# ABILITIES, TRANSFER, AND INFORMATION RETRIEVAL IN VERBAL LEARNING

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Project on Techniques for Investigation of Structure
of Individual Differences in Psychological Phenomena
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# Chapter I

## Cognitive Functioning in Verbal Learning

In the study of molar processes in verbal learning, there have been two streams of research which have been distinct in their objectives and in their methods of investigation. One stream has considered the relationship between individual differences in performance on ability tests and performance in learning tasks. These studies have been correlational in the sense that they have typically involved no treatment manipulation and have been concerned with predicting variation within the single treatment used.

A second stream has focused its attention on the effects of task variables on the subject's degree of "subjective organization" and use of mnemonics in learning blocks of material. The learning task has been conceptualized as an information retrieval problem, and verbal learning has been thought to consist of appropriately categorizing for recall words which have been "stored" in the subject's memory since he learned to speak the words. These studies have been typically bivariate (one independent and one dependent variable) and can be considered to be experimental in the sense that an independent variable, task characteristic, is manipulated.

The first stream has been concerned with relationships between abilities and learning performance, while the second has attempted to control performance by manipulating task parameters in accordance with information processing notions. It is felt that it would be desirable to integrate these two approaches to verbal learning, both theoretically and methodologically. Through an extension of Ferguson's (1956) theory of transfer and human abilities, a possible solution to the theoretical problem will be offered. As was suggested by Cronbach (1957), the methodological problem can be solved through multivariate experiments which are designed to measure organism "state" variables (e.g. abilities) and to manipulate task parameters (treatments).

## Abilities and human learning

The starting point for studies of the relationship between abilities and learning was the early definition of intelligence as "the ability to learn". Surprisingly little relationship had been found between intelligence and performance in learning tasks. Duncanson (1964) pointed out that this failure to find a relationship between ability measures and learning performance was due in part to the properties of the learning measures used. Some attempts to use learning measures other than final performance or gain scores (Allison, 1960; Stake, 1958) did show factors common to ability tests and learning performance measures.

Allison (1960), using Tucker's (1958a) interbattery method of factor analysis to determine factors common to abilities and learning measures for different tasks, found a Conceptual Process Factor, and a Rote Process Factor. Stake (1958) fitted Thurstone's rational learning curve to individual subject's data and determined three parameters. Analyzing these scores together with ability test scores he found several specific ability factors rather than a single learning factor. Duncanson (1964) observed that there were difficulties involved in the learning measures used previously (pp. 2-3) and, as an alternative, used Tucker's (1958b, 1960) procedure for determining parameters of a functional relation by factor analysis, to obtain performance measures. Duncanson used three types of learning tasks: concept formation, paired associates, and rote memory, and a variety of ability measures. Analyzing the learning and ability measures together, he found one factor specific to the ability measures, three common to ability and learning measures, and three factors specific to the learning measures.

The studies cited thus far have been concerned with the problem of finding a relationship between learning and other abilities and ascertaining whether or not learning represents an "independent" ability. Other studies have been specifically concerned with a functional analysis of the contribution of abilities to learning at different stages of practice. These studies represent the first attempts to "bridge the gap" between the multivariate, non-manipulative correlational studies and the manipulative bivariate experimental studies of cognitive functioning in verbal learning (Cattell, 1966).

By factor analyzing together ability test scores and trial-by-trial performance on a pursuit rotor task, Fleishman (1960) was able to estimate the covariation of ability factors with learning scores at successive stages of practice. Indeed, Fleishman (1957, 1960), Fleishman and Hempel (1954, 1955), and Fleishman and Rich (1963) have demonstrated clearly that, in the psychomotor area, the factorial composition of a learning task may change substantially with practice. Games (1962) found such changes for repeated memory span tests using sequences of consonants. Bunderson (1964), using a variation of Tucker's (1960) method of determining generalized learning curves, found temporal changes in the contribution of abilities to scores in a concept learning task. The most recent demonstration of temporal changes in the contribution of different abilities to scores in a learning task was that of Kohfeld (1966), who, using generalized learning curves representing early and late learning, obtained results suggesting "that verbal comprehension is more important early in perceptual-motor learning while motor skill is more critical in later learning" (p. 413).

Corballis (1965) has suggested that changes in factor structure of performance measures over time, such as those reported by Fleishman (1960), may be artifactual. He observed that a matrix of intercorrelations between practice trials on some task can be fitted by a simplex. Corballis argued that it seems reasonable to assume that the factor loadings of the task remain constant from trial to trial, but that the individuals' factor scores change (a possibility originally suggested by Humphreys (1960)), and that this notion is compatible with the view that practice is a stochastic process. However, Corballis also observed that when criterion factors (defined independently of the practice matrix) are correlated with trial scores, the resulting change in correlations with trials of practice can provide "fairly convincing evidence for genuine change in factor loadings with practice" (p. 404). The results of Fleishman and Rich (1963), Bunderson (1964), and Kohfeld (1966) are particularly convincing in the light of Corballis' observations. It will be suggested in the present paper that the "factorial composition" of a learning task reflects the kinds of strategies elicited by the task. Since strategies employed early in learning may be quite different from those employed late in learning, the consideration of strategies as mediating responses to the task situation may be important in eventually predicting changes in the "factorial composition" of a learning task with practice.

Retrieval mechanisms and the use of mnemonics in verbal learning

Research workers in verbal learning today often speak informally about recall in terms of information stored and methods of information retrieval. Tulving (1962, 1964) has formalized this by suggesting that theories of verbal learning consider "subjective organization" of the words in a long list as an important higher-order response, and "organizability" as an important task parameter. He suggested that the "trial-by-trial improvement in recall is a consequence of the development of higher-order units of material which mediate the retrieval of the information from the memory storage" (1964, p. 218). In free recall learning, the subject increases the accessibility of those items that are specified by the input list. Experimental results seem to indicate also that on a given trial the subject always remembers the same number of "new" items. This number may be related to Miller's (1956) "magical number seven" or the size of easily codable clusters of words.

Mandler and Pearlstone (1966), in a study of free and constrained concept learning and subsequent recall of verbal and pattern materials, asked subjects to sort fifty-two cards, each containing a word or figure, into anywhere from two to seven groups. The deck of cards was presented repeatedly and the order of the cards was randomized for each trial. The "free concept learning group" was instructed to use any "criterion, rule, or category" to sort the cards. They were also told that their objective should be two consecutive sorts which are identical. Subjects in the "constrained concept learning group" were told that they must find the correct categorization given N categories, where N is the number of categories used by a subject in the "free concept learning group". Thus, a "yoked design" was used. After placing a card in a category, each subject was then told that he was correct or incorrect. Mandler and Pearlstone found that subjects in the free concept learning situation performed much better than those in the constrained concept learning situation. Secondly, they found that for both free and constrained concept learning, recall of high frequency words was a linear function of the number of categories used in the concept learning part of the task.

Thus there is evidence supporting the notions that: (1) verbal learning consists of coding a list of words into higher-order subjective units of material which can be retrieved from storage, and (2) the kind of coding strategy used is a function of task parameters and is related to performance in the recall task.

## Abilities, transfer, and information retrieval

Correlational studies concerning the relationship between ability measures and learning performance have shown conclusively that systematic changes occur in the dependency of trial-by-trial learning measures on abilities as a function of practice on the learning task. Mandler and Pearlstone's results indicate that the type of grouping of the words into categories is related to performance in a task involving recall of the words already grouped. Ferguson (1956) has offered a theory of transfer and abilities which is supported strongly by evidence from studies of the factorial structure of learning tasks. With this as a starting point and with some additional statements about cognitive strategies as the mechanism of transfer, it may be possible to encompass information retrieval and abilities within a single theory. A multivariate experimental design will be presented which will test some consequences of the theory and provide an example for further multivariate experimental studies of the choice and attempted use of cognitive strategies as a mechanism of transfer from abilities to an intellectual task.

Ferguson (1956) defined the concept of transfer very generally, considering learning as a particular case of transfer. Transfer is regarded as a mathematical function relating a subject's performance on two tasks and the amount of practice he has had on both tasks. If $X$ and $Y$ denote an individual's performance on two tasks, and if $t_x$ and $t_y$ represent his amounts of practice on the two tasks, there is a concomitant change in $Y$ with $X$ which can be considered as a mathematical function $Y = f(X, t_x, t_y)$ where the form of the function is left unspecified.

If one considers practice on task $X$, $t_x$, to be extremely large, additional practice on $X$ produces very little effect on performance, and "a crude invariance of performance with practice is attained" (Ferguson, 1956, p. 125). In this case the measure of an individual's performance, $X$, is considered as a measure of his ability. The transfer function symbolizing transfer from ability $X$ to a task $Y$ takes the form $Y = f(X, t_y)$, i.e. performance on $Y$ is a function of practice on $Y$ and level of ability on $X$. This notion provides a link between learning and ability. Bunderson (1964) used an application of Tucker's (1960) generalized learning curves to determine such transfer functions from several abilities to a concept learning task.

An important implication of the notion of transfer and ability is that it enables one to consider the "state" of the organism as an important determiner within any theory of learning. Thus more variance within a learning system should be predictable when the "state" of the organism (with respect to previously learned abilities) is considered, in addition to task parameters, as a set of predictor variables. Furthermore, questions concerning the structure of the domain of abilities become relevant to theories of learning.

Frederiksen (1965) manipulated a task parameter related to "amount of organization of the material specified by the task" and recorded ratings by subjects of the extent to which they used four strategies. Results indicated that the structure of individual differences in learning performance was related to ratings by the subjects of the extent to which they used specific strategies, and to the task parameter. A theory was offered suggesting that performance is mediated by cognitive strategies which are a function of task characteristics and the organism state (abilities). The fact that ratings of use of strategies were related to the structure of individual differences in learning performance suggests that some abilities may function through the use of particular strategies. Associational Fluency may operate through choice of a strategy involving the formation of associations, while Verbal Closure may be related to a strategy involving finding some structure in a list of words which facilitates recall.

The consideration of strategies as mediators implies that transfer occurs from abilities to performance in the <u>restructured</u> learning task -- restructured by the individual through his choice of a strategy. This notion of strategies as mediators greatly widens the range of abilities which might be considered as important determiners of an individual's performance in learning tasks. It may make explicable relationships between abilities and performance that are otherwise difficult to explain. Also, an individual's being high or low in a particular ability may influence his performance by increasing or decreasing the probability that he will select specific strategies or by influencing, through positive transfer, his performance using these strategies. In the present experiment, the individual's cognitive strategies (methods of organizing a list of words into higher-order subjective units or clusters which can be retrieved from storage) are seen as mediators which are functions of the individual's particular abilities and the task characteristics. Strategies may function as both mechanisms for transfer from previously learned abilities and as higher-order responses to the task characteristics.

The results of Frederiksen (1965) indicated that, when subjects were required to recall a list of words in sequential clusters of sizes varying from one to sixty words (for a sixty word list), the strategies used were influenced by cluster size. If the clusters were codable, that is, if the clusters were small (five to ten words), active recoding strategies involving particular mnemonic devices were used. If the clusters were large (fifteen to twenty) the clusters were treated as short lists (separate learning problems) and such mnemonics were not necessary for recalling the words. When the clusters were of size one (serial learning), associative strategies were used together with other mnemonic strategies. In the free recall case (a single "cluster" of sixty words) there were large individual differences in the strategies used. Thus for some tasks, the choice of a retrieval strategy is subject to greater influence by the task constraints than for other tasks.

The above result suggests a means for investigating subjects' use of strategies in memorization tasks. By varying task characteristics it is possible to influence the choice of strategies. If measurements

# Chapter II

# Experimental Method

## Subjects

One hundred and twenty subjects were employed. They consisted of University of Illinois undergraduate and graduate students and one faculty member. All were paid for their services. They were randomly assigned to three groups, each consisting of forty subjects. It was required that they be native speakers of Englis One subject was rejected because he had a severe hearing loss.

## Ability measures

All subjects were given thirteen ability tests which were selected from the 1963 edition of the *Kit of Reference Tests for Cognitive Abilities* of French, Ekstrom, and Price. The tests were administered in one two-hour session, one or two days prior to the learning experimental session. As in the later session, subjects were tested in groups of from ten to fifteen subjects.

A list of the thirteen tests in their order of administration is found below in Table 2. The thirteen tests selected have been found to be markers for eight cognitive abilities: Flexibility of Closure, Speed of Closure, Associational Fluency, Expressional Fluency, Associative Memory, Span Memory, Vocabulary, and Semantic Spontaneous Flexibility. Short descriptions of seven of the abilities follow. For more complete descriptions of the abilities see the manual accompanying French, Ekstrom, and Price (1963).

of the subjects' abilities are made, the extent to which performance is predictable from abilities can be ascertained for a particular task. This experiment is intended to measure the extent to which attempted use of strategies and learning performance are predictable from ability measures for different situational constraints. Some hypotheses, suggested by considering strategies as mediators, will be offered concerning differential relationships for different task constraints. Support for these hypotheses will be interpreted as additional support for the notion of strategies as mediators.

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Flexibility of Closure, the ability to keep one or more definite configurations in mind despite perceptual distractions (measured here by "Hidden Patterns" and "Copying"), was included because of its possible relation to a "field-independence" dimension described by Witkin (1964). Speed of Closure (measured by "Concealed Words" and "Four-letter Words") has been described as the ability to unify an apparently disparate perceptual field into a single unified closure. One of the tests used to measure Speed of Closure, "Four-letter Words", was used to measure Verbal Closure in the 1954 edition of the Kit of Reference Tests for Cognitive Factors of French, et al. Pemberton (1952) wrote that "tests which are high on this factor all require speed in organizing or reorganizing a set of highly practiced symbols, such as letters or numbers" (p. 274).

Associational Fluency (measured by "Associations" and "Associational Fluency") has been described as an ability to produce words from a restricted area of meaning. Expressional Fluency (measured by "Word Arrangement" and "Expressional Fluency") has been described as a "facility in producing connected discourse that will fit restrictions imposed in terms of given words or letters" (French, et al., p. 14). Associative Memory is measured in the present experiment by a single test, "First and Last Names", which requires the subject to recall a list of paired associates after a single short presentation of the list. Memory Span, also measured here by a single test, "Auditory Letter Span", is an ability to accurately recall immediately a series of items after a single presentation of the series. Finally, Semantic Spontaneous Flexibility (measured by "Object Naming" and "Alternate Uses") has been described as the ability to produce many diverse verbally expressed ideas in a situation that is relatively unrestricted, the emphasis being on the extent to which the subject <u>changes set</u> spontaneously in producing a set of ideas.

## Experimental conditions

Three groups of subjects were asked to learn a list of sixty unrelated one syllable English words by an anticipation method. The sixty words were chosen randomly from lists used by Nancy C. Waugh and were found by her to be of approximately equal recall difficulty (personal communication). The sixty words were arranged randomly into a single order which was used for every presentation in this experiment.

One group of subjects, the <u>serial anticipation</u> group, was instructed to learn the words by the conventional method of serial anticipation. The list was first presented to the subjects by means of a tape recorder at a rate of one word every two seconds. The first anticipation trial began when a second tape was played in which pauses of five seconds were inserted between the words. During each pause the subject was asked to write his expectation of the next word in the list on a page in his examination booklet. After writing his anticipation of every word in the list, the subject was asked to turn the page and begin the next trial. Eighteen such anticipation trials were completed.

Two other groups were asked to anticipate the words in clusters: one group in clusters of five words and a second in a single "cluster" of sixty words (anticipation of the entire list). In a previous study (Frederiksen, 1965), clusters of five, ten, fifteen, twenty, and sixty words were used, and it was found that the five and ten words per cluster groups learned similarly, while the fifteen and twenty words per cluster groups also learned similarly. Here, only two groups were used, in addition to the serial anticipation group: (1) a group which was instructed to learn by anticipating the words in clusters of five words (the codable clusters group), and (2) a group which was instructed to learn the entire list by the method of free recall (the free recall group).

As in the case of the serial anticipation group, the entire list was first presented to the subject, but for the codable clusters group, the words were read as clusters. The total time for initially presenting the list was kept equal for all three groups -- two minutes. For the eighteen anticipation trials, seven minutes were required for each trial for all three groups of subjects. For the codable clusters group, after the initial presentation in which slight pauses were inserted to demarcate the clusters, a second tape was played in which longer pauses were inserted between the clusters. The subject was asked to anticipate each cluster in the same manner in which the serial anticipation group was asked to anticipate single words. The subjects were allowed to recall the words in any order within a cluster. The subjects in the free recall group were asked to anticipate the entire list. They were, thus, required to recall a "cluster" of sixty words during the anticipation trials.

