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ABSTRACT

The intensity of information processing engendered in different phases of standard memory tasks was examined in six experiments. Processing intensity was conceptualized as system capacity consumed, and was measured via a divided-attention procedure in which subjects performed a memory task and a simple reaction-time (RT) task concurrently. The more intensely a subject processed the memory information at any given point in the memory task, the less the residual capacity he could devote to the RT task, and the longer his RT to a signal occurring at that point should have been. Thus, RT served as an index of expended processing capacity. (EPC). Viewed collectively, the results shed considerable light on EPC during information input (list study) and output (recall). Input processing was enhanced by learning, list organization, input clarity, low information load, and an imagery memonic. Output processing was enhanced by learning, list organization, low information load, freedom of recall order, recency of input, and high item imagery. The results suggest ways in which learning and memory in practical situations can be conceptualized, diagnosed, and improved. (Author)

Final Report

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U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

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Preface

The writer wishes to acknowledge the assistance of several people who contributed considerable time, effort, and talent to this projects. First, Douglas Griffith and Rollie R. Wagstaff were graduate research assistants throughout the project period. Second, Robert Flickinger and Alan McConkie lent valuable assistance at various times during the grant period. Third, several undergraduate students provided patient and conscientious clerical assistance. These students include Robert Erickson, Eileen Davis, Helyn Woody, David Finch, and Kenneth Stake. Finally, I am grateful to the hundreds of undergraduate students who served as subjects in the experiments. Their cooperative assistance made the research program a success.

Table of Contents

Introduction

Human memory has an enormous influence on almost every aspect of human behavior. Memory determines how we perceive, learn, and behave. Without memory, life would present itself as an incoherent, continual bombardment of meaningless, unmanageable stimulation. Human memory ties all experience together; without it, society and its institutions would have no basis upon which to thrive. Hence, the countless hours of experimentation and thought that are devoted to this topic every year may be considered warranted. Unfortunately, as Tulving and Madigan (1970) argue, this mammoth research effort has yielded relatively little real insight into the nature of human memory. Clearly, major breakthroughs are needed in this research area if significant headway toward understanding human memory is to be gained. Innovation is called for along both theoretical and methodological lines. The present research program attempted to do both; it conceptualized memory within a human information-processing framework, and employed a methodology derived from that conceptualization.

The primary thrust of the research was on the diagnosis of the information-processing bases of established memory phenomena. An attempt was made to assess the extent to which important memory phenomena are attributable to the information processing engendered in different phases of standard memory tasks. The information presented for memory usually takes the form of a list of words or word pairs. Most laboratory memory tasks are comprised of at least two phases: a study phase in which a list is presented to a subject (S), and a recall or test phase in which S attempts to recall some or all of the list items. Occasionally, a rehearsal phase is interpolated between the study and recall phases to allow S free time to rehearse, organize, or otherwise process the memory items. Information processing was monitored during study and recall phases in all six studies of the present research program, and during a rehearsal phase in one study (Exp. IV).

The most common index of memory is the accuracy of recall, a measure grossly inadequate as the sole indicant of memory processes. After all, overt recall is but the end result of the complicated chain of information processing which begins at the onset of list study. A thorough understanding of human memory requires the elucidation of the entire course of information processing in memory tasks. We need to uncover the nature of processing at various links in the processing chain, and to extricate those links to which certain recall phenomena can be attributed. Certainly it would be futile to attempt to infer the nature of this processing chain by looking only at overt recall; yet that is precisely what the vast majority of memory research to date has done. Viewed from this perspective, the apparent diagnostic impotency of the research is hardly surprising. To try to achieve a thorough understanding of human memory by measuring only overt recall is rather like trying to infer the complete jig-saw puzzle from but one of its many pieces, or like trying to solve an intricate mystery from one frail clue.

The present research took steps to rectify the methodological shortcomings of traditional memory research by employing a procedure designed to monitor S's information processing at any point desired in the course of a memory task. While there are many dimensions of information processing, the present research focused on processing intensity. Specifically, an effort was made to assess how hard S was thinking at preselected points in the memory task. In a nutshell, the research program sought to trace established effects on recall accuracy to the intensity of processing incurred at various points over the entire course of the memory task.

General Method

Mensural Logic

Theorists agree that the human processing system has a finite capacity, a capacity presumably set by an important but severely limited central processor (Broadbent, 1958; Smith, 1968). Within this context, processing intensity can be conceptualized as system capacity consumed. That is, the intensity of S's processing at a specific point in a memory task may be regarded as the proportion of his finite capacity expended at that particular point. In a previous research effort, the writer developed a method for measuring processing intensity in memory tasks (Johnston, Greenberg, Fisher, & Martin, 1970). That method was further developed in the present program, and applied to the diagnosis of selected recall phenomena. The method requires S to perform a memory task and a subsidiary task at the same time. In the present research the subsidiary task was a simple reaction-time (RT) task. As S studied, rehearsed, and recalled words, he also pushed an RT button upon detecting light or tone signals. The logic was as follows: the more intensely S processes the memory information, the less of his finite capacity is left over for the RT task, and the slower his RTs should be. Hence, RT served as a gauge for monitoring the amount of processing capacity expended on the memory task; this measure of processing intensity will be referred to as expended processing capacity (EPC).

Tasks and Apparatus

The tasks and apparatus were generally uniform across the six experiments reported herein. All Ss served individually in a dimly lit cubicle. An ambient noise generator continually produced white noise (65 db.) to mask extraneous sounds. The RT task involved either light signals or tone signals. Light signals were used in Exp. I, II, III, and VI; tone signals were used in Exp. IV; and both types of RT signal were used Exp. V. A light signal was a momentary (100 msec.) brightening of a light source. The standard brightness of the source was 8 ftl., and the signal brightness was 32 and 64 ftl. for low and high intensity signals, respectively. The light source was emitted from a .25-in. opaque globe mounted at eye level. A tone signal was a momentary tone delivered over S's headset; it was around 1000 Hz. at 2 db., and 100 msec. in duration. An S detected a signal by pushing an RT button upon which his preferred finger rested. An electronic timer started in coincidence with a signal, and was stopped by S's button push.

The memory task involved the aural presentation of a memory list over S's headset. The lists were prerecorded in a male voice. The rate of presentation of the memory items varied across studies from one item every sec. to one item every 10 sec. An S's verbal recall was always tape recorded. Thus, in a typical study, S might have continually monitored the

RT signal source at the same time that he listened to and recalled words. To assess how hard S was thinking at any given point, a signal was presented (according to preprogram) and S's RT was recorded. Several hundred Ss were run altogether, and none showed any serious inability at performing the two tasks together.

Procedure

The general procedure was the same in all experiments, and consisted of at least one practice session followed after 24 hr. by at least one experimental session. The practice session was intended to bring S to stable asymptote in his performance of the two tasks, both separately and simultaneously, and to familiarize him with the general experimental setting. All studies included a monetary incentive system by which S was encouraged to devote whatever attention was needed to the memory task, and only residual attention to the RT task. In addition, all studies included a baseline control condition in which S performed the RT task without the imposition of a simultaneous memory requirement. This baseline allowed an assessment of the EPC occasioned by the memory component of dual-task conditions.

The Ss were male and female Ss recruited from the undergraduate population at the University of Utah. Some received course credit for their participation, and some received a base wage. All Ss were fully debriefed as to the nature of the experiment, and all their questions were answered.

A point of clarification should be made with respect to the procedures for measuring EPC. Specifically, RT signals occurred on an aperiodic basis; they did not occur upon the presentation and recall of every word. Thus, in order to monitor EPC over the full course of the memory task, each S performed several lists, where the temporal pattern of RT signals varied both between lists and between Ss.

Experimentation

For expository purposes, the order in which the six experiments are reported herein departs somewhat from the order in which they were actually conducted. Experiments I and II dealt with learning and list organization effects on recall, Exp. III and IV examined serial-position effects, and Exp. V and VI explored visual imagery effects. The actual order in which the experiments were run was I, III, II, V, IV, and VI. Much of the data from these studies are summarized in Table 1. In addition, the major analyses of variance performed on the data of each study are summarized in the appendix.

Experiments I and II: Learning and List Organization Effects on Memory.

