLE+1 were computed for each subject who had at least one available protocol by taking the mean of all available response pairs. These scores were treated as a within subjects variable in a factorial ANOVA in which information level and method were between subjects variables. The key position variable was found to have no significant interaction with the trials variable ($F < 1.0$) and therefore, a single ANOVA treating all key positions was conducted. The results of this analysis are summarized in Table 18.

TABLE 18

Comparison of Response Latencies on Trials TLE and TLE+1

All Key Positions

Treatment Group Means

Information Level	Method	N	Trial TLE	Trial TLE+1	TLE - TLE+1
1	Anticipation	15	1914	1652	262
1	Recall	15	1547	1470	77
2	Anticipation	15	1890	1608	282
2	Recall	15	2508	1580	925
3	Anticipation	15	2877	2826	51
3	Recall	15	2224	2321	-97
1	.	30	1730	1561	169
2	.	30	2199	1594	605
3	.	30	2550	2573	-23
.	Anticipation	45	2227	2029	198
.	Recall	45	2093	1790	303
Total		90	2160	1909	251

Analysis of Variance

(Reciprocal transformation)

Source	df	SS	MS	F
Between Ss Variance	89	67,692.50		
TLE vs. TLE+1	1	2,233.10	2,233.10	13.38 ***
I x T	2	1,460.65	730.32	4.38 *
M x T	1	3.37	3.37	< 1.00
I x M x T	2	1,752.61	876.30	5.25 **
Within Ss Error	84	14,016.07	166.86	
Total	179	87,158.30		

* $p < .05$
** $p < .01$
*** $p < .001$

Responses on trial TLE+1 were, on the average, 251 msec. faster than responses on the TLE. This was a significant reduction. The magnitude of the reduction in latency was a complex function of the information levels with the middle, two bit task demonstrating the greatest change. There was, in addition, a significant three way interaction between information level, method and TLE relative trial number. 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 msec. that was much greater than that of the comparable anticipation group. Examination of the scores of the individual subjects in two bit, recall condition indicated that this was a consistent trend. Of the 15 subjects, 13 demonstrated a reduction in latency from the TLE to the next trial and of these 13, five had a reduction in latency that was greater than one 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.

<u>Latency trends in the area of the TLE</u>. 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 (disregarding initial anticipation responses) were selected. Approximately 50 per cent of the items met this criterion. Mean correct and incorrect response latencies for trials TLE-3 through TLE+3 were calculated for each subject who had at least one item protocol which met the criterion. All key positions were included and treated as equivalent. The scores of all the available subjects were then averaged together to obtain treatment group means. The resulting data together with the number of subjects available in each treatment group are presented in Table 19.

TABLE 19

Correct and Incorrect Response Latencies in the Area of the TLE

All Key Positions

Treatment: Infor. Level	Treatment: Method	N	Correct-Incorrect	TLE-3	TLE-2	TLE-1	TLE	TLE+1	TLE+2	TLE+3
				TLE Relative Trial Number						
1	Antcp.	14	C	1813	2269	1655		1439	1569	1414
			I	1806	1334	2092	1990			
1	Recall	14	C	1542	1309	1616		1565	1405	1260
			I	1723	1955	1625	1621			
2	Antcp.	16	C	1683	1941	1511		1660	1883	1521
			I	1521	2127	2013	1907			
2	Recall	13	C	2685	2047	2297		1755	1590	1359
			I	1843	2736	3172	2425			
3	Antcp.	16	C	2672	2923	2641		2692	2337	2117
			I	2893	2379	2642	2897			
3	Recall	15	C	2435	2249	1882		1916	1839	1721
			I	2193	2031	2485	2120			
1	.	28	C	1689	1852	1636		1502	1487	1337
			I	1769	1595	1920	1805			
2	.	29	C	2107	1987	1848		1703	1752	1448
			I	1642	2371	2510	2144			
3	.	31	C	2561	2608	2287		2317	2096	1925
			I	2579	2224	2567	2521			
.	Antcp.	46	C	2081	2417	1954		1952	1945	1696
			I	2126	2006	2260	2277			
.	Recall	42	C	2239	1913	1929		1749	1617	1455
			I	1963	2246	2491	2051			
Total		88	C	2152	2191	1943		1855	1789	1581
			I	2057	2108	2359	2169			

Although no statistical tests were made on these data, 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 19, 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 sample represented in Table 19 suggests 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

The final analysis reversed 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 subject. For subjects run under the anticipation procedure, the latency score used was that of the first correct response following the initial response to that item. All such first correct responses were then divided into two groups on the basis of whether or not the subject 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 subject, 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 subject. These scores were treated as a within subjects variable in a factorial ANOVA in which information level and training method were between subjects variables. Subjects whose data did not include both break and nonbreak items were excluded from consideration. At least 12 subjects were available in each treatment group. The key position variable did not interact with the break versus nonbreak item variable ($F = 1.66$, $df = 1, 56$) and therefore, all key positions were included in a single analysis. A summary of the data and the results of this analysis are presented in Table 20.

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. 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. The significant three-way interaction shown in Table 20 is the result of these varying relationships.