A summary of the experimental conditions for the three groups follows.

| Experimental Group | Words per Cluster | Presentation Time Timing | Rest | Total Time |
|---|---|---|---|---|
| Serial Anticipation | 1 | 6 sec/word (5 sec recall time before word is read) | 1 min | 7 min/trial |
| Codable Clusters | 5 | 30 sec/cluster (25 sec recall time before next cluster is read) | 1 min | 7 min/trial |
| Free Recall | 60 | 5 min to recall list, 1 min to read list | 1 min | 7 min/trial |

A single method of scoring the responses was adopted so as to be able to compare the responses of the three groups. The subjects were not told how their responses would be scored. This score, which will be termed the <u>response score</u>, is a count of the number of response words given irrespective of order on each trial and reflects the number of previously presented stimulus words which a subject is able to produce. Thus, the response score reflects the instructions most directly for the free recall condition and less directly for the other two conditions.

## <u>Assessment of strategy choice</u>

After completing the eighteen learning trials, a task requiring about two hours, the subjects were instructed to respond to a short questionnaire designed to measure their knowledge of the different strategies they employed in learning the list, and the extent to which they believed they used some strategies in preference to others. The questionnaire was designed to reliably assess several aspects of the retrieval mechanisms (strategies) the subjects used in facilitating their correct recall of the sixty words. In constructing the "strategy assessment test", four aspects of retrieval mechanisms were regarded as particularly important: the type of organization, the method of recoding or type of mnemonics used, flexibility of recoding, and identifiability of a retrieval mechanism. With these aspects in mind the following sixteen strategy statements were constructed.

1. No particular strategy. "I did not use any particular strategy in remembering this word."
2. Learning in order. "I remembered this word in the order in which it was presented in the list."
3. Reorganized the words. "I did not try to learn this word in order, but rather tried to reorganize the words, learning this word in the new order."
4. Made clusters. "I grouped the words into clusters and learned this word as a member of a cluster of words."
5. Sequential clusters. "I learned this word as a member of a cluster which contained a sequence of words in the order in which they were presented."
6. Freely formed clusters. "I grouped the words in my own way, ignoring the order in which the words were presented and learned this word as a member of such a group."
7. Selective attention. "I did not pay attention to this word all the time it was presented, ignoring it while I tried to remember other words in the list."
8. Frequent recategorization. "In organizing the cluster containing this word, I frequently shifted the word into a different cluster of words."

9. Common meaning. "In organizing the cluster containing this word, I looked for a concept (some common meaning) relating this word to all the others in the cluster."

10. Sound. "I learned this word by its sound in relation to other words."

11. Images. "I thought of a visual image or scene from which I could get this word and other words all together."

12. Stories. "I learned this word by making up a story containing this word along with others in the list."

13. Sentences or phrases. "I constructed a sentence or phrase containing this word along with others in the list. Then by learning the sentence or phrase, I was able to remember this word and other words in the sentence."

14. Associations. "I learned this word by associating it with the word immediately preceding it."

15. No order. "I did not learn this word in any particular position in the list."

16. Noticed effectiveness. "If my initial strategy in learning this word was not effective, I tried a new one."

The strategy assessment questionnaire consisted of two parts. Part I consisted of the above list of sixteen statements of possible methods for learning to recall the list of words. This was followed by a set of response pages. The subjects were instructed to study this list of possible learning methods or "strategies" carefully, making sure that they understood each statement of a method. After all the subjects had finished studying the set of statements, their questions about any of the method statements were answered. The subjects were then given twelve response sheets, one for every fifth word in the list.[1] Each sheet contained one of the words at the top, and below, the sixteen method statements. The subject's task was then to circle the number preceding each strategy statement which described <u>his</u> strategy for learning the word at the top of the sheet. Subjects were allowed to refer back to their examination booklets from the learning part of the experiment. A subject's score for Part I for each strategy statement is the number of words for which he circled that strategy.

After he had completed these response sheets, each subject read the instructions for Part II, asking him to consider the extent to which he used different strategies at different times in learning the list of words. He was asked to consider the words in three blocks of trials: (1) trials 1 to 6, (2) trials 7 to 12, and (3) trials 13 to 18. For each block of trials, the subject rated each method on a five point scale. Part II consisted of these three sets of ratings. A single score was computed for Part II by summing the three ratings for each strategy statement. This part of the questionnaire was used only in estimating (conservatively) the reliability of the subjects' scores on each of the sixteen strategy statements.

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1. To assess possible effects of this choice of words on strategy choice scores, subjects in the clusters group were asked informally whether or not they had employed strategies involving special treatment of the first word in each cluster. Only one subject answered in the affirmative indicating that there were very few position effects for the condition under which they might have been expected to occur.

# Chapter III

## Hypotheses

In the present experiment there are two sets of independent variables: (1) three treatment conditions and (2) a set of thirteen ability measures, and two sets of dependent variables: (3) the subjects' reports of the extent to which they used sixteen strategies (retrieval mechanisms) and (4) their response measure curves. Variable (1) is discrete and univariate. It is a specification of the amount of order-structure demanded of the subject by specifying cluster size. The greatest amount of pre-specified order occurs in the serial anticipation condition, the least in the free recall condition.

The sets of variables (2), (3), and (4) are continuous and multivariate, and thus the question of the extent to which the variables within each set covary is relevant. In other words, one can ask the question, "Can each of these sets of variables be represented by a smaller set of composite variables or factors?" Once such a reduced set of composite variables has been determined for each set, the investigation of function can then take the form of considering the relationships among composite predictor variables and composite criterion variables for each treatment condition. Cattell (1966) has pointed out that such a research strategy can contribute more to building theories in psychology than the traditional univariate experimental strategy. "For it is futile to seek laws joining single, specific, dependent or independent measured variables when the lawful relations really hold between dependent and independent concepts" (Cattell, 1966, p. 7).

The types of relations to be considered in this study are summarized in Figure 1. We are interested in the extent to which knowledge of state variables (the individual's particular abilities) and stimulus events (characteristics of the task situation) can allow us to predict an individual's covert responses (the strategies he uses) and overt responses (learning performance). Cognitive strategies are here seen as intervening between the stimulus conditions and state variables on the one hand, and responses in the recall task over time on the other. They are considered to be the mode through which the organism variables are expressed in behavior. Thus, each subject, presented with a particular learning task (stimulus event) and possessing his own attributes (state variables), responds to the task situation with a tactical response or strategy (covert response event) which he employs in attempting the required task of recalling a list of words (overt response events). Cronbach (1957) presented a similar diagram in which past situations were included affecting the "organism at present". In the present experiment past situations were uncontrolled, and thus are included within "uncontrolled factors" in the diagram. Other uncontrolled state variables are motivation and stylistic variables. The organism's perceived effectiveness of strategies at a particular stage of practice represents another uncontrolled factor.

Abilities, reported use of strategies, and response measures can consist of either unreduced sets of measures or composite measures which summarize the complete set of measures in a space with fewer dimensions. If such composites are meaningful hypothetical constructs, then our interest is in the extent to which scores on one set of construct factors are predictable from scores on others. Three kinds of hypotheses are to be considered: (1) hypotheses concerning structure, (2) hypotheses

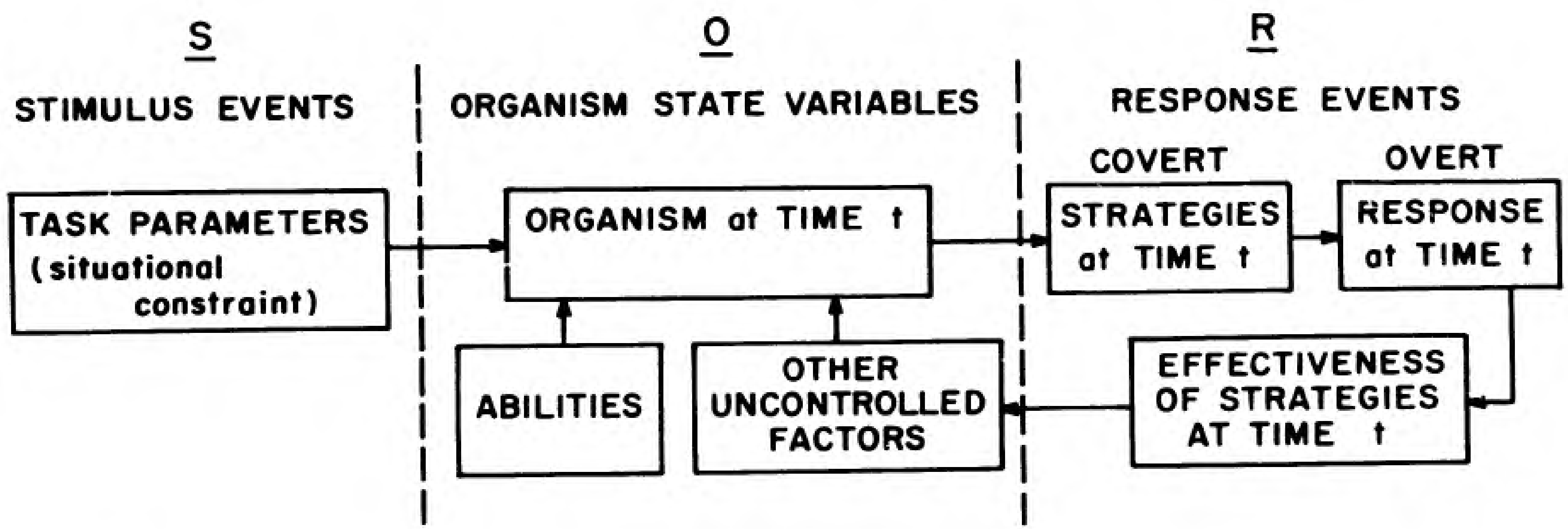


Figure 1. Diagram Representing the Four Variable Sets and Their Functional Interrelationships

concerning treatment group differences in the relative dependence of the measured abilities and response measures and the measured abilities and reported choices of strategies, and (3) hypotheses concerning group differences in relationships of specific abilities to response measures. Each of the latter two kinds of hypotheses can be described as an interaction of treatments and abilities in predicting strategies and performance. Relationships among the two sets of dependent variables can also be considered, specifically the relationships among strategies and response measures for each treatment group.

## Hypotheses concerning structure

Response scores for each subject on the eighteen trials are recorded as a row in a 120 by 18 score matrix. Each row of this subjects by trials matrix constitutes an individual response score curve. It is desired to determine the number of response parameters less than eighteen which are necessary to adequately describe individual differences in response measures for the sample of 120 subjects, and it is desired that such parameters have some heuristic value. Gulliksen (1959) observed that the number of parameters necessary is precisely the number of linearly independent rows or columns of the score matrix. Using this fact as a starting point, Tucker (1960) presented a method of determining learning parameters, scores on generalized learning curves, by an examination of linear dependencies in the score matrix. The number of generalized learning curves necessary is equal to the rank of the score matrix. Having determined the number of parameters needed, it then may be possible to determine generalized learning curves such that they represent increments in performance at different stages of practice. This is the desired heuristic property. In determining generalized response score curves in the present experiment, it was expected that at least three generalized response score curves representing early, middle, and late increments in performance could be determined and that at least three would be necessary to adequately summarize response measures.

The structure of the domain consisting of the subjects' reported strategies was unknown when this study was initiated. However, it was considered likely that the subjects' scores on the sixteen method statements could be summarized in four or five "strategy composites". It was felt that composite axes passing through prominent clusters of strategy statement vectors could be located by rotating the first four or five principal components to simple structure. Composites representing different aspects of learning strategies such as types of organization, methods of recoding, or flexibility of recoding, were considered likely results, since conceptually these aspects of strategies are somewhat independent.

The structure of the particular set of ability tests administered in this experiment was not considered, since the tests were selected as measures of specific ability factors appearing in the literature. The desire was to sample a rather wide range of abilities with a small amount of labor, examining the relation of ability composites defined on the tests with reported strategy choice and response measures. The definition of the ability composites is presented in Chapter V.

Hypotheses concerning the interaction of treatments and abilities in predicting strategies and response measures

Without prior knowledge of the structure of the dependent variables, it was difficult to make explicit hypotheses concerning the interaction of treatments and specific abilities in predicting strategies and response measures. However, the consideration of strategies as mediators suggests some general expectations about the kinds of relationships among variable sets that might occur.

First, it was expected that there would be large treatment group differences among group centroids in the strategies space. It was expected that the strategy measures would reflect treatment conditions more than would the response score curves, since the treatment conditions were chosen so that they would influence strategy choice. It was also considered possible that different strategies could result in similar response score curves. Relationships such as this have not been studied until the present.

The consideration of strategies as mediators leads to the consideration of two important aspects of a learning task. The first aspect may be called the range of effective strategies, i.e. the number of possible strategies which, once employed, are effective in facilitating successful recall. The second aspect of a learning task may be termed the strategy-choice specificity of the task, i.e. the relative number of strategy responses which are likely to be elicited by the learning situation (instructions). If a particular task elicits a wide range of strategies, it can be said to be relatively non-specific; if a particular task elicits a limited number of strategies, it can be said to be relatively specific with respect to strategy choice. The consideration of the experimental tasks in relation to these two aspects led to the second and third hypotheses.

Second, if differences among group centroids in the strategies space occurred, then it was expected that the set of measured ability tests should be more related to scores on the generalized response score curves under one treatment condition than under another. The wider the range of effective strategies, the greater the number of measured abilities that can be predictive of scores on generalized response score curves. This hypothesis presupposes: (1) that specific abilities influence the effectiveness of corresponding strategies, (2) that strategies function as mediators as described in the model in Figure 1, and (3) that the same strategies which facilitate "successful recall" vis-a-vis performance measures which reflect directly the instructions, also facilitate "successful recall" vis-a-vis response scores which do not take into account degree of task-specified order. Since it was expected that, of the three experimental tasks, the free recall task would exhibit the widest range of effective strategies, it was expected that the range of abilities related to scores on generalized response score curves would be greatest in this group and that the degree of association between the measured abilities and these response measures would be highest for this group.

Third, measured ability tests should be more related to strategy choices under one treatment condition than under another. The specificity of a learning task with respect to strategy choice limits the individual's range of possible strategy choices. The model (Figure 1) implies that strategy choice is a function of both task parameters (e.g. instructions) and organism state variables (e.g. abilities). In a highly specific situation, strategy choice should be mainly a function of instructions. In a situation which is non-specific, strategy choice should be more a function of organism state variables. If individuals tend to choose strategies reflecting their particular skills, then in the latter situation, strategy choice should be more a function of abilities than in the former situation. Since the three experimental tasks vary in specificity, the above hypothesis was obtained. The free recall task is without doubt the least specific experimental task, while the clusters and serial anticipation tasks are likely to be relatively specific with respect to strategy choice.

The above two hypotheses were suggested by consideration of the three learning tasks with respect to their range of effective strategies and relative specificity. The consideration of strategies as mediators suggested these two implicit task parameters. Support for these hypotheses would provide indirect support for the model. The following hypothesis is a necessary consequence of the model if treatment group differences in strategy profiles occur.

Fourth, some <u>individual</u> ability factors should be more predictive of response measures under particular treatment conditions than others. If there are large differences in the profiles of strategies used from one treatment condition to another, and if specific abilities are related to specific strategies, then specific abilities should predict response measures under each treatment condition. Which abilities are predictive of response measures under each condition will depend on the particular strategies elicited by that condition and the effectiveness of those strategies. If, on the other hand, the treatment groups do not differ with respect to their profiles of strategies used, then the relationships between individual abilities and response measures may remain constant over the groups. This would be the case if the strategies were equally effective for all conditions. In choosing the seven ability factors described in Chapter II, possible strategies that could be used under the three treatment conditions were considered. Abilities were chosen on the basis of their possible relationships to these strategies.

The first hypothesis provides a means for testing that part of the model which states that learning problems elicit characteristic higher-order responses called strategies; the fourth provides a means for testing that part of the model which states that strategies provide the mechanism through which transfer from abilities to learning performance occurs. The second and third hypotheses were suggested by a consideration of two implicit task parameters involving cognitive characteristics of a task. Support for the second hypothesis provides evidence concerning the hypothesized transfer mechanism. The third hypothesis provides a means for testing that part of the model which states that strategy choice is to some extent a function of abilities.

# Chapter IV

## Analytical Methods

The model presented in Figure 1 suggested two kinds of hypotheses -- those concerning structure and those concerning differential relationships among variable sets. To investigate structure for the measures obtained corresponding to a variable set, one can ask how many dimensions are necessary to span the measures space. This question of dimensionality can be approached by techniques of factor analysis, component analysis, or related techniques, or can be avoided by specifying the number of dimensions by previously defining composite measures corresponding to the relevant hypothetical variables. In the present study, ability factors were defined in this last way, while strategy composites were determined using component analysis to select the number of dimensions necessary to adequately approximate the set of unreduced measures. Response scores at different stages of practice were reduced to a smaller number of response parameters by using Tucker's (1960, 1966) procedure for determining generalized learning curves. Tucker's procedure is described in more detail below.