In Exp. I, the Ss performed a free-recall task for 12 study-test cycles. A 9-word list was presented in random order on each study phase, and S attempted to recall all nine words in any order on each test phase. The 12 male Ss learned several lists in this manner across two experimental sessions. Some of the lists were categorized, and some noncategorized. The categorized lists were comprised of three words from each of three taxonomic categories, and the noncategorized lists were comprised of nine words representing nine different categories. EPC was monitored

Table I

Mean EPC (RT) over a Range of Conditions in Experiments I-VI
(note: ISI stands for intersignal interval in the RT task)

Experiment	Description	Condition	Study	Test
I	9-Word Lists, 12-Trial Free-Recall Learning, N=12, Mean ISI=6 sec.	Dual-Task	432	486
		Noncategorized Lists	445	505
		Categorized Lists	418	467
		RT-Only	338	338
II	6-Word Noncategorized Lists, 18-Trial Probed-Recall Learning, N=24, Mean ISI=6 sec.	Dual-Task	406	558
		Trial 1	445	625
		Asymptote	400	525
		RT-Only	380	380
III	5-Word Noncategorized Lists, Single-Trial Probed-Recall, N=16, Mean ISI=8 sec.	Dual-Task	440	531
		Semantic Probe		522
		Positional Probe		540
		Low S/N	460	540
		High S/N	421	522
		Correct Recall		544
		Incorrect Recall		616
		RT-Only	312	312
IV	10-Word Noncategorized Lists, Single-Trial Probed-Recall, N=20 in each of 4 Groups, Mean ISI=7 sec.	Dual-Task	430	660
		Low Expectancy	428	639
		High Expectancy	432	680
		Early Probe	404	635
		Late Probe	457	685
		RT-Only	288	288
V	23-Item Paired-Associate Lists, Single Trial Study-Test, N=16 in each of 4 Groups, Mean ISI=13 sec.	Experimental Lists	484	539
		Low Imagery	490	561
		High Imagery	478	517
		Imagery Set	462	538
		Rehearsal Set	506	541
		*Control Lists	364	397
VI	23-Item Paired-Associate Lists with Overt Processing During List Study, N=16 in each of 2 Groups, Mean ISI=13 sec.	Experimental Lists	667	638
		Low Imagery	665	667
		High Imagery	669	608
		Imagery Set	651	600
		Semantic Set	684	675
		*Control Lists	481	481

* The control lists used in Exp. V and VI incorporated all the characteristics of the memory lists save the memory requirement itself.

for many of the lists (dual-task trials), and was not monitored for others (memory-only trials). In addition, trials were included in which Ss performed the RT task by itself (RT-only trials).

Recall accuracy improved across the 12 test phases allotted a list, and was higher for categorized lists than for noncategorized lists. Moreover, recall accuracy was just as high on dual-task trials as on memory-only trials. Hence, the measurement of EPC on dual-task trials did not appear to alter the memory processes under investigation. The data of primary interest were the EPC data shown in Fig. 1. Statistical analyses confirmed that EPC was less for categorized lists than for noncategorized lists, and was an inverse function of trials (study-test cycles). However, the effect of list organization held up more on the test phases (recall) than on the study phases, and the effect of learning was confined to the study phases. The two lower curves in Fig. 1 represent RT-only baselines.

The effects of learning on EPC may have been spurious. For one thing, the failure for learning to show up in terms of EPC at recall may have resulted from offsetting factors: a reduction in the intensity of processing required to retrieve any given word counteracted by an increase in the number of words retrieved. For another thing, the learning that did show up in terms of EPC during list study may have resulted simply from S's inattention to list input once a list was learned. That is, once a list is well learned, why should S study it at all?

Experiment II attempted to control these possible artifacts. The first possible artifact was obviated through the use of a probed-recall task in place of free recall. The 24 male Ss performed 18 study-test cycles on each of several 6-word lists. Noncategorized lists were used, and the target word (e.g., CARROT) on the test phase of a given cycle (trial) was probed for by its category name (e.g., VEGETABLE). Since recall was limited to only one word per trial, any learning effect on recall EPC could not be masked by an increase in number of words recalled. As the upper curve in Fig. 2 attests, learning did show up in terms of EPC at recall. The second possible artifact in Exp. I was obviated through the use of an intrusion-monitoring requirement during list study. In addition to studying a list for learning and memory purposes, S had to monitor it for intrusions (e.g., CABBAGE presented in place of CARROT). An S was to push a special button upon detecting an intrusion. Intrusions were programmed to occur on a random 6 of the last 12 study phases allotted a list. As the lower curve in Fig. 2 testifies, learning showed up in terms of study EPC despite the fact that S was forced to attend to list input on every trial. The horizontal broken line in Fig. 2 represents the RT-only baseline for Exp. II.

Viewed collectively, the results of Exp. I and II indicate that learning is a phenomenon of both the encoding and the retrieval of list information. Presumably, memory representations of list items are utilized during list study as well as recall, and are rendered more accessible as a result of learning. Moreover, Exp. I indicated that list organization fosters both list study and recall, though more so the latter than the former. Like learning, organization probably affects the accessibility of information for processing. In brief, the well-established effects of learning and list organization on recall were traced to the intensity of information processing engendered during both list study and recall.

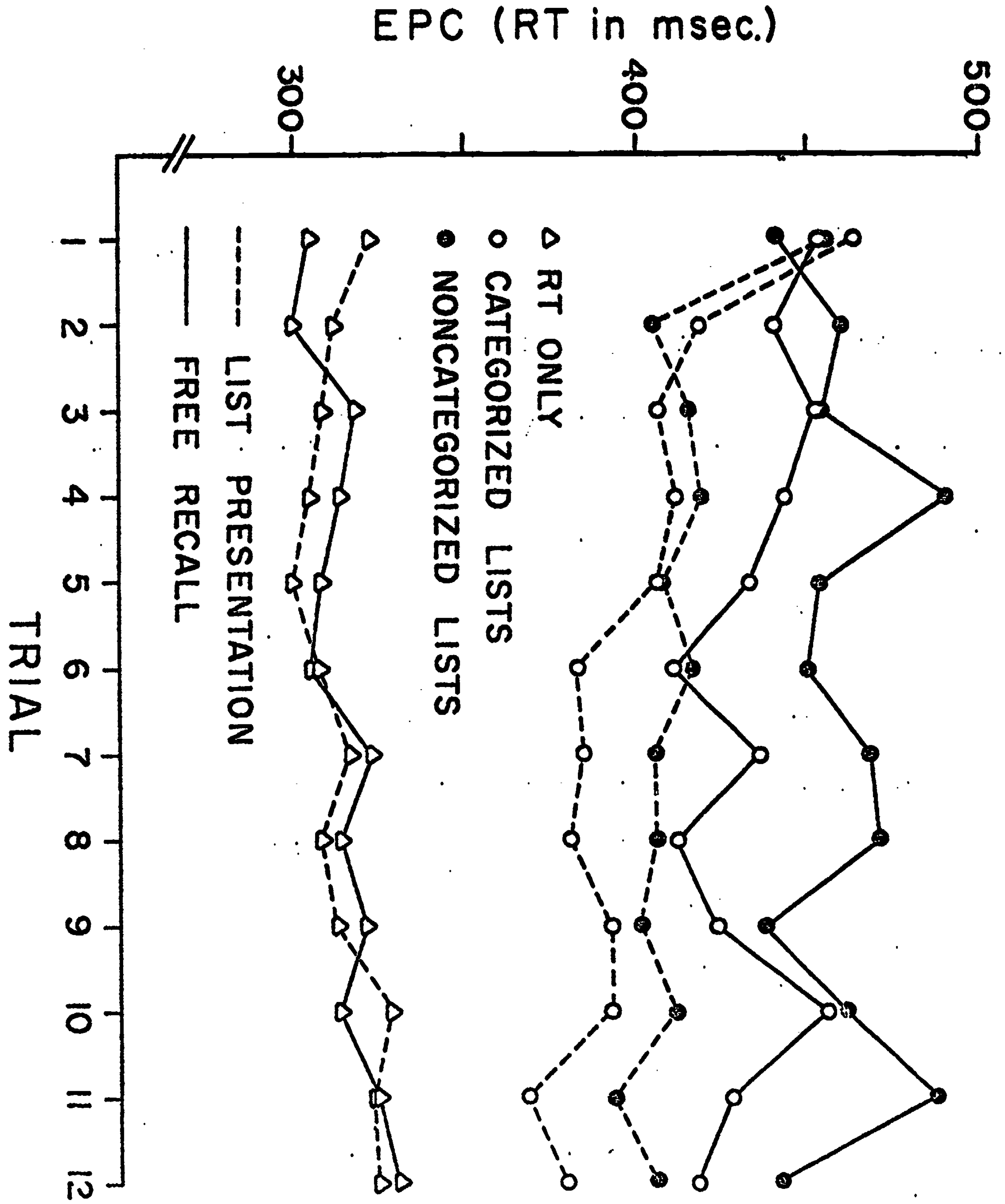

Figure 1. EPC learning curves in Experiment I as a function of task phase and type of list.