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,

TABLE 20

Latencies of First Correct Responses
Divided on the Basis of the
occurrence of Subsequent Errors

All Key Positions

Treatment Group Means

Treatment: Information Level	Treatment: Method	N	Break Items	Nonbreak Items	Break-Nonbreak
1	Anticipation	12	1746	1647	99
1	Recall	12	1544	1248	296
2	Anticipation	12	1436	1285	151
2	Recall	12	2707	1589	1118
3	Anticipation	12	2774	2367	407
3	Recall	12	1846	2119	-273
1	.	24	1645	1447	198
2	.	24	2071	1437	634
3	.	24	2310	2243	67
.	Anticipation	36	1985	1766	219
.	Recall	36	2032	1652	380
Total		72	2009	1709	300

Analysis of Variance

(Reciprocal transformation)

Source	df	SS	MS	F	
Between Ss Variance	71	61,918.75			
Break vs. Nonbreak	1	3,433.14	3,433.14	19.44	**
I x B	2	25.02	12.51		
M x B	1	1.30	1.30		
I x M x B	2	1,161.07	580.53	3.29	*
Within Ss Error	66	11,653.78	176.57		
Total	143	78,193.06			

* $p < .05$
** $p < .001$

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, the subject's very first production of the correct response was substantially faster than the preceding responses.

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. In previous work, Peterson (1965) was unable to identify any consistent trends prior to the TLE. He suggested that the absence of apparent trends was due to the high variability of latency measures and further suggested that the variability early in learning might be due to interference effects resulting from the confounding of training and testing procedures under the anticipation paradigm. The present investigation 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 post-criterion error rate--a finding which is in agreement with previous research (Battig and Brackett, 1961; Battig and 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. Averaged over all post-TLE latencies, the ratio of the standard deviation to the mean was 0.40 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' subjects learned word pairs by the anticipation method. Knowledge of results was exposed for either one or four 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 was 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 was 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 the subjects 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 0.01, 0.13, and 0.36 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 through 16. There is no reason to expect that the function would not have become linear for all keys if practice had been continued for several more trials.

Several summarizing conclusions may be drawn. Response latency increased as the number of response alternatives was increased. The subject'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

A subject'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 subjects were simply guessing on the first trial while the recall subjects, 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 definitely 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 per cent, 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 0.25 by chance alone. The obtained probability, averaged over the entire pre-TLE period, was 0.45. 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 0.40 while the probability expected by chance alone would be only 0.125. Thus, approximately 70 per cent 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 msec. faster than incorrect responses. For items assigned to inside keys, correct responses were 434 msec. slower than incorrect responses. A portion of this discrepancy may be attributed to differences in average response speed between the keys. It will be recalled that, 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 this 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.

One of the few factors which did have a significant influence on latency during the pre-TLE period was the number of response alternatives. As was discussed in the previous section, latencies were proportional to the maximum amount of information which could be transmitted in each task even though much less information was actually being transmitted.

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 msec. slower than the easiest items. There was also a significant interaction with information level for these keys and the item latency by 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 the subjects 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.

If subjects did recognize difficult items and responded more slowly to these items, it might be expected that all or most of a subject's average pre-TLE response latency would be relatively slow as compared to the average latency of a fast learner. This was not found to be the case. There was a fairly broad range of individual differences in subject learning rate as defined by the average number of pre-TLE trials per item but pre-TLE latency was independent of subject learning rate. If pre-TLE latencies do vary as a function of item difficulty, it is apparently a matter of the relative difficulty for that particular subject.

Response Latency in the Area of the TLE

The TLE is by definition a meaningful transition point in the learning process as it is measured by response probability. It was therefore anticipated that the TLE would be a point at which sharp, systematic changes in latency measurements would also 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 importance of the TLE was further implied by the finding of Suppes, Groen and Schlag-Rey (1966) that latency on the TLE was greater than the latencies of the immediately preceding or subsequent responses a higher proportion of the time than would be expected on the basis of chance alone. 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 Suppes *et al*. study.

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, Groen and Schlag-Rey, 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. The reduction was greatest for the four response task and within this task, the decline was more pronounced for the recall training condition. The recall condition demonstrated only negligible differences between the two trials on the two and eight response tasks and it is not evident what factors were responsible for these significant interactions.

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 the probability of a correct response reaches asymptote on or soon after the TLE and latencies begin to decline one or two trials before or after the TLE.

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 ten trials past the TLE.

Both the information level and method variables had significant effects during overlearning. Latencies were a positive function of the amount of information transmitted per response and the recall procedure resulted in a more rapid decline in latency than did the anticipation procedure.