To investigate differential relationships among variable sets, three kinds of statistical questions can be asked. First, (corresponding to hypothesis one) questions concerning group differences in the reduced and unreduced variable spaces can be considered. For the case of response score curves (the trial scores constituting the unreduced variable set), the question is one of differences in mean response score curves obtained for the treatment groups. For the case of generalized response score curves (the reduced variable set), the question involves differences in group centroids in the reduced space consisting of scores on generalized response score curves. Analogous questions can be asked for the other dependent variable sets.

The second and third kinds of questions are relevant to hypotheses two and three. The second kind of question concerns measuring the degree of association of pairs of variable sets under each treatment condition. In measuring the degree of association of two sets of variables under a particular treatment condition, one computes the canonical correlation between the variable sets and then tests the hypothesis that the two sets of variables are statistically independent in the population corresponding to the particular treatment condition. This procedure is applicable to an investigation of the degree of association of abilities with either dependent variable set under each treatment condition. In considering the degree of association of the two sets of dependent variables, one can ask, "To what extent can I predict a set of response parameters from a set of measures of strategy choice within a treatment condition if effects due to differences in ability are held constant statistically?" This latter problem involves measuring the degree of association of two sets of variables with effects due to the third set held constant. To investigate this kind of problem one computes the canonical-partial correlation between two sets of variables and tests the hypothesis that the two sets of variables are independent when effects due to the third set are held constant.

The third kind of question concerns treatment group differences in the relative dependence of two sets of variables. An hypothesis may specify the relative ordering of the treatment groups from the highest degree of association of two sets of variables to the lowest. Some support for hypotheses concerning the relative ordering of groups can be obtained from the rank order of the groups with respect to the canonical correlations between the two variable sets obtained for each group. However, there is available no method for <u>statistically</u> comparing canonical correlations.

The statistical comparison of groups becomes possible in some instances when one considers the regression of each variable separately on the predictor set. Gulliksen and Wilks (1950) have provided a procedure for testing an hypothesis that two or more groups come from populations possessing the same regression equation. Three separate hypotheses are tested sequentially: the hypothesis of equivalent standard errors of estimate, the hypothesis of parallel regression planes (if the groups do not differ significantly in error of estimate variance), and the hypothesis of equal intercepts (if the groups do not differ significantly in either error of estimate variance or slope). Treatment group differences in the number or pattern of predictors related to a criterion set should produce group differences in standard error of estimate or slope respectively if the groups possess identical variances on the criterion variable. All the above procedures are described in more detail below.

## Determination of generalized response score curves

Response scores for the individuals on the learning trials are combined in a data matrix, $X$, with individuals as rows and trials as columns. It is desired to compute matrices $A_r$ and $S_r$ such that

$$X_r = A_r S_r \tag{1}$$

where $A_r$ is the matrix of individuals' scores on $r$ generalized response score curves and $S_r$ contains $r$ generalized response score curves as rows. Each row of $X$ contains an individual's response score curve while each row of $A_r$ contains an individual's scores on the $r$ generalized response score curves.

Let $a_{i1}, a_{i2}, \ldots, a_{ir}$ represent individual $i$'s scores on $r$ generalized response score curves, and let the row vectors $\underline{s}_1, \underline{s}_2, \ldots, \underline{s}_r$ represent the rows of $S_r$. The elements of these vectors, plotted against trials, represent $r$ generalized response score curves. The sum of these vectors weighted by the individual's scores,

$$a_{i1}\,\underline{s}_1 + a_{i2}\,\underline{s}_2 + \ldots + a_{ir}\,\underline{s}_r = \underline{\tilde{x}}_i \quad ,$$

is a vector $\underline{\tilde{x}}_i$ which is the least squares estimate of individual $i$'s observed response score curve based on $r$ generalized response score curves. Thus the matrix $X_r$ contains least squares estimates of the individual response score curves, represented as rows of $X$, based on $r$ generalized response score curves. The number $r$ should be chosen as small as possible, but so that the elements of the residual matrix $E$, where

$$E = X - X_r \quad , \tag{2}$$

are small and represent essentially random fluctuation.

Tucker (1960, 1966) defined the $A_r$ and $S_r$ matrices so that the mean square of the entries in each column of $A_r$ is unity, i.e.

$$A_r = N^{1/2}\,U_r \tag{3}$$

$$S_r = N^{-1/2}\,B_r\,V_r \tag{4}$$

where $N$ is the number of subjects, $B_r$ is a diagonal matrix containing the first $r$ of the ranked principal roots of $X$, $U_r$ and $V_r$ are the left and right principal vectors of $X$ corresponding to the $r$ principal roots, and the principal roots and vectors are computed using the Eckart-Young (1936) procedure. The application of the Eckart-Young procedure to the computation of principal roots and vectors may be found in Chapter V.

If we let $T$ be any $r$ by $r$ non-singular matrix, we can define

$$A_r^* = A_r T^{-1} \tag{5}$$

$$S_r^* = T S_r \tag{6}$$

and $T$ can be specified so that $A_r^*$ and $S_r^*$ possess some desirable properties. One such property is that if the rows of $S_r^*$, the transformed generalized response score curves, are plotted, they form a monotonic non-decreasing sequence of points over trials. For the purpose of examining the extent to which scores on the generalized response score curves are predictable from ability measurements for subjects within each treatment group, the generalized response score curves are here restricted to monotonically increasing "functions". In the past (Tucker, 1960; Weitzman, 1959; Kohfeld, 1966), "generalized learning curves" so restricted have been found to represent "early, middle, or late learning". Generalized response score curves such as these are very desirable for an analysis of the contribution of abilities and strategies in the prediction of learning performance at different stages of practice under different treatment conditions. A procedure for constructing $T$ such that $A_r^*$ and $S_r^*$ possess the desired property is outlined in Chapter V.

Testing group differences

Hypotheses concerning group differences in the reduced and unreduced variable sets can be tested statistically using multivariate analysis of variance. The hypothesis to be considered is that the centroids of the scores of several treatment groups are equal in the population. This is directly analogous to the univariate case in which an F-ratio is obtained to test the hypothesis that the mean scores on a single dependent variable are equivalent in the population. The multivariate procedure allows one to compute an F-ratio based on Wilks' likelihood-ratio criterion, and to determine a set of discriminant weights for each dependent variable. Together, the F-test and discriminant weights enable the experimenter to make statements about the "magnitude" of the group differences observed (relative to chance) and to identify those dependent variables which contribute most to the observed difference. For a discussion of multivariate analysis of variance and multiple discriminant function see, e.g., Anderson (1958) or Jones (1966).

Testing independence of variable sets

A measure of the degree of dependence of two sets of variables which reflects (a) the range of predictor variables which are related to the criterion set and (b) the strength of these relationships is provided by the canonical correlation between the two sets of variables, a measure of the degree of association of the two variable sets. The canonical correlation also provides a test of independence of two sets of variables.

Let the row vector $\underline{x}' = (x_1, x_2, \ldots, x_p)$ be a set of $p$ random variables and let the row vector $\underline{y}' = (y_1, y_2, \ldots, y_q)$ be a second set of $q$ random variables. One can designate either set as the predictor set if he is interested in the regression of one set on the other. Define two artificial variables $u$ and $v$ such that

$$\begin{aligned} u &= \underline{a}'\,\underline{x} \\ v &= \underline{b}'\,\underline{y} \end{aligned} \tag{7}$$

where $\underline{a}' = (a_1, a_2, \ldots, a_p)$ and $\underline{b}' = (b_1, b_2, \ldots, b_q)$ are two sets of weights chosen such that the correlation between $u$ and $v$ is a maximum. This correlation $r_{u,v} = r_{\underline{x},\underline{y}}$ is the canonical correlation between the two sets of random variables. Under the assumption that the sets of random variables are multivariate normal, one can test the hypothesis of independence by testing $H_o$: $r^2_{\underline{x},\underline{y}} = 0$ against the one-sided alternative. If the intercovariances of all variables are given by

$$\Sigma = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma'_{12} & \Sigma_{22} \end{pmatrix} \tag{8}$$

where $\Sigma_{11}$ is a matrix of intercovariances of the $\underline{x}$-set, $\Sigma_{22}$ is a matrix of intercovariances of the $\underline{y}$-set, and $\Sigma_{12}$ is a matrix of covariances of the $\underline{x}$-set with the $\underline{y}$-set, then $r^2_{\underline{x},\underline{y}}$ is the largest characteristic root of $\Sigma_{11}^{-1}\,\Sigma_{12}\,\Sigma_{22}^{-1}\,\Sigma'_{12}$. In practice, one replaces all statistics with their maximum likelihood estimates and carries out the significance test using Heck's charts (Heck, 1960) or the Bartlett (1941) approximation to a chi-square statistic. For a full discussion of canonical correlation see, e.g., Anderson (1958).

The second kind of hypothesis concerning independence, testing the hypothesis that the two sets of dependent variables are independent when a third set of "outside variables" is held constant, is a generalization of partial correlation. Let $\underline{x}$ and $\underline{y}$ be the two dependent variable sets defined as before, and let $\underline{z}' = (z_1, z_2, \ldots, z_s)$ be a set of $s$ "outside" variables to be held constant statistically. Let the intercovariances of all three sets be given by

$$\Sigma = \begin{pmatrix} \Sigma_{11} & \Sigma_{12} & \Sigma_{13} \\ \Sigma_{12}' & \Sigma_{22} & \Sigma_{23} \\ \Sigma_{13}' & \Sigma_{23}' & \Sigma_{33} \end{pmatrix} \tag{9}$$

where $\Sigma_{11}$, $\Sigma_{12}$, and $\Sigma_{22}$ are defined as before; $\Sigma_{33}$ is a matrix of intercovariances of the $\underline{z}$-set; and $\Sigma_{13}$ and $\Sigma_{23}$ contain as elements the covariances of the $\underline{x}$ and $\underline{y}$ sets with the $\underline{z}$-set respectively. Then

$$\begin{aligned} P_{11} &= \Sigma_{11} - \Sigma_{13}\Sigma_{33}^{-1}\Sigma_{13}' \\ P_{22} &= \Sigma_{22} - \Sigma_{23}\Sigma_{33}^{-1}\Sigma_{23}' \\ P_{12} &= \Sigma_{12} - \Sigma_{13}\Sigma_{33}^{-1}\Sigma_{23}' \end{aligned} \tag{10}$$

give the partial covariance matrices corresponding to $\Sigma_{11}$, $\Sigma_{22}$, and $\Sigma_{12}$ with the $\underline{z}$-set held constant. The canonical-partial correlation is equal to the largest characteristic root of $P_{11}^{-1} P_{12} P_{22}^{-1} P_{12}'$. The test of independence is made in the same way, except that the sample size is reduced by $s$ in computing the parameters for Heck's charts. If the number of variables controlled is large, then the canonical-partial correlation required for significance can be very large. Rolf Bargmann (personal communication) has generalized this procedure even further to the case in which two sets of outside variables are controlled, one set "partialled out" from $\underline{x}$ and another "partialled out" from $\underline{y}$.

## Regression tests

The third kind of question concerns testing the hypothesis that treatment groups come from populations possessing the same regression equation as a means of statistically comparing groups with respect to the degree of dependence of each criterion measure on the predictor set. Gulliksen and Wilks (1950) presented a statistical procedure for performing such tests which involves successively testing three hypotheses: (1) that all standard errors of estimate are equal, (2) that all regression planes are parallel (assuming hypothesis (1)), and (3) that the regression planes are identical (assuming hypotheses (1) and (2)). The tests that they presented are large sample tests based on straightforward application of Neyman-Pearson likelihood-ratio theory. For testing each hypothesis, a likelihood-ratio $\lambda_h$ is obtained. For large samples, $-2 \log_e \lambda_h$ is distributed as chi-square with degrees of freedom equal to the number of free parameters under the alternative hypothesis. The number of degrees of freedom used for the large sample chi-square test of each of the three hypotheses is presented in Gulliksen and Wilks (1950).

There is no guarantee, however, that the Gulliksen-Wilks regression tests always provide a statistical test for hypotheses concerning group differences in the range of predictors which are related to each criterion and the strength of these relationships (i.e. group differences in the degree of association of each criterion with a set of predictors). The multiple correlation of a criterion with a set of predictors is a measure of the degree of association of the criterion variable with the set of predictor variables. Just as in the case of canonical correlation, a statistical test of the hypothesis of independence can be made on each multiple correlation.

Statistical tests of group differences in the multiple correlations are provided by the test of the hypothesis that the groups possess equal error of estimate variances, but <u>only</u> when the groups possess identical variances on the criterion variable, since

$$s^2_{y \cdot x_1, \ldots, x_p} = (1 - R^2_{y \cdot x_1, \ldots, x_p}) s^2_y$$

where $s^2_{y \cdot x_1, \ldots, x_p}$ is the error of estimate variance obtained for predicting $y$ from $x_1, \ldots, x_p$ under a particular treatment condition, $s^2_y$ is the variance of the criterion variable $y$, and $R_{y \cdot x_1, \ldots, x_p}$ is the multiple correlation of $y$ with $x_1, \ldots, x_p$ (the set of $p$ predictors). An important pre-test, then, is a test for homogeneity of variance on each criterion variable. If the treatment groups do not differ significantly with respect to criterion variance, then for large samples, the Gulliksen-Wilks test of equality of error of estimate variances provides a test of differences in degree of association.[1] A possible procedure to use if there are small (but insignificant) treatment group differences in the variance on the criterion variable might be to obtain a "pooled" estimate of the criterion variance $s^2_y$ over treatment groups, and use this pooled estimate in the test of equality of error of estimate variances.

If treatment groups do not differ in either criterion variance or error of estimate variance, then the test of group differences in the

1. The Gulliksen-Wilks tests are large sample tests. For large samples, a test of homogeneity is likely to detect rather small differences in criterion variance.

slopes of the regression planes provides a means for evaluating statistically differences in the patterns of relationships of the predictor variables with each criterion. When treatment groups do differ significantly with respect to variance on a criterion, it is possible that they may not differ significantly with respect to standard error of estimate. If this case occurs, then tests for differences in slopes may be performed.

# Chapter V

## Group Differences in the Reduced and Unreduced Spaces

The present section is concerned with presenting the results of analyses of group differences with respect to each variable set considered individually. Results concerning the interrelationships among the three variable sets -- abilities, strategies, and response measures -- will be considered in the next section. Results presented here consist of the basic statistics for strategy statements and ability tests, comparison of group centroids for the unreduced variable sets -- group response score curves and strategy statements -- the reduction of variable sets, and comparisons of group centroids for the reduced variable sets.

### Reliabilities of measures

Sample means, standard deviations, and estimated reliabilities for each of the strategy statements are presented in Table 1. The means and standard deviations are computed over all 120 subjects and are for Part I of the strategy assessment questionnaire. Each mean is the mean number of words (out of a possible twelve) for which each statement was circled. Reliability estimates were computed by correlating the scores obtained for Part II with those obtained for Part I. Three subjects failed to complete Part II, and therefore reliability estimates were computed over only 117 subjects. These reliability estimates are likely to be underestimates, since the type of judgment called for in Part I of the questionnaire is quite different from that required in Part II. In Part I the subject must remember the method or strategy he used in learning a particular word. (Experience with pilot subjects indicated that this is easy

Table 1

Reliabilities, Means, and Standard Deviations of Strategy Statements

| Strategy Statement | Estimated Reliability | Mean | Standard Deviation |
|---|---|---|---|
| 1. No Particular Strategy | .450 | 1.342 | 1.573 |
| 2. Learning in Order | .616 | 4.775 | 4.094 |
| 3. Reorganized | .467 | .842 | 2.327 |
| 4. Made Clusters | .521 | 3.242 | 3.766 |
| 5. Sequential Clusters | .676 | 2.583 | 3.089 |
| 6. Freely-formed Clusters | .605 | 1.650 | 2.667 |
| 7. Selective Attention | .381 | 2.600 | 3.310 |
| 8. Frequent Recategorization | .436 | .308 | .603 |
| 9. Common Meaning | .638 | 1.492 | 2.198 |
| 10. Sound | .559 | 1.942 | 2.177 |
| 11. Images | .668 | 1.850 | 2.452 |
| 12. Stories | .838 | 1.675 | 2.858 |
| 13. Sentences or Phrases | .713 | 1.717 | 2.454 |
| 14. Associations | .609 | 2.433 | 2.886 |
| 15. No Order | .610 | 1.250 | 2.563 |
| 16. Noticed Effectiveness | .203 | .942 | 1.660 |
| | N = 117 | N = 120 | N = 120 |

Table 2

Reliabilities, Means, and Standard Deviations of Ability Tests

| Ability Test | Estimated Reliability | Mean | Standard Deviation |
|---|---|---|---|
| 1. Hidden Patterns | --- | 34.117 | 9.790 |
| 2. Copying | --- | 16.492 | 4.699 |
| 3. Concealed Words | .554 | 13.708 | 3.018 |
| 4. Four-letter Words | --- | 20.775 | 5.583 |
| 5. Associations IV | .477 | 4.675 | 2.374 |
| 6. Word Arrangement | --- | 13.608 | 4.278 |
| 7. Object Naming | .539 | 9.400 | 3.743 |
| 8. Wide-range Vocabulary | .726 | 16.112 | 3.736 |
| 9. Associational Fluency | .715 | 14.725 | 4.674 |
| 10. Expressional Fluency | .356 | 4.850 | 2.170 |
| 11. Alternate Uses | .659 | 16.350 | 4.823 |
| 12. First and Last Names | .789 | 22.025 | 7.048 |
| 13. Auditory Letter Span | .615 | 7.975 | 2.580 |

N = 120

for subjects in experiments involving repeated recall of a list of materials.) In Part II he must think of a stage in his learning (early, middle, or late) and rate the number of words for which he used each method. The data for Part II indicated a tendency for subjects to use few strategies late in learning; presumably the words had already been "learned" and recall was relatively automatic. Thus, scores on Part II should not necessarily be expected to correlate perfectly with those on Part I. The strategy statements for which reliabilities estimated in this way are low very possibly are those for which the two types of reports should be least related. Taking these considerations into account the true reliabilities are probably quite high.