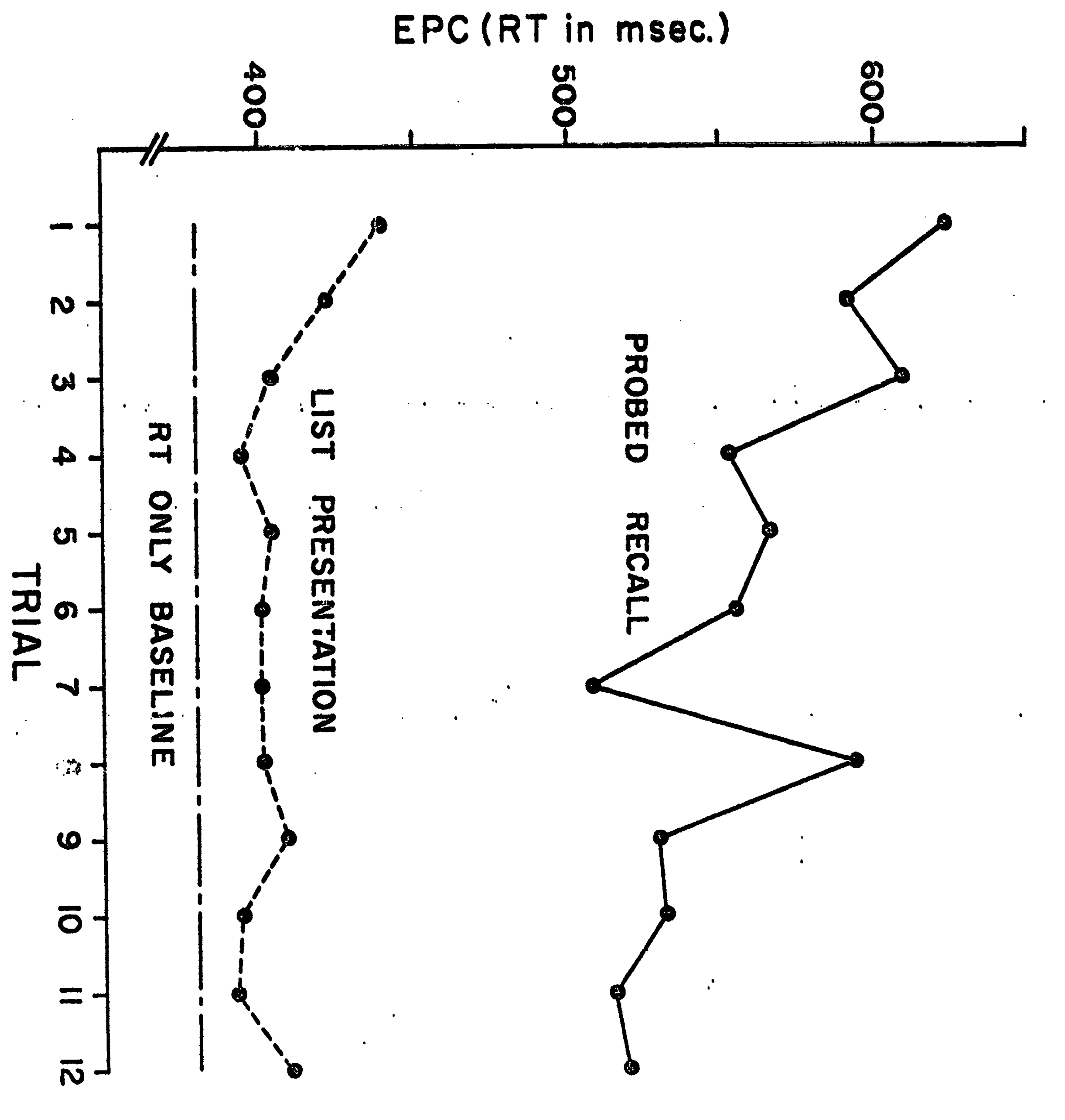

Figure 2. EPC learning curves in Experiment II as a function of task phase.

Experiments III and IV: Serial Position Effects on Memory.

Serial-position effects on recall are among the most well-established effects in the entire domain of memory research. Until recently, however, these effects have withstood systematic interpretation. The classic serial-position curve is bow shaped; it arises from the enhanced recall of items from both the initial (primacy effect) and terminal (recency effect) portions of a list. Experiments III and IV dealt mainly with the recency effect. The recency effect is usually attributed to a special short-term store (STS) which is distinguished from long-term storage (LTS) by its limited-capacity and easy-access features. Upon being perceived, information is automatically registered in the easy-access STS wherein it can be readily processed and perhaps transferred into LTS. Owing to the limited capacity of STS, information held there is highly vulnerable to loss, e.g., displacement by newly registered items. However, an item of information can be held in STS for as long as necessary by rehearsing or otherwise thinking about the item. The longer the item resides in STS, the greater its opportunity for being systematically encoded (transferred) into LTS. Theories of this general type are known as _dual-store theories_.

Experiment III investigated the easy-access feature of STS, and Exp. IV explored the nature of STS-to-LTS transfer. Only the more crucial results will be discussed here; some ancillary findings of these experiments are summarized in Table 1. In Exp. III, 16 male _Ss_ performed a probed-recall task on each of several 5-word lists. Standard serial position effects were obtained in terms of recall accuracy and recall latency. In addition to serial position, other variables included type of probe (semantic or category vs positional) and input ambiguity (S/N). Probe type affected the accuracy and latency of recall, but had no important effects on EPC. Therefore, probe type will be disregarded in the ensuing discussion. Some of the lists were presented amidst white noise (low S/N), and some were not (high S/N). The low S/N EPC data are depicted by the dashed lines in Fig. 3 and 4, and the high S/N data are depicted by the solid lines. In general, EPC increased over the course of list study (Fig.3), and was lower during the probed recall of a terminal item than during recall of an initial list item (Fig. 4). These results indicate that STS fills up during list presentation, and that terminal items are the ones most likely to be registered in the easy-access STS at the end of list study. The curvilinearity to the low S/N functions can be attributed to a selective encoding strategy in which the initial item in an ambiguous list is selectively processed during list input, and kept in STS at the expense of subsequent items. The most important result is the high retrievability of terminal items on an immediate recall test; this provides empirical documentation for the easy-access feature of STS.

Experiment IV sought to determine what it takes to transfer terminal items from STS into LTS. The issue addressed was whether simple rote rehearsal is sufficient, or whether a more sophisticated mnemonic strategy is required. All 80 male and female _Ss_ performed a probed-recall task on each of 30 10-word lists, and then attempted to free recall all 300 words. Some of the _Ss_ were forced to rehearse terminal items by the interpolation of a 15 sec. free-processing (rehearsal) period between list study and probed recall (late probe). These _Ss_ had to rehearse terminal items during the 15-sec. interval to keep them available in STS