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 0.53 prior to the TLE and 0.40 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, Groen and Schlag-Rey (1966) indicate that longer pre-TLE response protocols and 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. Simley (1933) had demonstrated a similar effect within the data of individual subjects but the data were derived from only a portion of the responses of only three subjects and were obtained under a prompting paradigm. 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 were more pronounced immediately after the TLE. The interesting aspect of this relationship 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 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. Shiffrin and Logan (1965) demonstrated that paired associate response latencies were longer if previous practice was controlled at a slower response rate. 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 intrasubject differences in latency as the result of item difficulty, post-TLE latencies were demonstrated to be related to subject 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 subject learning rate and if post-TLE latencies are indeed a measure of overlearning, this suggests that the number of trials required for a subject 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. Furthermore, post-TLE response latencies may provide a means of determining the amount of overlearning practice which would be required for a particular subject 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 subjects reached a response probability criterion with fewer trials than did the anticipation method subjects. 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 0.54 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. It may well be that latency would be useful as a measure of other task parameters which influence learning. There is also a possibility that 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 subject 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. 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: (1) prior to the TLE, latency was a measure of task complexity but did not measure the development of associative strength; (2) 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 Computer-Assisted 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. Inter-response 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 would be questionable.

Summary

The purpose of this experiment was to investigate response latency as a measure of associative strength or degree of learning and as a possible basis for instructional decisions in computer-assisted instruction. Although latency is widely accepted as an indicant of associative strength, there has been little investigation of systematic changes in latency over the course of verbal learning or of the factors which may influence the relationship of latency to learning. Two parameters of the learning situation which past research and theory had indicated could influence latency were investigated: training method and the amount of information transmitted by the subject per response. The training variable contrasted the anticipation and recall paradigms in order to possibly uncover factors which contribute to the high variability characteristic of latency measures. The information transfer variable was suggested by the traditional disjunctive reaction time studies which are undergoing re-examination in the light of theories of information processing. The investigation of several points concerning the relationship of latency to learning was suggested by recent experiments which have found systematic trends in latency measures with respect to the trial of last error (TLE).

A group of 96 subjects were run in a factorial design experiment under on-line computer control which examined changes in latency over the course of learning a short list of paired-associates. Anticipation and recall training paradigms were contrasted and three levels of information transmission (one, two, or three bits of information) were investigated by the use of an eight word stimulus list and response lists of two, four or eight responses. The stimuli were CVC trigrams of low association value and high similarity. The subjects indicated their responses by pressing unmarked buttons on a keyboard. Knowledge of results was provided by lights next to the correct key positions. The training session continued until each item had received at least ten trials of practice after reaching a criterion of six successive errorless trials. The trial preceding the first of the six successive errorless trials was defined as the TLE.

It was hypothesized that much of the variability characteristic of latency measures was due to interference effects deriving from the nature of

the anticipation paradigm and that the duration and variability of latencies would be reduced under the recall paradigm. The data obtained indicated that prior to the TLE, neither the duration nor variability of latency varied as a function of training method. Following the TLE, i.e., during overlearning, the recall paradigm resulted in shorter latencies than did anticipation. Subjects reached the response probability criterion in a smaller number of trials under the recall paradigm and the shorter post-TLE latencies may have reflected a similar superiority of the recall paradigm during overlearning.

Prior to the TLE, latency was found to be a positive monotonic function of the potential number of bits of information in each task, that is, the amount of information which the subject was required to transmit for errorless responding. Immediately following the TLE, latency was a positively accelerated function of the amount of information transmitted with the highest information level task having disproportionately long latencies. As practice progressed, the function approximated the linearity characteristic of increasingly complex disjunctive reaction time tasks.

Several specific points were investigated with respect to systematic changes in response latency as a function of the stage of learning. Latencies remained relatively constant prior to the TLE and did not reflect the increase in associative strength indicated by a substantial increase in correct response probability. The latency of correct and incorrect responses did not differ systematically during this period. However, subsequent to the TLE, there was a large and consistent reduction in latency which did not appear to have reached asymptote after 16 post-TLE trials. In the area of the TLE itself, no systematic trends could be reliably identified. This area might best be described as being similar to a threshold area in psychophysics in that while distinctly different behaviors occur on either side of the transition area, the behavior observed in the area itself is highly inconsistent.

Two aspects of latency as a function of learning rate were investigated. First, latency was found to vary as a positive function of intrasubject differences in item difficulty. For a particular subject, those items which required a greater number of trials to reach criterion had longer latencies both prior to and after the TLE. The post-TLE difference is particularly interesting since, on the basis of correct response probability alone, the items would be described as having attained equivalent degrees of learning. Secondly, it was found that latency prior to the TLE was a positive function of subject learning rate. That is, slow learners were slow responders during the early stages of learning. Post-TLE latencies were independent of subject learning rate.

The latency of the first correct response to an item was found to be a function of the occurrence of subsequent errors in that the response was faster if there were no subsequent incorrect responses to that item.

In general, it was concluded that latency is not a sensitive measure of associative strength during the pre-TLE period but latency may well be an accurate measure of associative strength during overlearning, after the TLE. It has generally been accepted that response probability and response latency are similar measures of the degree of learning. Experiments generally employ either measure depending on the details of the experimental task. This study suggests that while response probability and latency do indeed both measure strength of learning, they do so, at least in a rote verbal learning task, during different stages of learning.

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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 furing 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. Both pre- and post-TLE latencies were an increasing function of intre-subject differences in item difficulty. Pre-TLE latencies were an inverse function of subject learning rate. Post-TLE latencies were independent of subject 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 learning task, may be a sensitive measure of strength of learning during the over-learning phase, but not during initial learning.

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