Means and standard deviations for the thirteen ability tests are presented in Table 2 together with reliability estimates for nine of the tests. Two parts were administered for tests 7, 9, 10, 11, and 12 (as numbered in the table) and reliability estimates for these tests were obtained by correlating scores on the two parts. For the remaining eight tests only one part was administered. Reliability estimates were computed for four of these tests by dividing the tests into roughly parallel halves. Such divisions were impossible for tests 1, 2, and 4 because they were speeded tests, and for test 6 since a single part consisted of only one item. The test called "Expressional Fluency" was not considered in subsequent analyses. The reliability estimates obtained from the present sample for the ability tests are comparable in magnitude to those obtained for the strategy measures.

Comparison of group centroids for the unreduced variable sets

Mean response score curves for the three treatment groups are plotted in Figure 2. It can be seen that the mean response score curves for the serial anticipation and clusters groups are virtually identical (with the means for the serial anticipation condition being slightly higher for a majority of the trials), while the free recall curve is higher initially and then considerably lower than the curves for the other two groups after trial five. The serial anticipation curve shows during the first seven trials the almost linear increase which is typical for this condition. The free recall curve has the typical decreasing slope, but the difficulty of the free recall task observed here is perhaps greater than usual.

To test the hypothesis that the three groups have identical mean response score curves and to ascertain which trials contribute most to observed differences, a multivariate analysis of variance was performed. A summary of this analysis is reported in Table 3. The F-test using Rao's (1952) approximation to the F-ratio (Jones, 1966) indicates a highly significant difference among the group response score curves. An examination of the characteristic roots of $C_b C_w^{-1}$ (where $C_b$ is the between variance-covariance matrix and $C_w$ the within variance-covariance matrix) indicates that the groups differ for the most part along a single dimension. The characteristic vector corresponding to the larger of these two characteristic roots contains the coefficients of the discriminant function which maximally discriminates among groups in a least squares sense. The standardized coefficients are presented for each trial in Table 3 and indicate by their relative absolute value which trials contribute most to

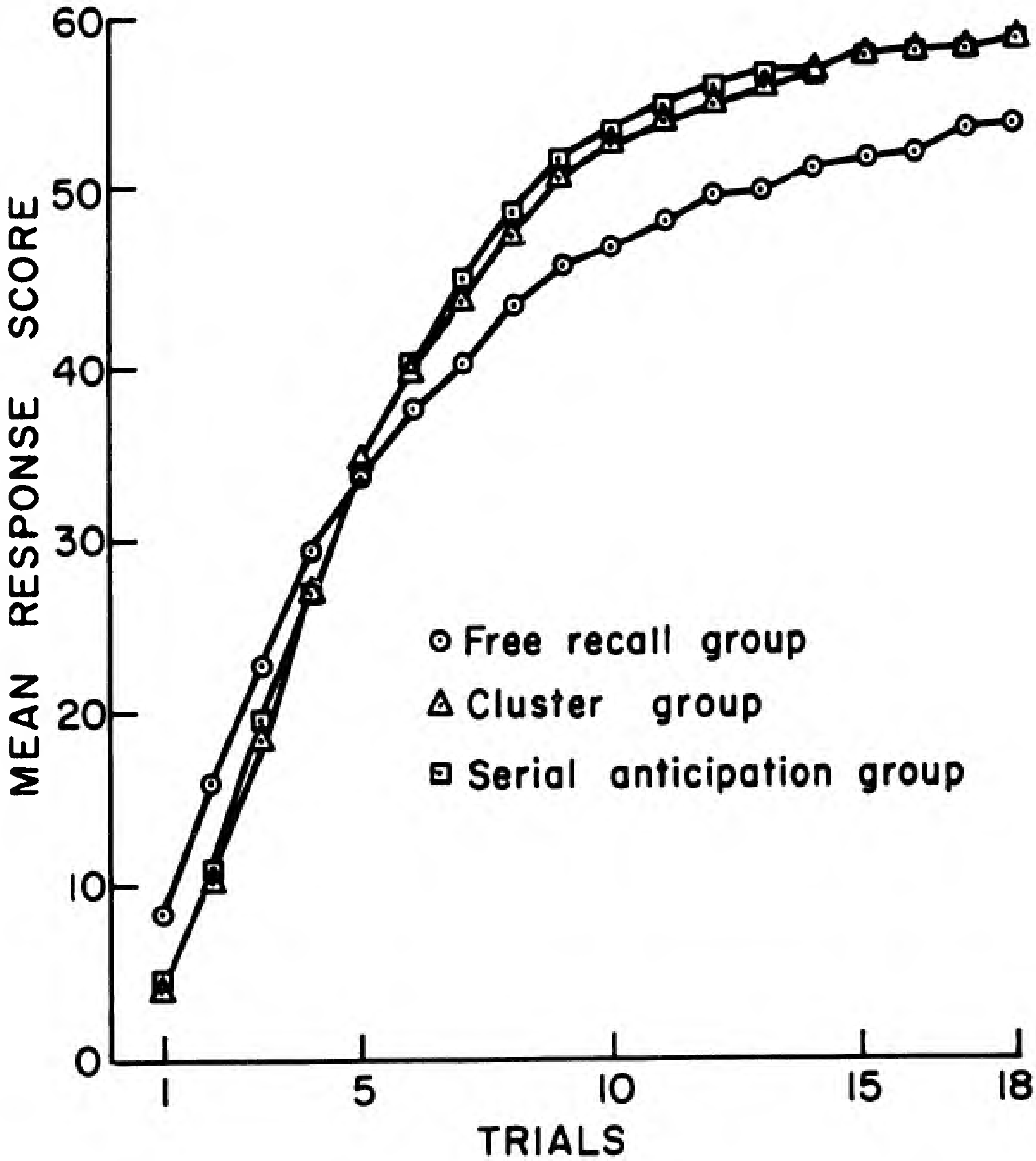


Figure 2. Mean Response Score Curves for the Three Treatment Conditions

Table 3

Group Response Score Curves and Multivariate Analysis of Variance

| | Mean Response Score Curves | | | Discriminant Function | | Standard Deviations | | |
|---|---|---|---|---|---|---|---|---|
| Trial | Free Recall | Clusters | Serial Anticipation | Raw-score Coefficients | Standardized Coefficients | Free Recall | Clusters | Serial Anticipation |
| 1 | 8.100 | 3.825 | 4.100 | -.32 | -.80 | 3.011 | 1.880 | 2.499 |
| 2 | 15.900 | 10.425 | 10.850 | -.12 | -.62 | 4.272 | 5.387 | 5.646 |
| 3 | 22.475 | 18.400 | 19.500 | .02 | .15 | 6.064 | 7.507 | 8.111 |
| 4 | 28.950 | 26.800 | 26.775 | .04 | .37 | 7.404 | 10.148 | 10.052 |
| 5 | 33.500 | 34.025 | 33.900 | .02 | .21 | 7.952 | 11.722 | 11.277 |
| 6 | 37.150 | 39.300 | 39.675 | -.08 | -.87 | 8.390 | 12.304 | 11.685 |
| 7 | 39.800 | 43.500 | 44.825 | .02 | .22 | 8.751 | 12.034 | 11.188 |
| 8 | 43.050 | 47.050 | 48.475 | -.01 | -.10 | 8.397 | 11.558 | 10.614 |
| 9 | 45.350 | 50.425 | 51.500 | .03 | .28 | 8.050 | 10.210 | 9.925 |
| 10 | 46.150 | 52.475 | 52.850 | .08 | .72 | 7.305 | 9.416 | 10.194 |
| 11 | 47.975 | 53.775 | 54.550 | -.01 | -.08 | 7.184 | 8.235 | 9.342 |
| 12 | 49.400 | 54.900 | 55.725 | -.05 | -.39 | 6.920 | 7.537 | 8.587 |
| 13 | 49.500 | 55.700 | 56.300 | .06 | .45 | 6.691 | 8.231 | 7.596 |
| 14 | 51.050 | 56.850 | 56.650 | .02 | .13 | 5.991 | 6.049 | 7.976 |
| 15 | 51.575 | 57.300 | 57.350 | -.13 | -.82 | 5.982 | 6.174 | 6.747 |
| 16 | 51.925 | 57.950 | 57.750 | .18 | 1.03 | 6.006 | 5.282 | 5.786 |
| 17 | 53.300 | 57.900 | 57.875 | -.11 | -.60 | 5.971 | 5.448 | 4.757 |
| 18 | 53.475 | 58.125 | 58.200 | .04 | .21 | 5.556 | 5.770 | 4.214 |

Wilks' lambda criterion = .37

F (36, 200) = 3.57 ; p is less than .005

Characteristic roots: 85.88 , 5.41

the observed differences among response score curves.

Mean scores on strategy statements for the three treatment groups are presented in Table 4. By inspection, all three groups differ considerably in mean "strategy statement profile". It is interesting to note that the two groups which had almost identical mean response score curves -- the clusters and serial anticipation groups -- differ considerably in their mean profile of strategy statements, suggesting that the response score curves fail to reflect the fact that these two groups approach the learning problem in quite different ways.

In Table 4 are also reported results from a multivariate analysis of variance testing the hypothesis that the three treatment groups have identical "strategy statement profiles" (i.e., that the centroids for the treatment groups in the space consisting of strategy statements are identical in the population). The significance test, again using Rao's approximation to the F-ratio, indicates a highly significant difference among the group centroids. Since the second characteristic root of $C_b C_w^{-1}$ is large relative to the first and statistically significant ($\chi^2(15) = 46.95$, $p < .001$), the groups can be considered to differ along two orthogonal dimensions.[1] Therefore two sets of discriminant coefficients were computed, namely the two characteristic vectors associated respectively with the two characteristic roots. An examination of the two sets of standardized coefficients suggests that the same statements contribute most to the observed differences for both discriminant functions.

1. See Rao (1952) for the appropriate significance test.

Table 4

Mean Scores on Strategy Statements and Multivariate Analysis of Variance

| | Mean Strategy Scores | | | Discriminant Function Coefficients | | | | Standard Deviations | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Raw-score | | Standardized | | | | |
| | Free Recall | Clusters | Serial Antici-pation | I | II | I | II | Free Recall | Clusters | Serial Antici-pation |
| No Particular Strategy | 1.750 | 1.725 | .550 | -.24 | -.20 | -.36 | -.30 | 1.691 | 1.754 | .846 |
| Learning in Order | 1.825 | 5.675 | 6.825 | .08 | -.15 | .28 | -.81 | 1.986 | 4.097 | 4.094 |
| Reorganized | 1.550 | .800 | .175 | .03 | -.03 | .07 | -.07 | 3.396 | 1.977 | .501 |
| Made Clusters | 4.050 | 2.750 | 2.925 | -.07 | .04 | -.26 | .15 | 3.464 | 3.998 | 3.826 |
| Sequential Clusters | 1.375 | 2.200 | 4.175 | .10 | .09 | .29 | .26 | 1.793 | 3.228 | 3.388 |
| Freely-formed Clusters | 3.625 | .975 | .350 | -.16 | .17 | -.37 | .39 | 3.387 | 1.761 | 1.051 |
| Selective Attention | 2.725 | 3.075 | 2.000 | -.06 | -.07 | -.20 | -.23 | 3.870 | 3.654 | 2.184 |
| Frequent Recategorization | .450 | .150 | .325 | .39 | .39 | .23 | .23 | .783 | .362 | .572 |
| Common Meaning | 1.925 | 1.000 | 1.550 | -.07 | .11 | -.15 | .24 | 2.411 | 1.783 | 2.331 |
| Sound | 1.850 | 2.025 | 1.950 | -.03 | -.12 | -.07 | -.26 | 1.916 | 2.293 | 2.375 |
| Images | 1.150 | 2.350 | 2.050 | .06 | -.24 | .15 | -.58 | 2.058 | 2.293 | 2.864 |
| Stories | 1.225 | 1.850 | 1.950 | .02 | -.02 | .06 | -.06 | 2.380 | 3.017 | 3.170 |
| Sentences or Phrases | .675 | 2.100 | 2.375 | .05 | -.06 | .12 | -.14 | 1.207 | 2.799 | 2.743 |
| Associations | 1.150 | 1.150 | 5.000 | .30 | .24 | .68 | .54 | 1.477 | 1.511 | 3.320 |
| No Order | 2.425 | 1.075 | .250 | .00 | -.02 | .00 | -.05 | 3.493 | 2.212 | .809 |
| Noticed Effectiveness | 1.425 | .550 | .850 | -.07 | .17 | -.11 | .28 | 1.752 | 1.239 | 1.861 |

Wilks' lambda criterion = .26

F (32, 204) = 6.19 ; p is less than .001

Characteristic roots: 83.91 , 34.89

Determination of generalized response score curves

Response scores for 120 subjects on 18 learning trials were combined in the data matrix $X$ with individuals as rows and trials as columns. Following the procedure of Tucker (1960, 1966) the principal roots and vectors of $X$ were computed. This involved computing the matrix of sums of squares and cross products $P_x = X'X$ and computing the characteristic roots and vectors of $P_x$. The principal roots of $X$ are the square roots of the characteristic roots of $P_x$. These characteristic roots (principal roots, squared) are reported in Table 5.

Mean square ratios, similar to variance ratios used in analysis of variance were determined for each principal root using Tucker's (1960, 1966) procedure. The mean square ratios, presented in Table 5, are an index of the rank of $X$. Each mean square ratio $(MSR_m)$ $(m = 1, 2, \ldots, 18)$ is a ratio of the mean sum of squares of the entries in $X$ accounted for by root $m$. Inspection of the column of mean square ratios indicates that the first three are somewhat above the remaining values, and that retaining the fourth and fifth roots in the approximation might further decrease the error of approximation $X - X_r$, where $X_r$ is an approximation to $X$ based on a rank of $r$. Therefore five roots $(r = 5)$ were retained in the approximation of equation (1).