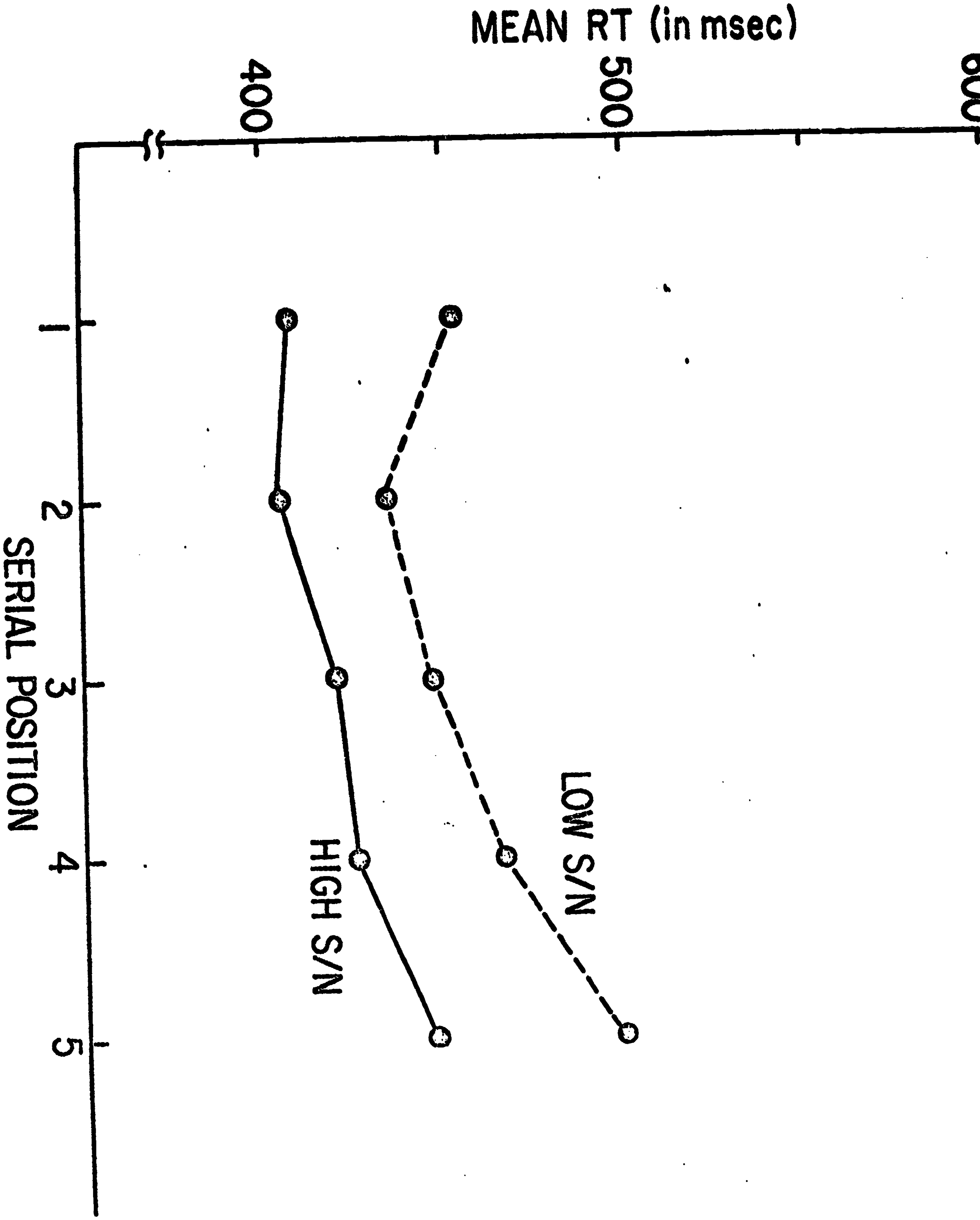

Figure 3. RT during list study in Experiment III as a function of serial position and input quality (low vs. high S/N).

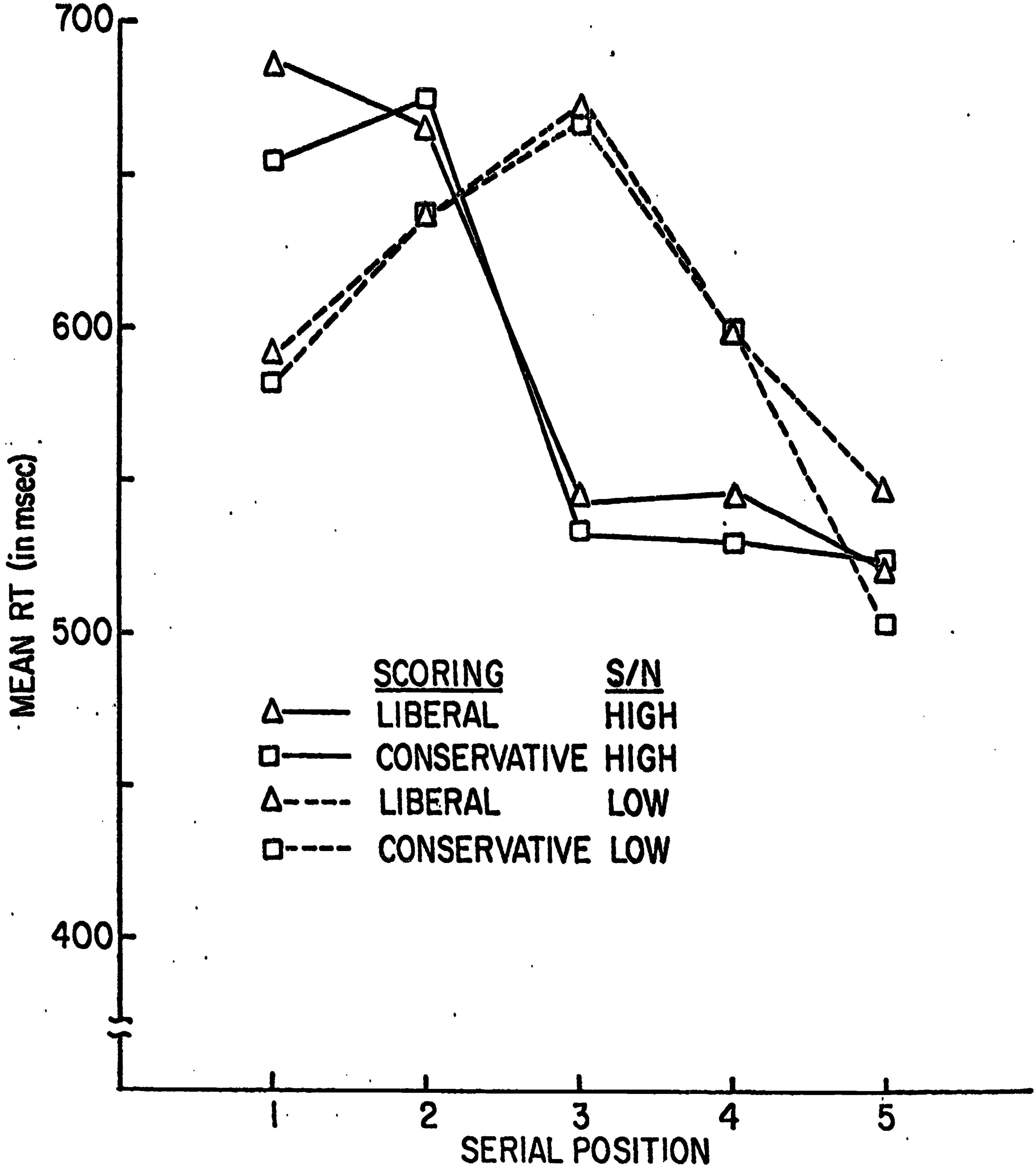

Figure 4. EPC during probed recall in Experiment III as a function of target position and input ambiguity (low vs. high S/N). Missed signals were counted as high RTs in liberal scoring, and were not counted in stringent scoring.

lost one be called for by the late probe. Other Ss did not have to rehearse terminal items as they received a probed-recall test immediately after list study (early probe), and were not given a free-processing period until after probed recall. For both early and late probes, some Ss were forewarned of the delayed free-recall test (high expectancy), and some were not (low expectancy). Only high expectancy Ss should have been motivated to engage in the systematic, strategic transfer of terminal items into LTS. Clearcut serial-position effects on recall accuracy emerged from both the probed-recall and delayed free-recall tests.

As the right-hand panel of Fig. 5 shows, Ss did process memory information during the rehearsal periods that preceded late probes. This is indicated by the steady high EPC throughout the rehearsal period under late-probed conditions. Relatively little processing was engendered during rehearsal periods that followed early probes. Moreover, these trends were not altered by S's expectancy of delayed free recall. The left-hand portion of Fig. 5 depicts EPC over the course of list study. The Ss receiving late probes engaged in more intense list study than those receiving early probes, but expectancy did not affect EPC during list study. As Fig. 6 shows, the rehearsal generated under late probe conditions did succeed in bolstering the delayed free recall of terminal items. When probed-recall immediately followed list study (early probe), terminal items received relatively little processing during the free-processing period, and thus were not well encoded in LTS. Again, expectancy had no effect on these data. Hence, Ss did rehearse during pre-recall rehearsal periods (as indicated by EPC), and this rehearsal succeeded in transferring terminal items into LTS (as indicated by delayed free recall). The fact that this was just as true for low expectancy Ss as for high expectancy Ss indicates that an intentional, strategic type of processing is not necessary for LTS encoding of information. These findings support a simplistic version of dual-store models of the sort advanced by Waugh and Norman (1965).

In summary, Exp. III confirmed the easy-access feature of STS, and Exp. IV shed light on the nature of STS-to-LTS transfer. Apparently, freshly perceived information is automatically registered in an easy-access, limited-capacity STS. Continued processing of this information yields transfer into LTS; it appears to be the duration, rather than the nature, of this processing that determines the degree of transfer.

Experiments V and VI: Visual Imagery Effects on Memory.

Perhaps the most potent determinant of recall investigated to date is that of visual imagery (Paivio, 1971). The standard manipulations of this variable have been through instructional set and item imagery. In the case of instructional set, one group is instructed on the use of a visual imagery mnemonic, and another group is taught an alternative encoding strategy (usually rote rehearsal). Item imagery is manipulated simply in terms of normative ratings of words (low vs. high imagery ratings). Both of these imagery manipulations have striking effects on recall; recall being most accurate with imagery instructions and high imagery items. Curiously, however, these variables seem to have independent effects on recall. That is, studies which have manipulated both

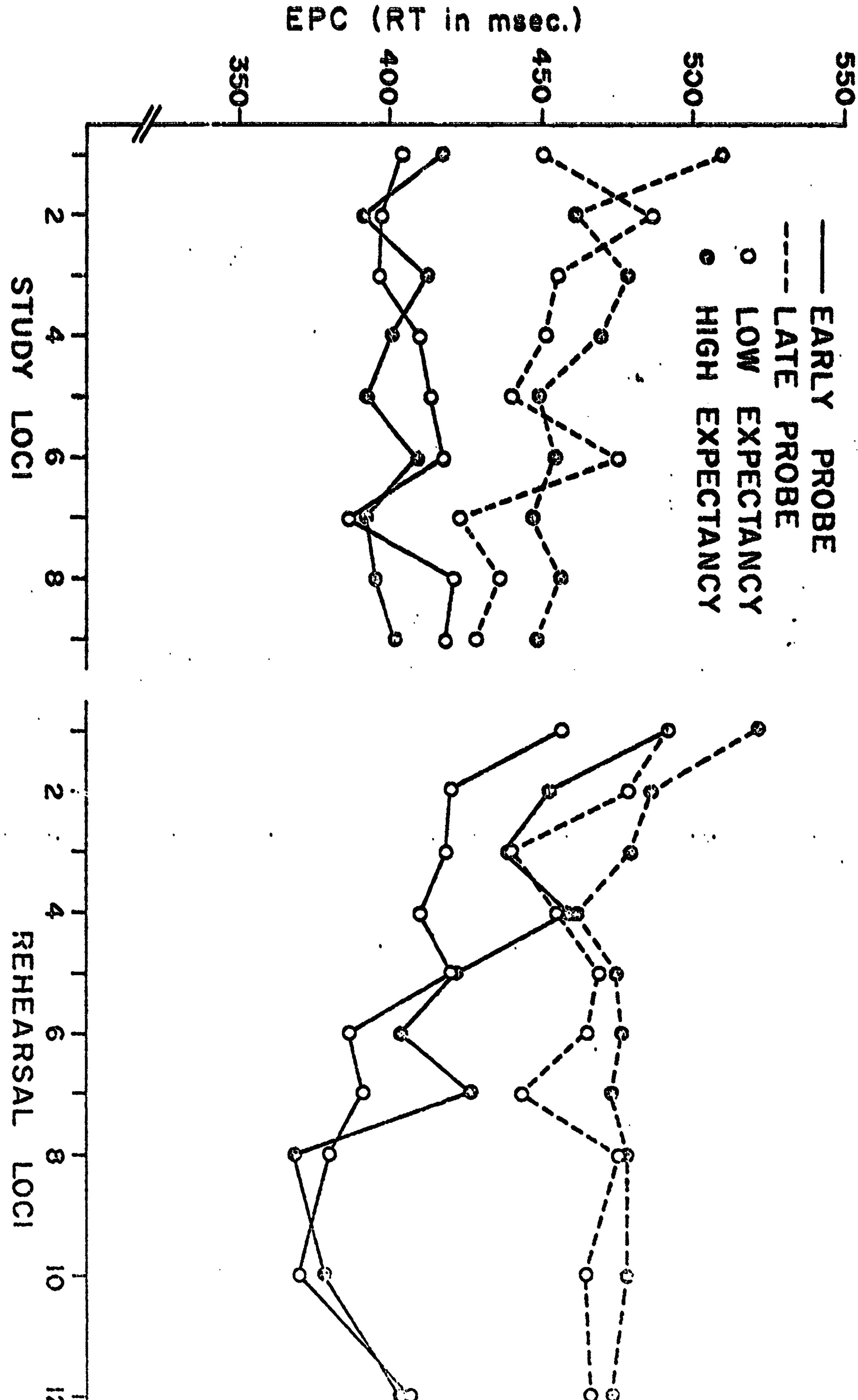

Figure 5. EPC in Experiment IV as a function of study and rehearsal loci for each combination of probe position and expectancy.

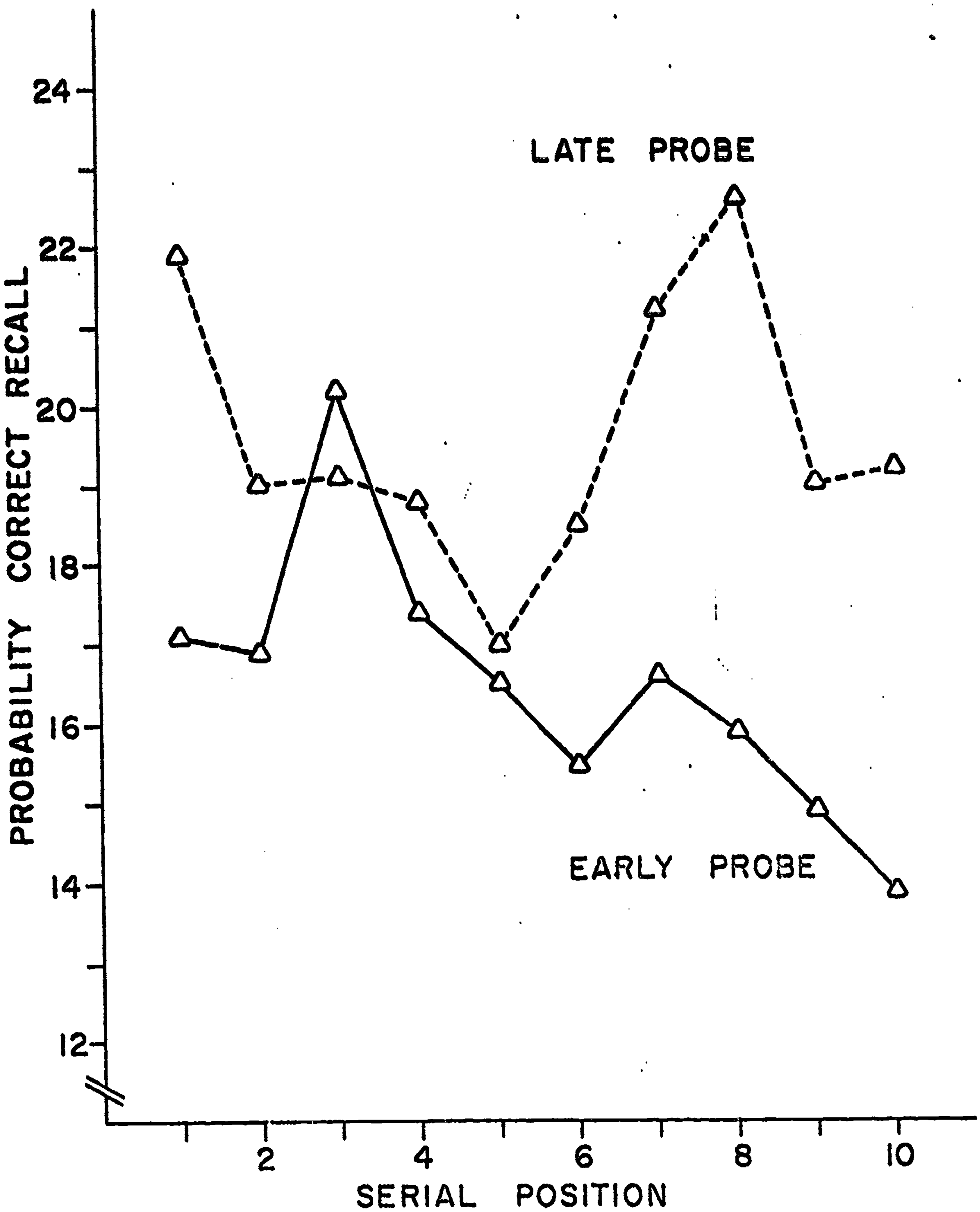

Figure 6. Probability of delayed free recall in Experiment IV as a function of serial position and probe position.

variables have uncovered highly significant main effects but no interaction.

Experiments V and VI attempted to diagnose the effects of instructional set and item imagery on paired-associate performance. The Ss performed a single study-test cycle on each of several 23-pair lists. List study involved the presentation of the 23 pairs at the rate of one pair every 10 sec., and the test phase involved the presentation of the first (stimulus) word of each pair at the rate of one stimulus every 10 sec. Upon hearing the stimulus member of a pair, S attempted to recall the second (response) word within the 10 sec. provided.

In Exp. V, an imagery mnemonic was compared with a rote rehearsal mnemonic. The imagery mnemonic required S to form a vivid visual image representing each word pair, and the rote rehearsal mnemonic required that S simply repeat the pair over and over to himself. In addition, the RT signals were aural for some Ss and visual for others. Each S performed some lists comprised of low imagery nouns, and other lists comprised of high imagery nouns. In addition, each S performed control lists which had all the main features of the paired-associate lists save a memory requirement. The contol lists were used to establish a baseline for inferring EPC in the experimental (paired-associate) lists. The design required four groups of 16 male and female Ss each. Instructional set and item imagery had the expected noninteractive effects on recall accuracy. The main EPC data are summarized in Fig. 7. The left-hand panel depicts EPC during list study, and the right-hand panel depicts EPC during recall. The main results were that (a) imagery conditions reduced EPC, (b) imagery instructions and high item imagery reduced EPC in different task phases, and (c) EPC decreased over the interval (signal loci) allotted for both the study of a pair and the recall of a response word. Only the more diagnostic loci of the entire 10-sec. interval are shown in Fig. 7. These results were borne out for both types of RT signal (visual and aural). The most important implication of the results is that imagery instructions facilitated only the encoding of word pairs, and high imagery items enhanced only the retrieval of response words. This is consistent with, and helps to clarify, the noninteractive effects of instructional set and item imagery on recall. The decline in EPC over the recall interval merely reflects that EPC is greater during retrieval of response information than after it; the later the signal locus, the more likely S is to have recalled the response word. The decline in EPC over the study interval is of more theoretical interest; it indicates that Ss do not distribute their processing capacity evenly over the time allotted for the study of a word pair.