The characteristic vectors corresponding to the characteristic roots of $P_x$ were computed. These are defined as the right principal vectors of $X$, the rows of the matrix $V$ (say). Let $B$ be a diagonal matrix containing the principal roots of $X$ in its main diagonal such that the roots are ordered from greatest to least. Let the vectors in $V$ be ordered so that they correspond row by row to the rows of $B$. Then the

Table 5

Principal Roots of Data Matrix

| Root Number | Principal Root | Roots, Squared Cumulative | Degrees of Freedom Factor | Degrees of Freedom Cumulative | Mean Square Ratio |
|---|---|---|---|---|---|
| | | 4579622.19 | | 2160 | |
| 1 | 4534010.69 | 45611.53 | 137 | 2023 | 1467.86 |
| 2 | 29511.79 | 16099.74 | 135 | 1888 | 25.64 |
| 3 | 6959.76 | 9139.98 | 133 | 1755 | 10.05 |
| 4 | 2308.94 | 6831.04 | 131 | 1624 | 4.19 |
| 5 | 1248.15 | 5582.89 | 129 | 1495 | 2.59 |
| 6 | 822.70 | 4760.19 | 127 | 1368 | 1.86 |
| 7 | 766.02 | 3994.17 | 125 | 1243 | 1.91 |
| 8 | 637.69 | 3356.48 | 123 | 1120 | 1.73 |
| 9 | 600.48 | 2756.00 | 121 | 999 | 1.80 |
| 10 | 494.94 | 2261.06 | 119 | 880 | 1.62 |
| 11 | 466.95 | 1794.11 | 117 | 763 | 1.70 |
| 12 | 384.58 | 1409.53 | 115 | 648 | 1.54 |
| 13 | 383.29 | 1026.24 | 113 | 535 | 1.77 |
| 14 | 295.63 | 730.62 | 111 | 424 | 1.55 |
| 15 | 238.49 | 492.12 | 109 | 315 | 1.40 |
| 16 | 185.22 | 306.90 | 107 | 208 | 1.17 |
| 17 | 163.64 | 143.26 | 105 | 103 | 1.12 |
| 18 | 143.26 | .00 | 103 | 0 | .00 |

Table 6

Unrotated Generalized Response Score Curves

| Trial | I | II | III | IV | V |
|---|---|---|---|---|---|
| 1 | 5.315 | - .724 | 1.892 | .943 | 1.352 |
| 2 | 12.554 | -2.835 | 3.816 | 1.426 | .486 |
| 3 | 20.571 | -4.639 | 3.122 | .769 | -.664 |
| 4 | 28.222 | -6.025 | 2.290 | .170 | -.306 |
| 5 | 34.682 | -6.306 | .483 | -1.412 | -.448 |
| 6 | 39.676 | -5.755 | - .946 | -1.890 | -.472 |
| 7 | 43.754 | -4.617 | -1.840 | - .696 | .463 |
| 8 | 47.144 | -3.220 | -2.181 | .596 | 1.537 |
| 9 | 49.939 | -1.719 | -1.650 | .889 | .683 |
| 10 | 51.314 | - .503 | -1.865 | 1.367 | .111 |
| 11 | 52.780 | .506 | -1.291 | 1.450 | -.618 |
| 12 | 53.879 | 1.368 | - .605 | .887 | -.791 |
| 13 | 54.337 | 2.044 | - .284 | .109 | -.680 |
| 14 | 55.208 | 2.794 | .582 | .421 | -.909 |
| 15 | 55.712 | 3.264 | .601 | - .159 | -.607 |
| 16 | 56.078 | 3.933 | 1.045 | - .626 | .073 |
| 17 | 56.445 | 3.907 | 1.610 | -1.110 | .877 |
| 18 | 56.674 | 4.033 | 1.702 | -1.382 | .943 |

left principal vectors of $X$ are given by

$$U = X V' B^{-1} \quad . \tag{11}$$

Equation (11) was used to compute the matrix $U$ of left principal vectors. Let $U_r$ , $B_r$ , and $V_r$ be defined as above in Chapter IV. Then equations (3) and (4) can be used to compute $A_r$ , the matrix of individuals' scores on $r$ generalized response score curves, and $S_r$ , the matrix containing the $r$ generalized response score curves as rows, respectively. The matrices $A_r$ and $S_r$ were computed in this way and the transposed matrix $S_r'$ is presented in Table 6.

Having obtained the approximation to the matrix of raw response score curves given by equation (1), it was desired to transform $A_r$ and $S_r$ so that the transformed matrix $S_r^*$ possesses the property described in Chapter IV, namely that when the transformed generalized response score curves are plotted, they represent a monotonic non-decreasing sequence of points over trials. To accomplish this transformation it was necessary to determine the transformation matrix $T$ specified in equations (5) and (6). It was further specified initially that $T$ be an orthonormal matrix, i.e. that $T' = T^{-1}$ . The procedure used to construct a transformation matrix with the desired properties will now be described.

First, plots were made of each pair of rows of $S_r$ . Each plot for a pair of coordinates (any pair of rows of $S_r$) contained a configuration of trial points. Successive trial points were connected by straight lines. An examination of all ten of these plots indicated points of inflection in some of the configurations and that these occurred very prominently for trials 2, 4, and 7. A submatrix of $S_r$ consisting of columns 1, 2, 4, 7, and 18 was constructed and labeled $F_c$ . The matrix $F_c$

is reported in Table 7.

It was then desired to construct an orthonormal transformation matrix $T$ such that

$$T\ F_c = G \tag{12}$$

where $G$ is an upper triangular matrix of order five. It is always possible to obtain such a transformation by applying the Gram-Schmidt process which allows one to construct an orthonormal basis for a vector space from any set of vectors which form a basis for the space (c.f. Hohn, 1958, p. 203). The requirement that the product of equation (12) be upper triangular was chosen as a means of initially producing transformed generalized response score curves representing increments at different stages of practice. Since $G$ is upper triangular, only one generalized response score curve has values greater than zero for trial one (all others have been set equal to zero for the first trial). For trial two, two generalized response score curves have values greater than zero, and so on for the other selected trials.

The obtained transformation matrix $T$ and the product matrix $G$ are reported in Table 7. The transformation matrix was constructed by applying the Gram-Schmidt process in constructing an orthonormal basis for $F_c$. The obtained transformation matrix was substituted into equations (5) and (6). Thus $A_r^*$, the transformed matrix of individuals' scores on $r$ generalized response score curves, was obtained.[2] The latter is reported in Table 8. The transformed generalized response score curves (columns of Table 8) are plotted against trials in Figure 3.

2. Note that since the constructed $T$ was not perfectly column-wise orthonormal, $T^{-1}$ was used rather than $T'$ in equation (5).

Table 7

Construction of the Orthonormal Transformation Matrix

Sub-matrix Chosen from the Matrix $S_r$
of Unrotated Generalized Response Score Curves

(Matrix $F_c$)

| | | Learning Trial | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 4 | 7 | 18 |
| Unrotated | I | 5.315 | 12.554 | 28.222 | 43.754 | 56.674 |
| Generalized | II | -.724 | -2.835 | -6.025 | -4.617 | 4.033 |
| Response | III | 1.892 | 3.816 | 2.290 | -1.840 | 1.702 |
| Score | IV | .943 | 1.426 | .170 | - .696 | -1.382 |
| Curves | V | 1.352 | .486 | - .306 | .463 | .943 |

Orthonormal Transformation Matrix T

| | | Unrotated Generalized Response Score Curves | | | | |
|---|---|---|---|---|---|---|
| | | I | II | III | IV | V |
| Transformed | A | .897499 | -.122255 | .319486 | .159237 | .228302 |
| Generalized | B | .244394 | -.408334 | -.130672 | -.223808 | -.840470 |
| Response | C | .322877 | .171148 | -.837973 | -.334733 | .228504 |
| Score | D | .168195 | .835885 | .006063 | .297415 | -.429550 |
| Curves | E | .047512 | .330237 | .413472 | -.847184 | .002381 |

Upper Triangular Matrix G

| | | Learning Trial | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 4 | 7 | 18 |
| Transformed | A | 5.922 | 13.171 | 26.755 | 39.241 | 50.911 |
| Generalized | B | 0 | 2.999 | 9.269 | 12.586 | 11.498 |
| Response | C | 0 | 0 | 6.035 | 15.218 | 18.241 |
| Score | D | 0 | 0 | 0 | 3.083 | 12.098 |
| Curves | E | 0 | 0 | 0 | 0 | 5.901 |

Table 8

Transformed Generalized Response Score Curves

| Trial | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | 5.922 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2 | 13.171 | 2.999 | 0.004 | -0.020 | 0.031 |
| 3 | 19.998 | 6.900 | 2.823 | 0.115 | 0.083 |
| 4 | 26.755 | 9.277 | 6.035 | -0.094 | 0.153 |
| 5 | 31.725 | 11.680 | 10.084 | 0.338 | 0.960 |
| 6 | 35.602 | 12.990 | 13.143 | 1.498 | 1.193 |
| 7 | 39.241 | 12.586 | 15.218 | 3.083 | 0.384 |
| 8 | 42.454 | 11.696 | 16.650 | 4.742 | -0.227 |
| 9 | 44.801 | 12.349 | 17.071 | 6.924 | 0.371 |
| 10 | 45.763 | 12.591 | 17.613 | 8.558 | 0.343 |
| 11 | 46.985 | 13.056 | 17.583 | 9.989 | 0.911 |
| 12 | 47.956 | 13.154 | 17.660 | 10.806 | 2.008 |
| 13 | 48.289 | 13.029 | 17.940 | 11.171 | 3.045 |
| 14 | 49.253 | 12.945 | 17.467 | 12.140 | 3.428 |
| 15 | 49.631 | 12.750 | 17.958 | 12.316 | 4.107 |
| 16 | 50.100 | 12.041 | 18.130 | 12.508 | 4.926 |
| 17 | 50.720 | 11.500 | 18.116 | 12.062 | 5.580 |
| 18 | 50.911 | 11.498 | 18.241 | 12.098 | 5.901 |

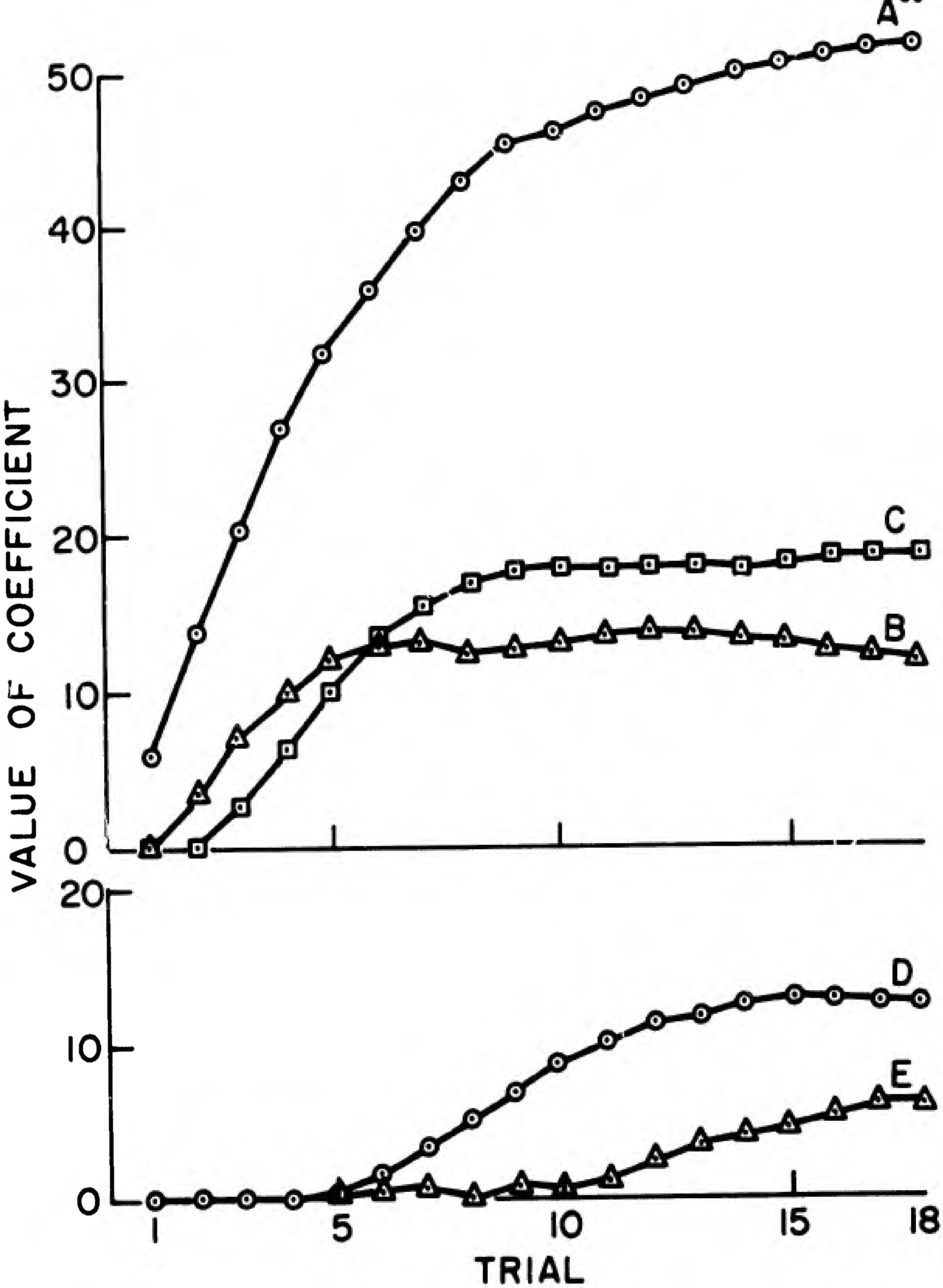


Figure 3. Coefficients of Transformed Generalized Response Score Curves (Entries in the Matrix $S_r^*$ ) Plotted Against Trials

Since these transformed generalized response score curves were found to be approximately monotonic non-decreasing and are interpretable as performance increments at different stages of practice, the initial transformation was used without further adjustment. In the remainder of this report the words "generalized response score curves" will be used to refer to these transformed generalized response score curves and the curves will be denoted with the Roman numerals I - V rather than the letters A - E respectively.

Determination of strategy composites

Scores for all 120 subjects for each of the sixteen strategy statements were combined in a 120 by 16 matrix of strategy scores. The matrix of intercorrelations among the strategy statements was then computed. The problem of determining a set of strategy composites which are sufficient in number to reproduce observed differences among individuals and which are linear combinations of scores on strategy statements which were observed to covary was investigated using the method of principal components (c.f. Anderson, 1958). It was desired first to obtain an adequate lower rank approximation to the matrix of standardized strategy scores by choosing to retain a suitable number of principal components in the approximation. It was desired also to rotate the principal components to simple structure so that strategy composites corresponding to clusters of strategy statements could be defined. Hypotheses concerning the probable structure of the strategy statements were offered in Chapter III.

The characteristic roots of the matrix of intercorrelations of strategy statements taking unity on the main diagonal are reported in Table 9.

Table 9

Characteristic Roots of Matrix of
Intercorrelations of Strategy Statements

| Number | Value |
|---|---|
| 1 | 3.0479 |
| 2 | 2.5479 |
| 3 | 1.5896 |
| 4 | 1.4237 |
| 5 | 1.1617 |
| 6 | .9266 |
| 7 | .8179 |
| 8 | .7693 |
| 9 | .6344 |
| 10 | .6212 |
| 11 | .5098 |
| 12 | .4677 |
| 13 | .4363 |
| 14 | .3865 |
| 15 | .3692 |
| 16 | .2903 |

Table 10

Unrotated Principal Components of Strategy Statements

| Strategy Statement | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. No Particular Strategy | .010 | .553 | -.266 | -.123 | .285 |
| 2. Learning in Order | .372 | -.560 | .300 | -.055 | .152 |
| 3. Reorganized | -.694 | .086 | .097 | -.201 | -.283 |
| 4. Made Clusters | -.577 | -.279 | .372 | .093 | -.060 |
| 5. Sequential Clusters | .310 | -.443 | .630 | -.006 | -.105 |
| 6. Freely-formed Clusters | -.802 | .298 | .108 | .085 | .052 |
| 7. Selective Attention | -.359 | -.122 | .457 | -.433 | -.133 |
| 8. Frequent Recategorization | -.537 | -.118 | .258 | .190 | .343 |
| 9. Common Meaning | -.498 | -.362 | -.412 | .219 | -.162 |
| 10. Sound | -.126 | -.255 | .229 | .669 | .129 |
| 11. Images | -.471 | -.579 | -.311 | -.182 | -.041 |
| 12. Stories | -.345 | -.564 | -.451 | .030 | -.170 |
| 13. Sentences or Phrases | .029 | -.378 | -.060 | -.733 | .244 |
| 14. Associations | .162 | -.535 | -.184 | -.047 | .286 |
| 15. No Order | -.436 | .500 | .195 | -.237 | .023 |
| 16. Noticed Effectiveness | -.341 | -.019 | -.013 | .012 | .781 |

Using Guttman's weaker lower bound (the number of characteristic roots greater than one) as a criterion, it was decided to consider five principal components in the approximation. The first five principal components were then computed and are reported in Table 10. The five principal components were rotated analytically using Kaiser's (1958) Varimax Criterion. The rotated principal components are presented in Table 11. These five rotated principal components were used to define five strategy composites.

Each principal component was interpreted as a cluster of strategy statements which subjects tended to group together in their descriptions of the methods they employed in the learning task. If a principal component represented a cluster of statements which could be considered as representing a single strategy, then the strategy composite corresponding to the principal component was denoted by a phrase descriptive of this strategy.