Experiment VI sought to compare imagery instructions with a more effective mnemonic than rote rehearsal. It may not be that imagery instructions facilitate encoding so much as that an ineffective mnemonic like rehearsal inhibits encoding. The alternative mnemonic chosen required that S semantically associate the two words of a pair. Specifically, S was to determine some way in which the two words of a pair were alike. Moreover, to ensure that they adhered to instructions, all Ss overtly verbalized their processing during list study. Item imagery was again a within-S variable, but signal type was not varied (only visual RT signals were employed). The design required two groups of 16 male and female Ss each. Item imagery was manipulated in the same way as in Exp. V

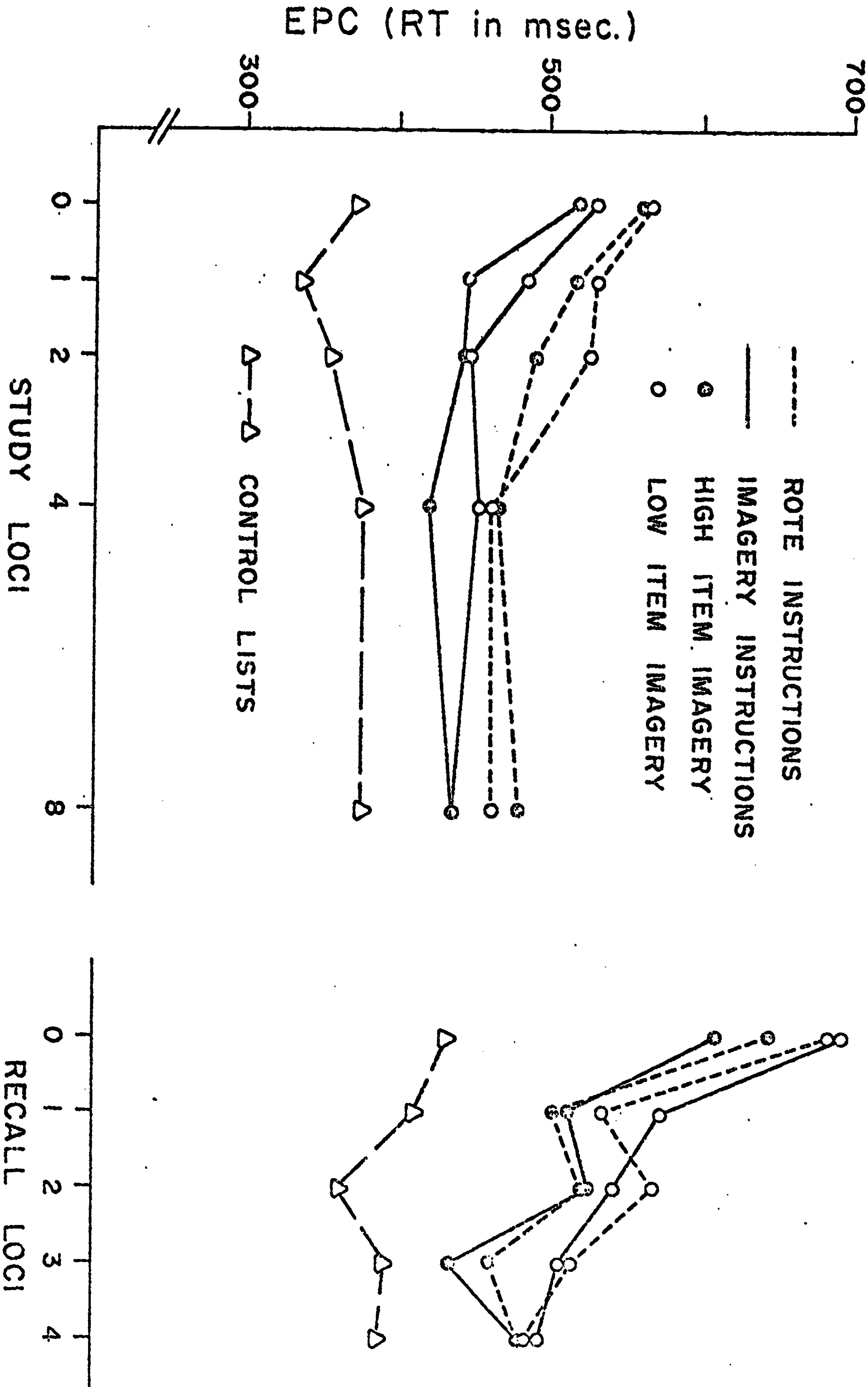

Figure 7. EPC in Experiment V as a function of study and recall loci for the different treatment conditions.

with the same outcome: item imagery affected EPC only at recall. Instructional set was manipulated in a different way with slightly different results: imagery instructions enhanced information processing in both task phases. It is important to note that the two instructional sets yielded equally accurate recall. Hence, imagery instructions proved easy to follow even when pitted against instructions which were equally effective in terms of recall accuracy.

Together, Exp. V and VI shed considerable light on the effects of visual imagery. High imagery items are relatively easy to retrieve but not particularly easy to encode. Imagery instructions enhance encoding primarily; whether or not they also enhance retrieval depends on the alternative instructions against which they are pitted.

Overview of the Research

Several general points should be made about the research program. One is that EPC was successfully measured in all studies despite considerable variation in the RT task. The RT signals varied in intensity (Exp. I), modality (aural in Exp. IV, visual in Exp. I, II, III, and VI; and both in Exp. V), and rate (intersignal intervals from a 6-sec. average in Exp. I and II to a 13 sec. average in Exp. V and VI). These many variations notwithstanding, RT was highly sensitive to the demands imposed by the memory task. The absolute memory demands are most apparent in Fig. 7. Since the control and experimental lists differed only in the memory requirement of the latter, the difference of as much as 225 msec. between them is a pure estimate memory demands.

Another general point is that the diagnostic utility of EPC was clearly evident in all six studies. Among the variables localized to one or more stages of the memory task were input ambiguity (Exp. III), list organization (Exp. I), learning (Exp. I and II), serial position (Exp. III and IV), item imagery (Exp. V and VI), and instructional set (Exp. V and VI). Although the present program was only an initial step in the direction of examing the information processing bases of memory, the data indicate that it was a step in the right direction.

One advantage of the EPC measure is that it provides a common basis on which to compare grossly different experiments. That comparison is provided in Fig. 8. The experiments are distinguished on the abscissa in terms of the information load and type of task they entailed. Starting with the left-most end (9-FR) and moving to the right, the experiments are represented in the following order: I, III, II, IV, and VI. The ordinate represents an estimate of absolute EPC (dual-task RT minus baseline RT). An inspection of this graph reveals several points of interest. First, some amount of capacity was consumed by the memory task in both the study and test phases of all experiments. Second, recall generally required more EPC than did list study. One exception to this was Exp. VI, wherein Ss processed overtly during list study. Comparing Exp. V and VI in terms of study EPC suggests that the overt study requirement of Exp. VI consumed about 70 msec. worth of processing capacity. Still, under standard conditions, list study appears to be substantially easier (in terms of EPC) than recall. A third point evident in Fig. 8 is that the experiments varied more in terms of recall EPC than study EPC.

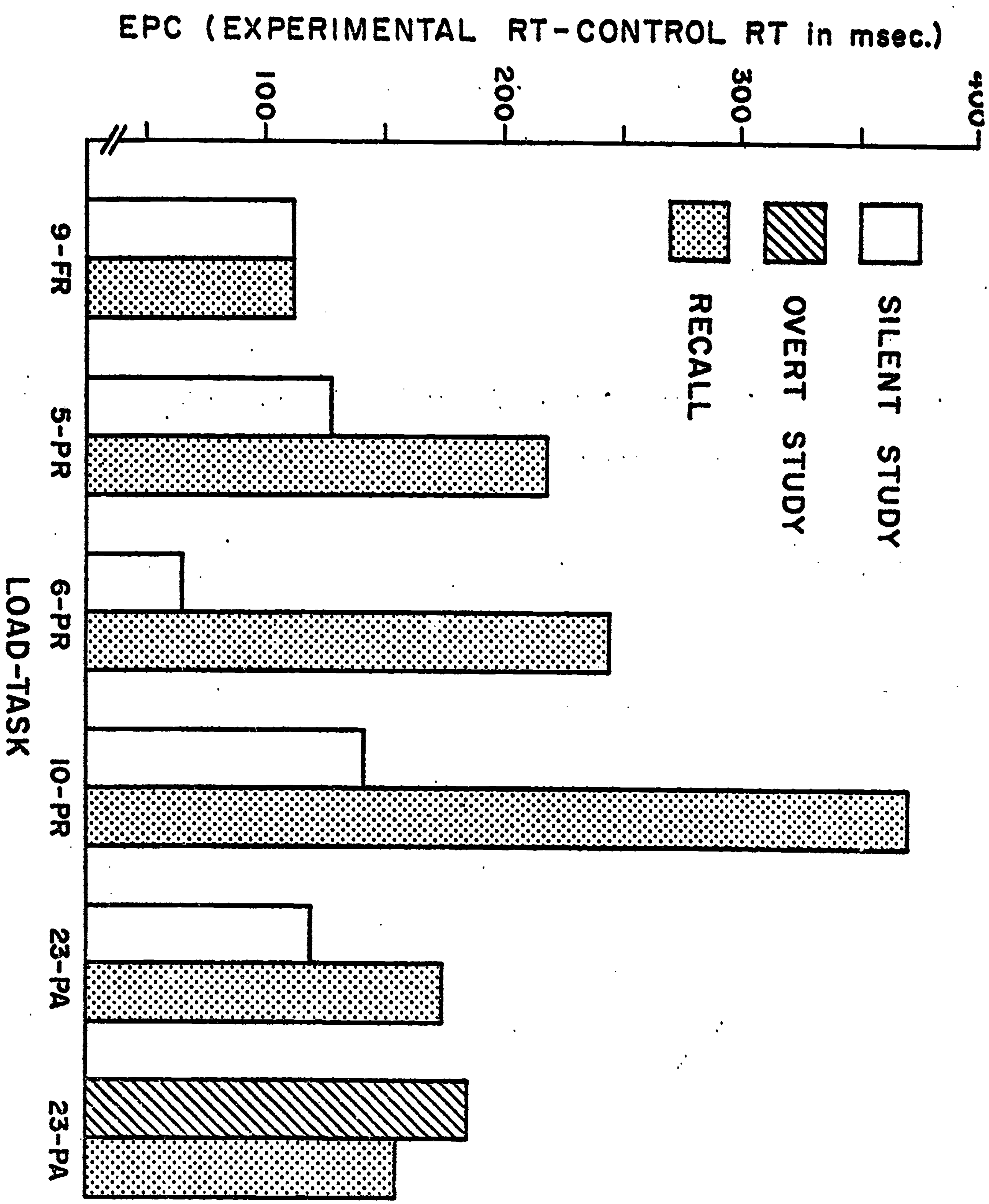

Figure [illegible]. EPC in all six experiments as a function of task load (number of list items) and type of task (FR=free recall, PR=probed recall, and PA=paired associate).

This indicates that different load-task combinations primarily yield different retrieval demands. It appears that retrieval is easier when it is free (Exp. I; 9-FR) than when it is restricted (all other studies), and is easier when S has had a good chance to study the stimulus-response association (Exp. V and VI; 23-PA) than when he has not (Exp. II-IV; 5-, 6-, and 10-PR). Finally, the difficulty of probed recall (PR) is a direct function of the number of list items from which the target is probed (5-10). Figure 8 serves to further document the diagnostic power of the EPC measure.

Discussion and Implications

The present research program sought to monitor the intensity of processing engendered in standard memory tasks. The EPC methodology served this objective well. The data offer substantial support for the general notion that memory phenomena are attributable to the information processing incurred at various points in the processing chain leading up to overt recall. An important dimension to information processing in memory tasks is that of processing intensity. Experiment IV provided an apt illustration of this point in suggesting that the encoding of information into LTS is dictated more by how hard S thinks about (processes) the information than by how or what he thinks. That is, the nonstrategic processing engendered in low expectancy Ss was just as effective in promoting LTS encoding as was the strategic processing presumably fostered in high expectancy Ss.

Viewed collectively, the data indicate that the intensity of processing during the study or recall of verbal information is a reliable function of important memory variables. Thus, the intensity of processing during list study was affected by list organization, learning, item serial position, input ambiguity (S/H), probe position (early vs late), and encoding strategy (instructional set). The intensity of processing at recall was affected by list organization, learning, input position of target word, type of probe (semantic vs positional; see Exp. III in Table I), item imagery, degree of restriction on recall, and number of list items (see Fig. 8). In the one relevant study (Exp. IV), the intensity of information processing during a free-processing period was affected by whether that period preceded (late probe) or followed (early probe) probed recall. The inference is that these variations in processing intensity were responsible for the observed variations in recall accuracy. Hence, well-established effects on recall accuracy might be due, in some degree, to the intensity of information processing engendered in different phases of the memory task. The present findings support this thesis, and call for more diagnostic efforts of the sort decribed herein. This kind of research should provide a powerful data bed from which new and deeper insights into human memory can be gained.

Once the information-processing bases of human memory are determined, important and viable practical implications should be forthcoming. A few implications can be drawn from the present research, but they must be considered tentative pending further empirical support. One implication is that one's memory can be enhanced via intense thinking. To get a child to learn something, one may need only to get him to think intensely about it; elaborate instructional techniques may be effective only to the extent that they yield intense processing on the part of the student. Another implication is that we can determine the intensity of the child's processing via an EPC procedure. Hence, the EPC method could serve as an effective diagnostic device. With it, we can identify learners who do not process instructional material with sufficient intensity, and then manipulate the learning conditions in order to establish methods for stimulating the learner's information processing.

What might we do to increase learning efficiency in an educational setting? In addition to accelerating overall processing intensity, the present data suggest that the educator should organize the input and offer plenty of practice (Exp. I and II), present the information unambiguously (Exp. III), elicit considerable processing of information while it is still in STS (Exp. IV), employ high imagery material where possible (Exp. V and VI), and train the learners on the use of an imagery mnemonic (Exp. V and VI). Again, the EPC procedure could be used as a diagnostic device in determining the extent to which these and other instructional techniques are effective with any given learner.

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APPENDIX

Analysis of Variance Tables

Table 1

ANOVA of Recall Accuracy for Exp. I

Source	df	MS	F
Between S	11		
Within S	852		
Attention Condition (AC)	2	2.751	1.238
Error	22	2.223	
List Organization (LO)	1	202.285	48.158 ***
Error	11	4.200	
Trials	11	39.960	107.080 ***
Error	121	.373	
AC X LO	2	1.639	.859
Error	22	1.907	
AC X Trials	22	.138	.938
Error	242	.147	
LO X Trials	11	1.219	4.409 ***
Error	121	.276	
AC X LO X Trials	22	.140	.755
Error	242	.186	

*** $p < .001$

Table 2

ANOVA of EPC for Exp. I

Source	df	MS	F
Between S	11		
Within S	1716		
Signal Intensity (SI)	1	1.507	61.654 ***
Error	11	.024	
Attention Condition (AC)	2	2.453	57.614 ***
Error	22	.043	
Phase	1	.336	18.878 ***
Error	11	.018	
Trials	11	.009	1.941 *
Error	121	.004	
SI X AC	2	.039	1.904
Error	22	.021	
SI X Phase	1	.030	7.846 *
Error	11	.004	
SI X Trials	11	.002	.608
Error	121	.004	
SI X AC X Phase	2	.010	3.20
Error	242	.003	
SI X Phase X Trials	11	.003	.843
Error	121	.004	
AC X Phase X Trials	22	.003	.829
Error	242	.003	
SI X AC X Phase X Trials	22	.002	.690
Error	242	.004	

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

Table 3

ANOVA of EPC During List Study for Exp. II

Source	df	MS	F
Between S	23		
Within S	1704		
Trials	11	25897.326	4.373 ***
Error	253		
Serial Position (SP)	5	18036.459	3.784 **
Error	115	4766.404	
Trials X SP	55	8692.140	1.582 **
Error	1265	5494.888	

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

Table 4

ANOVA of EPC During Probed Recall for Exp. II

Source	df	MS	F
Between S	23		
Within S	1704		
Trials	11	219580.939	8.040 ***
Error	253	27310.409	
Serial Position (SP)	5	44515.485	1.858
Error	115	23961.835	
Trials X SP	55	62670.059	2.649 ***
Error	1265	23[illegible].9878	

*** $p < .001$

Table 5

ANOVA of Recall Accuracy for Exp. III

Source	df	MS	F
Between S	15		
Within S	304		
S/N	1	201.612	28.560 ***
Error	15	7.059	
Probe Type (PT)	1	9.800	3.148
Error	15	3.713	
Serial Position (SP)	4	86.395	23.359 ***
Error	60	3.699	
S/N X PT	1	4.512	2.303
Error	15	2.247	
S/N X SP	4	1.417	.631
Error	60	2.247	
S/N X PT X SP	4	.223	.144
Error	60	1.553	