The strategy statements loading highest on the first principal component are "Reorganized", "Made Clusters", "Freely-formed Clusters", "Selective Attention" and "No Order". All of these statements are compatible with the notion of a strategy involving organization of the list by grouping the words into clusters. The second principal axis passes through a cluster of strategy statements containing "Common Meaning", "Images", and "Stories". It was regarded as representing a strategy involving the production of semantic mnemonics to recode clusters of words to facilitate later recall. "Learning in Order" and "Sequential Clusters" have large positive loadings on the third principal component, while "No Particular Strategy" has a moderate negative loading on this component. This aggregate of strategy statements seems to share the notion of actively organizing the words sequentially (as opposed to learning the words in order

Table 11

Rotated Principal Components of Strategy Statements

| Strategy Statement | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. No Particular Strategy | -.065 | -.285 | -.595 | .126 | .131 |
| 2. Learning in Order | -.306 | -.020 | .662 | .159 | .101 |
| 3. Reorganized | .730 | .258 | -.129 | .046 | -.025 |
| 4. Made Clusters | .548 | .258 | .321 | -.167 | .253 |
| 5. Sequential Clusters | -.013 | -.190 | .811 | -.001 | -.078 |
| 6. Freely-formed Clusters | .696 | .114 | -.324 | -.210 | .328 |
| 7. Selective Attention | .601 | -.019 | .313 | .311 | .024 |
| 8. Frequent Recategorization | .354 | .118 | .102 | -.191 | .580 |
| 9. Common Meaning | .109 | .749 | -.110 | -.182 | .069 |
| 10. Sound | -.052 | .121 | .303 | -.624 | .315 |
| 11. Images | .143 | .758 | .097 | .245 | .154 |
| 12. Stories | -.025 | .816 | .039 | .047 | .001 |
| 13. Sentences or Phrases | -.036 | .147 | .195 | .813 | .153 |
| 14. Associations | -.405 | .304 | .263 | .215 | .241 |
| 15. No Order | .585 | -.254 | -.330 | .090 | .106 |
| 16. Noticed Effectiveness | .009 | .002 | -.151 | .100 | .833 |

by rote).

Loading on the fourth rotated principal component are two strategy statements: "Sentences or Phrases" (positively) and "Sound" (negatively). Although this component hardly represents a strategy, it represents an index of a balance between two order preserving mnemonics, "Sentences or Phrases" on the one hand (an "active" mnemonic) and "Sound" on the other (a "passive" mnemonic). Clustering about the fifth component are "Frequent Recategorization" and "Noticed Effectiveness". The former refers to frequently shifting a word into different clusters, and the latter, to changing strategies if they are found to be ineffective. Thus a person scoring highly on the fifth principal component is one who tends to report that for many of the words he often modifies his choice of a strategy.

Composite variables corresponding to these five principal components were defined; a summary of their definitions is found in Table 12. The five composites were designated by descriptive phrases based on the above interpretations of the five corresponding principal components. "Associations" had loadings on all five principal components. This suggests that "Associations" may be an aggregate of strategies rather than a unitary strategy. Because of this, "Associations" was not included in the definitions of the five strategy composites.

## Definition of ability composites

On the basis of previous factorial studies of abilities as reported in the manual of French, et al. (1963), composite ability measures were defined from the thirteen ability tests. A summary of the definitions of the seven composite ability measures is presented in Table 13. Since

Table 12

Definition of Strategy Composite Scores

| Strategy Statements |
| --- |
| $X_1$ = No Particular Strategy |
| $X_2$ = Learning in Order |
| $X_3$ = Reorganized the Words |
| $X_4$ = Made Clusters |
| $X_5$ = Sequential Clusters |
| $X_6$ = Freely-formed Clusters |
| $X_7$ = Selective Attention |
| $X_8$ = Frequent Recategorization |
| $X_9$ = Common Meaning |
| $X_{10}$ = Sound |
| $X_{11}$ = Images |
| $X_{12}$ = Stories |
| $X_{13}$ = Sentences or Phrases |
| $X_{14}$ = Associations |
| $X_{15}$ = No Order |
| $X_{16}$ = Noticed Effectiveness |

| Composites (corresponding to the five rotated principal components) | Names |
| --- | --- |
| $Y_1 = X_3 + X_4 + X_6 + X_7 + X_{15}$ | "organization by grouping" |
| $Y_2 = X_9 + X_{11} + X_{12}$ | "semantic mnemonics" |
| $Y_3 = -X_1 + X_2 + X_5$ | "active sequential organization" |
| $Y_4 = -X_{10} + X_{13}$ | "(+)active vs. (-)passive order preserving mnemonics" |
| $Y_5 = X_8 + X_{16}$ | "modification of strategies" |

Table 13

Definition of Ability Composite Scores

| Ability Tests | | |
|---|---|---|
| $X_1$ | = | Hidden Patterns |
| $X_2$ | = | Copying |
| $X_3$ | = | Concealed Words |
| $X_4$ | = | Four-letter Words |
| $X_5$ | = | Associations |
| $X_6$ | = | Word Arrangement |
| $X_7$ | = | Object Naming |
| $X_8$ | = | Wide-range Vocabulary |
| $X_9$ | = | Associational Fluency |
| $X_{10}$ | = | Expressional Fluency |
| $X_{11}$ | = | Alternate Uses |
| $X_{12}$ | = | First and Last Names |
| $X_{13}$ | = | Auditory Letter Span |

| Composite | Ability | Abbreviation |
|---|---|---|
| $Y_1 = 2X_3 + X_4$ | Speed of Closure | Cs |
| $Y_2 = X_5 + X_9$ | Associational Fluency | Fa |
| $Y_3 = X_6$ | Expressional Fluency | Fe |
| $Y_4 = X_{12}$ | Associative Memory | Ma |
| $Y_5 = X_{13}$ | Span Memory | Ms |
| $Y_6 = X_8$ | Vocabulary | V |
| $Y_7 = X_7 + X_{11}$ | Semantic Spontaneous Flexibility | Xs |

the two tests marking Flexibility of Closure failed to correlate with any of the performance or strategy measures, no composite measure of this ability was defined. The seven composite measures will be denoted by the names of the abilities they measure in the remainder of this report.

<u>Comparison of group centroids for the reduced variable sets</u>

From the matrix $A_r^*$, group mean scores on the five generalized response score curves were computed. The group means are reported in Table 14. As in the case of group mean response score curves, the clusters group and serial anticipation group have nearly identical centroids in the space of generalized response score curves. A multivariate analysis of variance was performed testing the hypothesis that the group centroids are identical. The results of the analysis are reported in Table 14.

The group differences were found to be highly significant. The characteristic roots indicate a single large root, and therefore the coefficients of a single discriminant function were computed. The mean discriminant scores for the three groups illustrate further that the projections of the clusters group and the serial anticipation group on the axis that best discriminates among the groups are very close together. The standardized coefficients of the discriminant function indicate that generalized response score curves I to IV contribute most to the observed group differences, while generalized response score curve V contributes very little to group differences.

Since the group standard deviations appeared to differ considerably for scores on all except the first generalized response score curve,

Table 14

Comparison of Group Centroids for Generalized Response Score Curves

| Generalized Response Score Curves | Treatment Group Means | | | Discriminant Function Coefficients | |
|---|---|---|---|---|---|
| | FR | C | SA | Raw-score | Standardized |
| I | 1.246 | .695 | .766 | 2.85 | 1.02 |
| II | -.159 | .427 | .263 | 1.13 | 1.09 |
| III | -.438 | .638 | .665 | 2.08 | 1.70 |
| IV | -.125 | .426 | .359 | 1.29 | 1.23 |
| V | .243 | .182 | -.069 | .35 | .35 |
| Mean Discriminant Score | .284 | 2.847 | 2.616 | | |

Multivariate Analysis of Variance

Between Dispersion Matrix

$$\begin{pmatrix} 3.601 & & & & \\ -3.582 & 3.653 & & & \\ -7.482 & 7.278 & 15.853 & & \\ -3.609 & 3.587 & 7.504 & 3.616 & \\ 1.105 & -.841 & -2.777 & -1.118 & 1.090 \end{pmatrix}$$

Within Dispersion Matrix

$$\begin{pmatrix} .129 & & & & \\ -.103 & .931 & & & \\ -.139 & -.178 & .669 & & \\ -.142 & -.094 & -.188 & .915 & \\ -.129 & -.018 & .003 & -.042 & .994 \end{pmatrix}$$

Wilks' lambda criterion = 0.52
$F\ (10,\ 226) = 8.66 \quad p < .001$
Characteristic roots: $\lambda_1 = 51.55$ ; $\lambda_2 = .99$

Bartlett Tests for Homogeneity of Variance

| Generalized Response Score Curves | FR | C | SA | Chi-square | p |
|---|---|---|---|---|---|
| I | .369 | .311 | .382 | - | n.s. |
| II | .728 | .821 | 1.233 | 12.39 | .005 |
| III | .534 | .950 | .878 | 13.03 | .005 |
| IV | .629 | 1.095 | 1.041 | 12.55 | .005 |
| V | .707 | .988 | 1.196 | 10.21 | .005 |

Degrees of freedom = 2

tests of homogeneity of variance were performed. The results of these tests are also reported in Table 14. Significant lack of homogeneity of variance was found for scores on all except the first generalized response score curve.

Mean scores on the five strategy composites were computed for each group, together with the group standard deviations. Group means on each strategy composite are plotted in Figure 4. From these plots it is possible to ascertain the relative use of strategies for the different treatment conditions. The greatest amount of reorganization by grouping was reported for the free recall condition while the least was reported for the serial anticipation condition. The plot of the group mean scores on active sequential organization showed the reverse trend. The clusters group fell in an intermediate position for both of these strategies.

For the strategy involving use of semantic mnemonics, a weak trend occurred with the fre recall group scoring lowest, the clusters group intermediate, and the serial anticipation group highest. Active order-preserving mnemonics ("Sentences or Phrases") predominate over passive ("Sound") for the serial anticipation group while the passive predominate for the free recall group. The clusters group shows the least tendency to report frequent modification of strategies, while the free recall group shows the greatest tendency.

To test the hypothesis that the three groups have identical strategy composite "profiles", a multivariate analysis of variance was performed. The interpretation of the results of this test depends upon the robustness of the test, since the group standard deviations show definite lack of homogeneity as shown by the Bartlett tests reported in Table 15. The results of the analysis of variance are also reported in Table 15. The

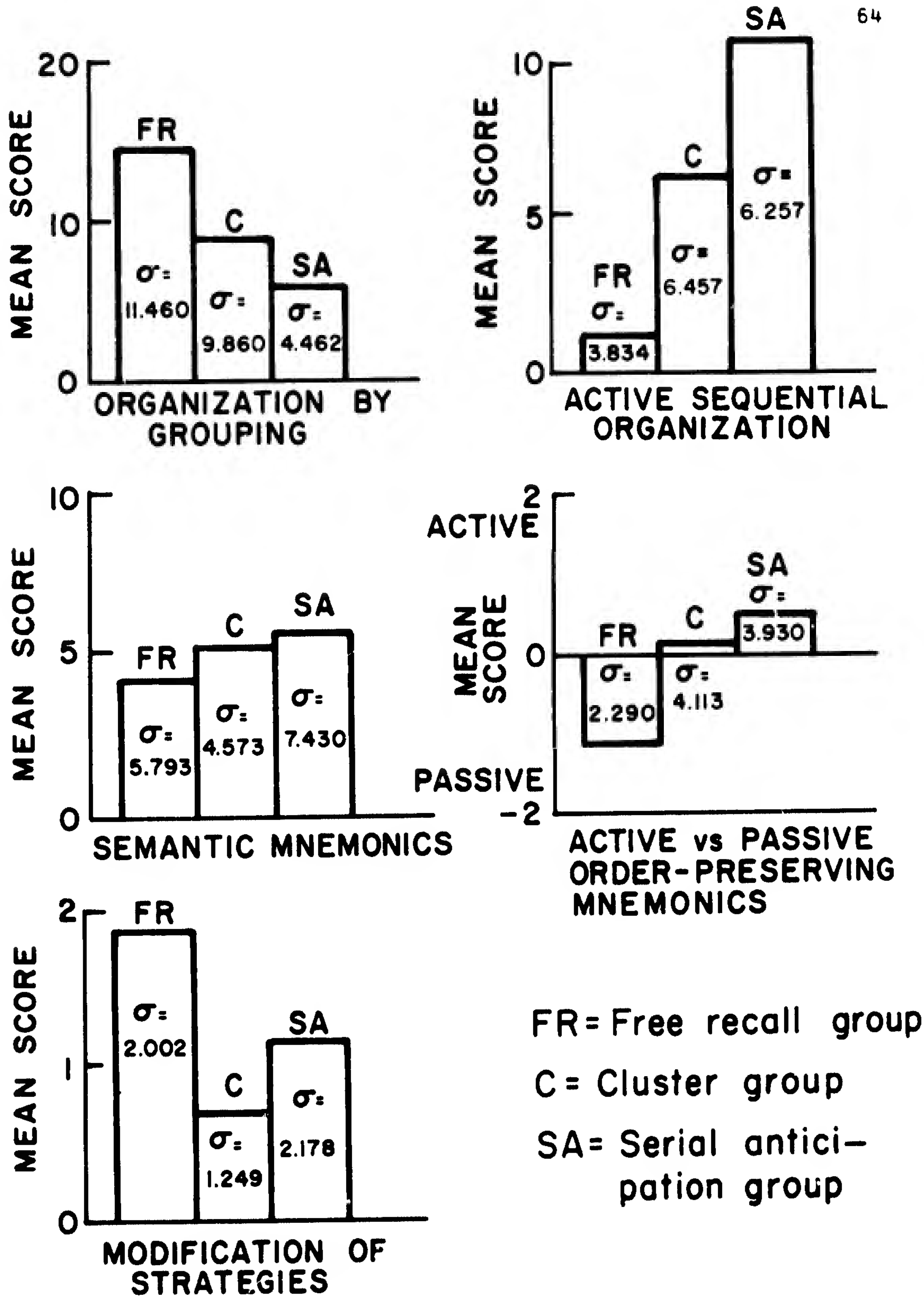


Figure 4. Means and Standard Deviations for Groups on Strategy Composites

Table 15

Comparison of Group Centroids for Strategy Composites

| | Treatment Group Means | | | Discriminant Function Coefficients | | | |
|---|---|---|---|---|---|---|---|
| | | | | Raw-score | | Standard | |
| Strategy Composite | FR | C | SA | I | II | I | II |
| Reorganization by Grouping | 14.375 | 8.675 | 5.700 | -.06 | -.01 | -.55 | -.09 |
| Semantic Mnemonics | 4.300 | 5.200 | 5.550 | .05 | -.03 | .31 | -.18 |
| Active Sequential Organization | 1.450 | 6.150 | 10.450 | .14 | .05 | .80 | .29 |
| Order Preserving Mnemonics | -1.175 | .075 | .425 | .09 | -.05 | .32 | -.18 |
| Modification of Strategies | 1.875 | .700 | 1.175 | -.06 | .51 | -.11 | .96 |

| | | | | |
|---|---|---|---|---|
| Mean Discriminant Score | I | -5.983 | 1.715 | 6.955 |
| | II | .319 | .669 | 2.499 |

Multivariate Analysis of Variance

Between Dispersion Matrix

$$\begin{pmatrix} 777.311 & & & & \\ -113.432 & 16.634 & & & \\ -784.382 & 113.234 & 810.534 & & \\ -146.975 & 21.650 & 145.200 & 28.300 & \\ 75.713 & -11.775 & -65.200 & -16.150 & 13.975 \end{pmatrix}$$

Within Dispersion Matrix

$$\begin{pmatrix} 83.270 & & & & \\ 14.621 & 37.493 & & & \\ 3.561 & -1.936 & 32.743 & & \\ 1.715 & .676 & -1.589 & 12.857 & \\ 3.761 & 1.915 & -.163 & .103 & 3.526 \end{pmatrix}$$

Wilks' lambda criterion = .55

$F\ (10,\ 266) = 8.01 \qquad p < .001$

Characteristic roots: $\lambda_1 = 44.40 \ ; \ \lambda_2 = 2.52$

Bartlett Tests for Homogeneity of Variance

| | Standard Deviations | | | | |
|---|---|---|---|---|---|
| Strategy Composite | FR | C | SA | Chi-square | p |
| Reorganization by Grouping | 11.460 | 9.608 | 4.462 | 30.69 | .001 |
| Semantic Mnemonics | 5.793 | 4.573 | 7.430 | 8.96 | .05 |
| Active Sequential Organization | 3.934 | 6.475 | 6.257 | 10.46 | .01 |
| Order Preserving Mnemonics | 2.290 | 4.113 | 3.930 | 14.05 | .001 |
| Modification of Strategies | 2.002 | 1.249 | 2.178 | 12.12 | .005 |

Degrees of freedom = 2

results indicate a highly significant difference in mean strategy "profile". Two discriminant functions were computed: the standardized coefficients of the first indicate that the first four strategy composites contribute to the observed effect, while the standardized coefficients of the second indicate that modification of strategies contributes most to group differences along this orthogonal discriminant function. However the second discriminant function was <u>not</u> found to be statistically significant $[\chi^2(4) = 1.34]$ . The mean discriminant scores are in contrast to those of Table 14. In the present case, all three groups are well separated in the two-dimensional discriminant space.

# Chapter VI

## Differential Relationships among Sets of Variables

In this section, results concerning group differences in the relationships among the variable sets will be presented. Considered first will be group differences in the within-group relationships among the two sets of dependent variables, strategies and response measures. Then, for each treatment condition, each of the dependent variable sets will be considered in relation to the set of independent variables (abilities). Throughout the analyses of relationships among variable sets, the interest was in how the relationships change when the characteristics of the learning problem are changed. Correlations of abilities and strategies with trial-by-trial response measures will also be presented for each treatment condition.

### Group differences in the relationship of strategies to response measures

A sample correlation matrix corresponding to $\Sigma$ in equation (8) was computed separately for each treatment group. The sample intercorrelations among the strategy composites for each group are presented in Table 16; the intercorrelations among the five generalized response score curves for each group are presented in Table 17. Group standard deviations for each measure are also reported in Figure 4 for the strategy composites and in Table 17 for the generalized response score curves.

Table 18 contains the correlations of strategy composites with generalized response score curves obtained under each treatment condition.

Table 16

Intercorrelations of Strategy Composites for Each Group

| | Strategy Composite 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Free Recall Group | | | | | |
| 1. Reorganization by Grouping | - | | | | |
| 2. Semantic Mnemonics | .379 | - | | | |
| 3. Active Sequential Organization | -.119 | -.026 | - | | |
| 4. Order Preserving Mnemonics | -.279 | .028 | .040 | - | |
| 5. Modification of Strategies | .238 | .102 | -.019 | .170 | - |
| Clusters Group | | | | | |
| 1. Reorganization by Grouping | - | | | | |
| 2. Semantic Mnemonics | .114 | - | | | |
| 3. Active Sequential Organization | .158 | .232 | - | | |
| 4. Order Preserving Mnemonics | .452 | .010 | .040 | - | |
| 5. Modification of Strategies | .125 | -.143 | .006 | -.039 | - |
| Serial Anticipation Group | | | | | |
| 1. Reorganization by Grouping | - | | | | |
| 2. Semantic Mnemonics | .381 | - | | | |
| 3. Active Sequential Organization | .208 | -.257 | - | | |
| 4. Order Preserving Mnemonics | -.315 | .049 | -.247 | - | |
| 5. Modification of Strategies | .414 | .323 | -.028 | -.032 | - |

Table 17

Intercorrelations of Generalized Response Score Curves for Each Group

| Generalized Response Score Curves | I | II | III | IV | V | S.D. |
|---|---|---|---|---|---|---|
| Free Recall Group | | | | | | |
| I | - | | | | | .369 |
| II | -.474 | - | | | | .728 |
| III | -.473 | -.173 | - | | | .534 |
| IV | -.778 | .362 | .002 | - | | .629 |
| V | -.493 | .006 | .251 | .319 | - | .707 |
| Clusters Group | | | | | | |
| I | - | | | | | .311 |
| II | -.065 | - | | | | .821 |
| III | -.549 | -.113 | - | | | .950 |
| IV | -.192 | -.418 | -.434 | - | | 1.095 |
| V | -.324 | -.058 | .007 | -.076 | - | .988 |
| Serial Anticipation Group | | | | | | |
| I | - | | | | | .382 |
| II | -.332 | - | | | | 1.233 |
| III | -.452 | -.338 | - | | | .878 |
| IV | -.427 | -.051 | -.107 | - | | 1.041 |
| V | -.324 | -.006 | -.089 | -.147 | - | 1.196 |

Table 18

Correlations of Strategy Composites with Generalized Response Score Curves

| Strategy Composites | Generalized Response Score Curves I | II | III | IV | V |
|---|---|---|---|---|---|
| Free Recall Group | | | | | |
| 1. Reorganization by Grouping | .170 | -.008 | -.132 | -.105 | -.194 |
| 2. Semantic Mnemonics | .141 | -.040 | -.104 | .034 | -.117 |
| 3. Active Sequential Organization | .053 | -.160 | .091 | -.016 | .177 |
| 4. Order Preserving Mnemonics | -.284* | -.130 | .474* | .212 | .144 |
| 5. Modification of Strategies | -.009 | -.360* | .114 | .008 | .144 |
| Clusters Group | | | | | |
| 1. Reorganization by Grouping | .131 | .012 | .023 | -.147 | .081 |
| 2. Semantic Mnemonics | .003 | .145 | .047 | -.160 | .073 |
| 3. Active Sequential Organization | -.063 | .355* | .211 | -.341* | -.181 |
| 4. Order Preserving Mnemonics | .353* | .140 | -.223 | -.098 | -.118 |
| 5. Modification of Strategies | -.181 | .103 | .056 | -.033 | .183 |
| Serial Anticipation Group | | | | | |
| 1. Reorganization by Grouping | -.240 | .039 | .169 | .029 | .097 |
| 2. Semantic Mnemonics | -.126 | .259* | .218 | -.234 | -.105 |
| 3. Active Sequential Organization | -.305* | .046 | .127 | .382* | -.076 |
| 4. Order Preserving Mnemonics | -.034 | .128 | .102 | -.253 | .083 |
| 5. Modification of Strategies | -.232 | .061 | .147 | .180 | -.104 |

$Pr(r > .257) = .05$ ; $Pr(r > .358) = .01$

Table 19

Correlations of Strategy Composites with Trial-by-trial Response Scores for the Free Recall Group

| Trial | Strategy Composites 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | .146 | .111 | .053 | -.299* | .090 |
| 2 | .099 | .129 | .003 | -.289* | -.277* |
| 3 | .252 | .191 | -.067 | -.339* | -.233 |
| 4 | .130 | .040 | -.033 | -.326* | -.320* |
| 5 | .142 | .099 | -.012 | -.248 | -.287* |
| 6 | .118 | .065 | -.017 | -.126 | -.297* |
| 7 | .083 | .119 | .009 | -.113 | -.337* |
| 8 | .184 | .140 | .065 | -.123 | -.262* |
| 9 | .156 | .123 | .009 | -.025 | -.249 |
| 10 | .104 | .193 | .005 | -.076 | -.333* |
| 11 | .057 | .122 | -.015 | -.022 | -.335* |
| 12 | .141 | .177 | .069 | .019 | -.292* |
| 13 | .049 | .196 | .130 | .057 | -.322* |
| 14 | .148 | .187 | .125 | -.101 | -.371* |
| 15 | -.005 | .232 | .152 | .022 | -.368* |
| 16 | .156 | .150 | .183 | .030 | -.249 |
| 17 | .006 | .161 | .165 | .048 | -.270* |
| 18 | .019 | .217 | .159 | .134 | -.234 |

The analyses of variance reported in Chapter V indicate that to a large extent, reported strategy usage is determined by task constraints. The relationships among the two sets of dependent variables under consideration here are _relationships based on within group variability_ in reported strategy usage and response measures.

Tables 19, 20, and 21 contain the correlations of the five strategy composites with trial-by-trial response scores for the free recall, clusters, and serial anticipation groups respectively. These correlations reflect the within group covariation about the group mean of scores on strategy composites with trial-by-trial response scores. These tables, together with Table 18, can be used to trace the relationships between use of specific strategies and trial-by-trial response measures within each treatment condition. Significant correlations in Table 18 are indicative of significant trends in the correlations of strategies with trial-by-trial response measures, and these appear to be less sensitive to isolated single trial relationships than are the correlations in the latter three tables.

For the _free recall_ group, all significant correlations in Table 18 occur for the strategy composites designated as order preserving mnemonics and modification of strategies. Within group correlations of scores on these two strategy composites with trial-by-trial response scores are given in columns four and five of Table 19. The negative within group correlations of order preserving mnemonics with response scores for the first four or five trials indicate that within the free recall group, subjects who learned by sound (passive order preserving mnemonics), more than by constructing sentences or phrases, tended to show higher response scores during the first four or five trials. Column five of Table 19

Table 20

Correlations of Strategy Composites with Trial-by-trial Response Scores for the Clusters Group

| Trial | Strategy Composites 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | .295* | -.022 | .110 | .224 | -.195 |
| 2 | .046 | .039 | .005 | .352* | -.056 |
| 3 | .123 | .175 | .334* | .391* | -.009 |
| 4 | .160 | .139 | .362* | .213 | -.081 |
| 5 | .134 | .146 | .375* | .217 | -.031 |
| 6 | .144 | .169 | .394* | .178 | .014 |
| 7 | .133 | .134 | .412* | .215 | -.010 |
| 8 | .113 | .131 | .376* | .168 | -.073 |
| 9 | .134 | .110 | .325* | .216 | -.087 |
| 10 | .139 | .104 | .289* | .187 | -.082 |
| 11 | .068 | .046 | .349* | .190 | -.085 |
| 12 | .090 | .095 | .295* | .193 | -.113 |
| 13 | .104 | .117 | .234 | .162 | -.056 |
| 14 | .187 | .072 | .171 | .283 | -.113 |
| 15 | .157 | .082 | .138 | .205 | -.087 |
| 16 | .221 | .069 | .105 | .252 | -.056 |
| 17 | .186 | .063 | .087 | .231 | -.105 |
| 18 | .161 | .136 | .109 | .146 | -.023 |

Table 21

Correlations of Strategy Composites with Trial-by-trial Response Scores for the Serial Anticipation Group

| Trial | Strategy Composites 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | -.190 | -.218 | -.022 | .011 | -.282* |
| 2 | -.124 | .100 | -.226 | -.037 | -.134 |
| 3 | -.192 | .186 | -.259* | .186 | -.105 |
| 4 | -.106 | .291* | -.205 | .191 | -.099 |
| 5 | -.070 | .365* | -.153 | .184 | -.084 |
| 6 | -.023 | .372* | -.105 | .240 | -.042 |
| 7 | -.049 | .402* | -.086 | .142 | .049 |
| 8 | -.078 | .330* | -.032 | .152 | -.003 |
| 9 | -.080 | .373* | -.040 | .162 | .070 |
| 10 | -.067 | .319* | .048 | .086 | .040 |
| 11 | -.069 | .288* | .127 | .013 | .098 |
| 12 | -.076 | .267* | .175 | .052 | .064 |
| 13 | -.048 | .234 | .195 | .030 | .121 |
| 14 | -.029 | .261* | .242 | .006 | .106 |
| 15 | -.065 | .241 | .212 | .045 | .108 |
| 16 | -.097 | .219 | .222 | .045 | .086 |
| 17 | -.083 | .262* | .224 | .027 | .046 |
| 18 | -.095 | .225 | .181 | .038 | .062 |

indicates that within this group, subjects who tended to frequently recategorize words or change strategies (or both), also tended to perform poorly throughout the experimental session.

Table 18 indicates that within the clusters condition, relationships occurred between the third and fourth strategy composites (active sequential organization and order preserving mnemonics), and response measures. From Table 20 it can be seen that within this group, active sequential organization correlated positively with response measures from trials three until thirteen, the relationship increasing from trial three to seven and then decreasing. Table 20 also indicates that within the clusters group, use of active order preserving mnemonics was related to higher response scores for early trials.

Since within the serial anticipation group, significant correlations were obtained between scores on semantic mnemonics and active sequential organization on the one hand, and scores on generalized response score curves on the other (Table 18), columns two and three of Table 21 were examined. Column two indicates that within the serial anticipation group, use of semantic mnemonics was positively correlated with response measures after the third trial; column three indicates first a negative relationship between active sequential organization and trial-by-trial response scores, followed by a positive relationship with late scores. The latter result is probably due to the fact th[illegible] ds recalled by this group were scored irrespective of their order in the list; subjects who by guessing initially ignored the requirement that they learn the words in order received higher scores.

The degree of association of the two sets of dependent variables, reported strategy usage and response measures, under each treatment condition was investigated using canonical analysis. For each treatment group, the canonical correlation between the two sets of dependent variables was calculated and used as a measure of the degree of association of the two sets of measured variables. If the matrix $\Sigma$ of equation (8) is replaced with the corresponding correlation matrix,

$$R = \begin{pmatrix} R_{11} & R_{12} \\ R'_{12} & R_{22} \end{pmatrix} ,$$

the characteristic roots of $R_{11}^{-1}R_{12}R_{22}^{-1}R'_{12}$ are identical to the characteristic roots of the corresponding equation in covariances, and the associated characteristic vectors have been rescaled. The matrices $R_{11}$ , $R_{22}$ and $R_{12}$ computed separately for each group are the matrices in Tables 16, 17, and 18 respectively. The largest characteristic root of $R_{11}^{-1}R_{12}R_{22}^{-1}R'_{12}$ , for each group, is the square of the canonical correlation between the set of strategy composites and the set of generalized response score curves obtained for that group.

The canonical correlations between the set of strategy composites and the set of generalized response score curves for each treatment condition are reported in Table 22, together with the set of predictor weights and the set of criterion weights of equation (7) for each group. The canonical correlations indicate that the degree of association between the two sets of dependent variables is least for the clusters condition; however, the associations are not strong enough to reach significance for any of the groups with a sample size of forty.

From the model presented in Chapter III, it was suggested that strategy choice may be in part a response to characteristics of the task and in part a function of organism state variables such as abilities. If

Table 22

Canonical Correlations between

Strategy Composites and Generalized Response Score Curves

| Treatment Group | Canonical Correlation value | Canonical Correlation squared | Parameters for Heck's Charts s | m | n | p |
|---|---|---|---|---|---|---|
| Free Recall (FR) | .6331 | .4008 | 5 | -1/2 | 14 | n.s. |
| Clusters (C) | .5036 | .2536 | 5 | -1/2 | 14 | n.s. |
| Serial Anticipation (SA) | .5926 | .3512 | 5 | -1/2 | 14 | n.s. |

The critical value of the canonical correlation squared for rejecting the hypothesis of independence for $p < .05$ is .480 .

Canonical Weights

| | Treatment Group FR | C | SA |
|---|---|---|---|
| Predictors: Strategy Composites | | | |
| 1. Reorganization by Grouping | .101 | .313 | -.284 |
| 2. Semantic Mnemonics | .250 | -.045 | .920 |
| 3. Active Sequential Organization | .382 | -.988 | .786 |
| 4. Order Preserving Mnemonics | .908 | -.208 | .334 |
| 5. Modification of Strategies | -.160 | -.124 | .117 |
| Criteria: Generalized Response Score Curves | | | |
| I | 2.822 | .674 | 2.311 |
| II | .714 | -.301 | 2.244 |
| III | 1.992 | .379 | 2.563 |
| IV | 2.088 | .859 | 1.535 |
| V | .419 | .666 | .934 |

strategy choices are in part a function of abilities, then the within group relationships between strategy choice and response measures indicated in Tables 18-22 might be due only to the covariation of measures of strategy usage with abilities. Thus, it is necessary to test the hypothesis that the two sets of dependent variables are independent when a third set of "outside variables" (abilities) is held constant.

The matrices of partial correlations corresponding to $P_{11}$, $P_{22}$, and $P_{12}$ in equation (10) were computed. For each group the matrix $P_{12}$ containing the partial correlations of strategy composites with generalized response score curves holding abilities constant is presented in Table 23. The canonical-partial correlations obtained for each group are reported in Table 24 together with the sets of predictor and criterion weights.

The canonical-partial correlations indicate that the degree of association of strategy choice with response measures is least under the clusters condition, a result which is identical to that found when abilities were not controlled. When differences in ability were controlled statistically, the canonical correlations for the free recall and serial anticipation groups increased considerably, but the canonical correlation for the clusters group increased only slightly. The within group relationships between strategy choice and response measures, accordingly, are not due only to the covariation of measures of strategy usage with abilities.