*** $p < .001$

Table 6

ANOVA of Mean Latency for Correct Recall for Exp. III

Source	df	MS	F
Between S			
Within S			
S/N	1	931177.008	2.819
Error	15	330310.297	
Serial Position (SP)	4	2634021.781	34.852 ***
Error	60	75576.198	
Probe Type (PT)	1	680067.195	3.046
Error	15	223265.658	
S/N X SP	4	47394.872	.567
Error	60	83526.149	
S/N X PT	1	391.612	.002
Error	15	205063.178	
SP X PT	4	519642.809	7.229 ***
Error	60	71885.877	
S/N X SP X PT	4	138885.580	2.167
Error	60	3844537.375	

*** $p < .001$

Table 7

ANOVA of EPC During List Study for Exp. III

Source	df	MS	F
Between S	15		
Within S	304		
S/N	1	120318.828	13.834 **
Error	15	8697.635	
Signal Locus (SL)	1	.378	.000
Error	15	1745.038	
Serial Position (SP)	4	26284.067	11.389 ***
Error	60	2307.780	
S/N X SL	1	.378	.000
Error	15	841.5181	
S/N X SP	4	1769.117	2.142
Error	60	825.857	
SL X SP	4	1818.058	1.138
Error	60	1598.068	
S/N X SL X SP	4	1080.308	.946
Error	60	1141.564	

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

Table 8

ANOVA of EPC During Probed Recall for Exp. III

Source	df	MS	F
Between S	15		
Within S	944		
S/N	1	73727.676	2.811
Error	15	26223.403	
Probe Type (PT)	1	159212.258	6.239 *
Error	15	25516.866	
Signal Locus (SL)	2	1383492.125	20.363 ***
Error	30	67942.872	
Serial Position (SP)	4	87835.834	3.939 **
Error	60	22298.946	
S/N X PT	1	9306.376	.636
Error	15	14632.783	
S/N X SL	2	13981.220	.654
Error	30	21388.523	
S/N X SP	2	22431.622	.458
Error	60	26458.069	
PT X SL	2	22431.622	1.118
Error	30	20071.285	
PT X SP	4	35863.939	1.458
Error	60	24595.173	
SL X SP	8	74832.406	2.668 **
Error	120	28049.004	
S/N X PT X SL	4	29876.394	2.051
Error	30	20462.012	
S/N X PT X SP	4	29876.394	1.169
Error	60	25553.723	
S/N X SL X SP	8	74448.438	4.501 *
Error	120	16539.738	

Table 8 (Cont'd)

Source	df	MS	F
PT X SL X SP	8	37024.122	1.562
Error	120	23700.184	
S/N X PT X SL X SP	8	17788.462	.808
Error	120	22021.336	

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

Table 9

ANOVA of Mean Number Correct
During Immediate Recall for Exp. IV

Source	df	MS	F
Between S	79		
Probe Position (PP)	1	2.205	1.885
Expectancy (E)	1	.845	.723
PP X E	1	2.000	1.710
Error	76	1.169	
Within S	720		
Serial Position (SP)	9	13.211	16.835 ***
SP X PP	9	1.730	2.204 *
SP X E	9	1.414	1.802
SP X PP X E	9	.719	.916
Error	684	.785	

* p .05
*** p .001

Table 10

ANOVA of Mean Number Correct
During Delayed Recall for Exp. IV

Source	df	MS	F
Between S	79		
Expectancy (E)	1	71.401	3.710
Probe Position (PP)	1	143.651	7.465 **
E X PP	1	1.051	.055
Error	76	19.243	
Within S	720		
Serial Position (SP)	9	8.479	2.224 *
SP X E	9	2.423	.636
SP X PP	9	8.334	2.186 *
SP X E X PP	9	6.073	1.592

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

Table 11

ANOVA of EPC During List Study for Exp. IV

Source	df	MS	F
Between S	79		
Probe Position (PP)	1	496807.734	7.068 **
Expectancy (E)	1	3038.112	.043
PP X E	1	17830.401	.254
Error	76	70284.839	
Within S	640		
Serial Position (SP)	8	7592.262	3.124 **
SP X PP	8	5246.785	2.159 *
SP X E	8	5698.431	2.345 *
SP X PP X E	8	2706.726	1.114
Error	608	2430.166	

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

Table 12

ANOVA of EPC During Rehearsal Period for Exp. IV

Source	df	MS	F
Between S	79		
Probe Position (PP)	1	662803.406	8.195 **
Expectancy (E)	1	56599.301	.670
PP X E	1	488.501	.005
Error	76	80878.063	
Within S	720		
Serial Position (SP)	9	30242.426	9.507 ***
SP X PP	9	15002.008	4.716 ***
SP X E	9	3774.326	1.186
SP X PP X E	9	1769.037	.556
Error	684		

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

Table 13

ANOVA of Recall Accuracy for Exp. V

Source	df	MS	F
Between S	63		
Signal Type (ST)	1	33.008	.276
Instructional Set (IS)	1	1883.445	15.772 ***
ST X IS	1	89.445	.749
Error - Between	60	119.416	
Within S	64		
Item Imagery (II)	1	8336.633	237.120 ***
II X ST	1	11.883	.338
II X IS	1	82.883	2.357
II X ST X IS	1	.633	.012
Error	60	35.158	

*** $p < .001$

Table 14

ANOVA of EPC in the Experimental Lists for Exp. V

Source	df	MS	F
Between S	63		
Signal Type (ST)	1	1943527.437	6.926 **
Instructional Set (IS)	1	185931.506	.663
ST X IS	1	343.413	.001
Error	60	280614.215	
Within S	1216		
Phase	1	979418.469	44.582 ***
Phase X ST	1	112144.031	5.104 *
Phase X IS	1	134828.725	6.137 *
Phase X ST X IS	1	17.3445	.001
Error	60	21968.851	
Item Imagery (II)	1	253490.756	15.561 ***
II X ST	1	9564.844	.587
II X IS	1	12195.626	.749
II X ST X IS	1	2556.626	.157
Error	60	16289.227	
Signal Locus (SL)	4	762598.578	66.305 ***
SL X ST	4	22558.044	1.961
SL X IS	4	4803.267	.417
Sl X ST X IS	4	5448.712	.755
Error	240	11501.289	
Phase X II	1	79711.094	6.133 *
Phase X II X ST	1	9401.532	.723
Phase X II X IS	1	544.707	.042
Phase X II X ST X IS	1	10.332	.001
Error	60	12997.720	
Phase X SL	4	80356.407	10.117 ***
Phase X SL X ST	4	13735.643	1.729
Phase X SL X IS	4	12562.794	1.582
Phase X SL X ST X IS	4	5720.803	
Error	240	7942.798	

Table 14 (Cont'd)

Source	df	MS	F
II X SL	4	16503.958	2.365
II X SL X ST	4	5590.561	.801
II X SL X IS	4	10289.487	1.475
II X SL X ST X IS	4	7123.151	1.021
Error	240	6978.090	
Phase X II X SL	4	6775.425	1.001
Phase X II X SL X ST	4	7978.495	1.079
Phase X II X SL X IS	4	2286.517	.337
Phase X II X SL X ST X IS	4	5535.674	.817
Error	240	6769.260	

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

Table 15

ANOVA of EPC in the Control Lists for Exp. V

Source	df	MS	F
Between S	63		
Signal Type (ST)	1	896927.625	12.649 ***
Instructional Set (IS)	1	66035.938	.931
ST X IS	1	146440.250	2.065
Error	60	70910.498	
Within S	576		
Phase	1	180129.951	10.967 **
Phase X ST	1	24194.102	1.473
Phase X IS	1	349.577	.021
Phase X ST X IS	1	6306.376	.384
Error	60	16425.092	
Signal Locus (SL)	4	34007.098	10.282 ***
SL X ST	4	3976.107	1.200
SL X IS	4	4850.030	1.466
SL X ST X IS	4	2742.732	.829
Error	240	3307.574	
Phase X SL	4	33133.135	10.674 ***
Phase X SL X ST	4	1483.801	.478
Phase X SL X IS	4	5865.963	1.900
Phase X SL X ST X IS	4	1467.904	.473
Error	240	3103.970	

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

Table 16

ANOVA of Mean EPC in the Experimental Lists of Exp. VI

Source	df	MS	F
Between	31		
Instructional Set (IS)	1	85905.125	4.804 *
Error	30	17883.211	
Within	96		
Imagery Level (IL)	1	3960.500	.924
IL X IS	1	569.531	.133
Error	30	4287.982	
Phase	1	22419.031	18.887 ***
Phase X IS	1	2346.125	1.976
Error	30	1186.978	
IL X Phase	1	4465.125	5.706 *
IL X Phase X IS	1	2945.281	3.763
Error	30	782.503	

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