The results of the canonical analyses provide some evidence of a rank order nature for possible group differences in the degree of dependence of response measures and strategy choice. A statistical comparison of treatment groups with respect to the degree of association of

Table 23

Correlations of Strategy Composites with Generalized Response Score Curves Holding Abilities Constant

| Strategy Composite | Generalized Response Score Curves I | II | III | IV | V |
|---|---|---|---|---|---|
| **Free Recall Group** | | | | | |
| 1. Reorganization by Grouping | .004 | .066 | -.181 | .209 | -.211 |
| 2. Semantic Mnemonics | .161 | -.003 | -.205 | .109 | -.160 |
| 3. Active Sequential Organization | .078 | -.110 | .009 | .037 | .150 |
| 4. Order Preserving Mnemonics | -.048 | -.203 | .483* | -.065 | .096 |
| 5. Modification of Strategies | .086 | -.277 | .051 | -.084 | .025 |
| **Clusters Group** | | | | | |
| 1. Reorganization by Grouping | .053 | -.069 | -.035 | .003 | .227 |
| 2. Semantic Mnemonics | -.166 | .111 | .224 | -.182 | .175 |
| 3. Active Sequential Organization | -.150 | .326* | .144 | -.208 | -.133 |
| 4. Order Preserving Mnemonics | .308* | .053 | -.292 | .081 | -.117 |
| 5. Modification of Strategies | -.174 | .236 | .060 | -.182 | .291 |
| **Serial Anticipation Group** | | | | | |
| 1. Reorganization by Grouping | -.046 | .051 | .095 | -.140 | .022 |
| 2. Semantic Mnemonics | .007 | .294 | .121 | -.410* | -.023 |
| 3. Active Sequential Organization | -.291 | .089 | .047 | .316* | .040 |
| 4. Order Preserving Mnemonics | -.149 | .194 | .189 | -.295 | .120 |
| 5. Modification of Strategies | -.064 | .176 | -.017 | .024 | -.095 |

Pr(r > .296) = .05 ; Pr(r > .409) = .01

Table 24

Canonical-partial Correlations between Strategy Composites and Generalized Response Score Curves

| Treatment Group | Canonical-partial Correlation value | squared | Parameters for Heck's Charts s | m | n | p |
|---|---|---|---|---|---|---|
| Free Recall (FR) | .7081 | .5014 | 5 | -1/2 | 11 | n.s. |
| Clusters (C) | .5394 | .2910 | 5 | -1/2 | 11 | n.s. |
| Serial Anticipation (SA) | .6762 | .4572 | 5 | -1/2 | 11 | n.s. |

The critical value of the canonical-partial correlation squared for $p < .05$ is .550 .

Canonical Weights

| | Treatment Group FR | C | SA |
|---|---|---|---|
| Predictors: Strategy Composites | | | |
| 1. Reorganization by Grouping | .107 | -.376 | -.308 |
| 2. Semantic Mnemonics | .060 | -.600 | 1.032 |
| 3. Active Sequential Organization | .257 | .152 | .775 |
| 4. Order Preserving Mnemonics | .966 | .489 | .272 |
| 5. Modification of Strategies | -.397 | -.715 | .231 |
| Criteria: Generalized Response Score Curves | | | |
| I | 3.180 | .522 | 3.120 |
| II | 1.301 | -.053 | 2.854 |
| III | 2.261 | .214 | 3.105 |
| IV | 1.615 | .398 | 1.767 |
| V | .562 | -.677 | 1.487 |

individual response parameters and the set of strategy composites is possible only for those criterion response parameters for which the treatment groups possess identical variances. Since significant group differences in homogeneity of variance occurred for all except the first generalized response score curve (Table 14), a test of differences in error of estimate variance provides the desired test on the multiple correlations only for the first generalized response score curve. For those criteria for which the groups do not vary in <u>error of estimate</u> variance, tests of differences in slope can be made using the Gulliksen-Wilks (1950) procedure.

The multiple correlations of scores on the five strategy composites with the scores on each generalized response score curve for each treatment group are presented in Table 25. Within group and total multiple correlations are reported in the same table. The low within multiple correlations can be contrasted with the larger total multiple correlations obtained for predicting scores on the first three generalized response score curves. This result suggests that the total regression of "early learning performance" on "strategy choice" is due to regression of both on an artificial variable representing treatment group membership. Only for late increments in performance (measured by scores on generalized response score curves IV and V) are the within and total multiple correlations more nearly equal, suggesting that "late learning" may be more a function of strategy choice it is a function of task constraints.

The results of the analysis of treatment group differences in regression are reported in Table 26. The tests of equality of errors of estimate for the regression of each generalized response score curve on the

Table 25

Multiple Correlations of Strategies with Generalized Response Score Curves

| Criterion Generalized Response Score Curves | Treatment Group FR | C | SA | Within Groups | Total |
|---|---|---|---|---|---|
| I | .3315 | .3981 | .4377 | .2247 | .4117* |
| II | .4052 | .4243 | .3279 | .2347 | .3039* |
| III | .4982 | .3318 | .3350 | .2159 | .4326* |
| IV | .2259 | .3670 | .5185* | .2172 | .2255 |
| V | .3242 | .3433 | .3169 | .1067 | .1543 |

* = significant for $p < .05$

Table 26

Gulliksen-Wilks Regression Tests

| Criterion Variable | Chi-square | Degrees of Freedom | p |
|---|---|---|---|
| Tests of Equality of Errors of Estimate | | | |
| I | 1.9186 | 2 | n.s. |
| II | 14.9039 | 2 | < .001 |
| III | 17.4864 | 2 | < .001 |
| IV | 10.1012 | 2 | < .01 |
| V | 10.6927 | 2 | < .01 |
| Tests of Parallel Regression Planes | | | |
| I | 13.8124 | 10 | n.s. |
| Tests of Equality of Intercepts | | | |
| I | 30.65[illegible] | 2 | < .001 |

set of strategy composites indicate significant differences for every generalized response score curve except the first. The failure to find a significant difference in error of estimate variance for predicting scores on the first generalized response score curve indicates (a) that the treatment groups do not differ significantly in degree of dependence of scores on this criterion and scores on strategy composites and (b) that a test of differences in slopes can be made for this criterion. The test of equality of slopes for predicting scores on the first generalized response score curve indicates that the hypothesis that the regression planes are parallel cannot be rejected for this criterion. However, the test of equality of intercepts indicates a highly significant difference in predicted score on the first generalized response score curve.

## Group differences in the relationship of abilities to response measures

The intercorrelations of the seven ability measures were computed and are reported in Table 27, together with group means and standard deviations for each of the measures. Correlations between scores on each ability measure and scores on each generalized response score curve were also computed and are presented in Table 28. The within group correlations of abilities with generalized response score curves (representing performance increments at different stages of practice) indicate group differences in both the number and pattern of relationships. Significant correlations in these tables are indicative of trends in the within group correlations of abilities with trial-by-trial response measures. These latter correlations are presented in Tables 29, 30, and 31.

The pattern of relationships between abilities and trial-by-trial

Table 27

Intercorrelations of Abilities, Means, and Standard Deviations for Each Treatment Group

| Abilities | Cs | Fa | Fe | Ma | Ms | V | Mean | SD |
|---|---|---|---|---|---|---|---|---|
| Free Recall | | | | | | | | |
| Cs | - | | | | | | 46.675 | 8.839 |
| Fa | .240 | - | | | | | 18.225 | 6.275 |
| Fe | -.006 | .226 | - | | | | 14.050 | 4.696 |
| Ma | .114 | .225 | .203 | - | | | 21.950 | 7.110 |
| Ms | .390 | .337 | .126 | .357 | - | | 8.625 | 3.112 |
| V | .159 | .358 | .141 | .270 | .217 | - | 16.120 | 4.153 |
| Xs | -.021 | .499 | .485 | .325 | .368 | .407 | 25.050 | 6.633 |
| Clusters | | | | | | | | |
| Cs | - | | | | | | 47.225 | 8.211 |
| Fa | .152 | - | | | | | 18.250 | 5.190 |
| Fe | -.179 | -.029 | - | | | | 12.550 | 4.043 |
| Ma | -.065 | .120 | .183 | - | | | 20.375 | 7.700 |
| Ms | .101 | .241 | -.199 | .173 | - | | 7.700 | 2.003 |
| V | -.064 | .384 | .102 | .041 | .031 | - | 14.780 | 3.435 |
| Xs | .272 | .195 | .318 | -.051 | .083 | .297 | 26.850 | 7.384 |
| Serial Anticipation | | | | | | | | |
| Cs | - | | | | | | 49.675 | 8.745 |
| Fa | .206 | - | | | | | 21.725 | 4.853 |
| Fe | -.007 | .453 | - | | | | 14.225 | 3.850 |
| Ma | .178 | .236 | -.148 | - | | | 23.750 | 5.787 |
| Ms | .157 | .457 | .185 | .025 | - | | 7.600 | 2.375 |
| V | .236 | .346 | .123 | .330 | .120 | - | 17.435 | 3.051 |
| Xs | .173 | .448 | .396 | .118 | .130 | .276 | 25.350 | 7.168 |

Table 28

Correlations of Abilities with

Generalized Response Score Curves for Each Group

| Abilities | Generalized Response Score Curves I | II | III | IV | V |
|---|---|---|---|---|---|
| Free Recall | | | | | |
| Speed of Closure | .261* | -.147 | -.123 | -.261* | -.027 |
| Associational Fluency | .299* | -.115 | .091 | -.527* | .000 |
| Expressional Fluency | .148 | .008 | -.236 | -.082 | .004 |
| Associative Memory | .480* | .161 | -.279* | -.435* | -.365* |
| Memory Span | .294* | .084 | -.173 | -.276* | -.083 |
| Vocabulary | .353* | -.101 | -.034 | -.374* | -.107 |
| Semantic Spontaneous Flexibility | .134 | -.028 | -.054 | -.091 | -.010 |
| Clusters | | | | | |
| Speed of Closure | .081 | -.050 | -.009 | .087 | -.287* |
| Associational Fluency | .042 | -.199 | .252 | .037 | -.322* |
| Expressional Fluency | .280* | .197 | -.354* | -.123 | .167 |
| Associative Memory | .330* | .312* | .147 | -.561* | -.277* |
| Memory Span | -.043 | -.000 | .128 | -.083 | -.055 |
| Vocabulary | .035 | -.085 | -.019 | .195 | -.218 |
| Semantic Spontaneous Flexibility | .194 | .026 | -.421* | .152 | .028 |
| Serial Anticipation | | | | | |
| Speed of Closure | .156 | -.279* | .090 | -.031 | -.119 |
| Associational Fluency | .138 | -.030 | .062 | -.172 | -.127 |
| Expressional Fluency | .074 | -.296* | .185 | .120 | -.232 |
| Associative Memory | .330* | .134 | -.081 | -.215 | -.372* |
| Memory Span | .075 | -.087 | .015 | -.072 | .021 |
| Vocabulary | .332* | -.043 | -.109 | -.299* | -.082 |
| Semantic Spontaneous Flexibility | .351* | -.227 | -.096 | -.209 | .011 |

Table 29

Correlations of Abilities with Trial-by-Trial Response Scores for the Free Recall Group

| Trial | Cs | Fa | Fe | Ma | Ms | V | Xs |
|---|---|---|---|---|---|---|---|
| 1 | .410* | .150 | .231 | .471* | .342* | .274* | .075 |
| 2 | .131 | .240 | .079 | .586* | .313* | .305* | .056 |
| 3 | .086 | .351* | .128 | .668* | .396* | .395* | .170 |
| 4 | .199 | .326* | .132 | .686* | .387* | .363* | .157 |
| 5 | .258* | .388* | .073 | .599* | .443* | .342* | .115 |
| 6 | .007 | .326* | .054 | .666* | .358* | .370* | .130 |
| 7 | .122 | .343* | -.027 | .619* | .345* | .365* | .075 |
| 8 | .135 | .401* | .018 | .605* | .324* | .448* | .190 |
| 9 | .073 | .290* | -.001 | .629* | .393* | .340* | .153 |
| 10 | .076 | .238 | -.019 | .602* | .376* | .338* | .076 |
| 11 | -.003 | .216 | .025 | .608* | .346* | .311* | .122 |
| 12 | -.013 | .303* | -.059 | .576* | .328* | .353* | .198 |
| 13 | .029 | .182 | -.037 | .554* | .358* | .340* | .122 |
| 14 | .101 | .148 | .048 | .599* | .377* | .349* | .162 |
| 15 | .164 | .210 | -.088 | .493* | .361* | .350* | .110 |
| 16 | .047 | .221 | .078 | .556* | .343* | .362* | .241 |
| 17 | -.010 | .349* | .002 | .514* | .400* | .396* | .239 |
| 18 | .018 | .205 | -.075 | .453* | .333* | .330* | .091 |

Table 30

Correlations of Abilities with Trial-by-trial Response Scores for the Clusters Group

| Trial | Cs | Fa | Fe | Ma | Ms | V | Xs |
|---|---|---|---|---|---|---|---|
| 1 | .244 | .124 | .109 | .423* | .046 | -.153 | -.000 |
| 2 | .102 | -.018 | .281* | .372* | -.035 | .078 | .245 |
| 3 | -.062 | .012 | .291* | .579* | .049 | -.087 | -.027 |
| 4 | .029 | -.035 | .185 | .602* | .012 | -.033 | -.050 |
| 5 | .001 | .032 | .124 | .582* | .028 | -.102 | -.154 |
| 6 | .017 | .124 | .047 | .637* | .094 | -.023 | -.199 |
| 7 | .063 | .193 | -.014 | .640* | .117 | -.026 | -.255 |
| 8 | .052 | .242 | -.027 | .593* | .093 | .005 | -.275* |
| 9 | .116 | .277* | -.078 | .590* | .079 | .106 | -.259* |
| 10 | .108 | .331* | -.112 | .520* | .061 | .133 | -.260* |
| 11 | .150 | .318* | -.110 | .475* | .033 | .154 | -.272* |
| 12 | .147 | .331* | -.129 | .482* | .085 | .133 | -.285* |
| 13 | .122 | .337* | -.134 | .392* | .051 | .170 | -.302* |
| 14 | .158 | .322* | -.085 | .458* | .057 | .132 | -.242 |
| 15 | .073 | .348* | -.076 | .354* | .011 | .161 | -.296* |
| 16 | .050 | .360* | -.070 | .350* | .078 | .167 | -.295* |
| 17 | .019 | .304* | -.091 | .286* | .020 | .146 | -.327* |
| 18 | .021 | .321* | -.116 | .282* | -.019 | .163 | -.332* |

Table 31

Correlations of Abilities with Trial-by-trial Response Scores for the Serial Anticipation Group

| Trial | Cs | Fa | Fe | Ma | Ms | V | Xs |
|---|---|---|---|---|---|---|---|
| 1 | -.104 | -.138 | .048 | .187 | -.049 | -.040 | .132 |
| 2 | -.011 | .105 | -.196 | .444* | .007 | .270* | .121 |
| 3 | -.109 | .185 | -.090 | .345* | .054 | .282* | .120 |
| 4 | -.122 | .121 | -.205 | .480* | -.050 | .246 | .059 |
| 5 | -.115 | .130 | -.191 | .452* | -.036 | .201 | .015 |
| 6 | -.159 | .119 | -.163 | .390* | -.015 | .128 | -.066 |
| 7 | -.087 | .195 | -.041 | .474* | -.026 | .174 | -.009 |
| 8 | -.028 | .195 | .037 | .471* | .008 | .187 | .008 |
| 9 | -.047 | .143 | .046 | .469* | -.026 | .115 | -.044 |
| 10 | -.033 | .151 | .038 | .489* | -.057 | .100 | -.041 |
| 11 | -.050 | .130 | .042 | .459* | -.050 | .035 | -.099 |
| 12 | -.158 | .030 | -.013 | .409* | -.079 | -.027 | -.187 |
| 13 | -.170 | .027 | .015 | .388* | -.094 | -.010 | -.154 |
| 14 | -.150 | .065 | .037 | .382* | -.085 | -.054 | -.150 |
| 15 | -.145 | .050 | .016 | .355* | -.058 | -.057 | -.143 |
| 16 | -.115 | .031 | .000 | .387* | -.066 | -.065 | -.154 |
| 17 | -.134 | .115 | .069 | .411* | -.061 | .003 | -.077 |
| 18 | -.144 | .047 | .013 | .377* | -.055 | -.040 | -.079 |

response measures obtained for the free recall condition can be seen in Table 29. Five of the seven abilities show significant within-group correlations. The form of these relationships is given by considering the change in the correlations from trials one to eighteen. Strongly related to trial-by-trial response measures throughout practice are Associative Memory (Ma), Memory Span (Ms), and Vocabulary (V). Associational Fluency (Fa) correlated strongly with trial-by-trial response measures from trials three to ten, showing small positive correlations after trial ten. Speed of Closure (Cs) is correlated strongly with response measures on the first trial.

Four abilities show significant within-group correlations with trial-by-trial response measures under the clusters condition (Table 30). Associational Fluency shows a positive relationship with late response measures (after trial ten) while Semantic Spontaneous Flexibility (Xs) shows a significant negative relationship to trial-by-trial response measures after trial six. Associative Memory again correlates positively with response scores throughout practice. Expressional Fluency (Fe) is correlated positively with the response scores on early trials.

For the serial anticipation group, only Associative Memory was strongly correlated with trial-by-trial response measures (Table 31), although other small trends occur, as indicated by the correlations with scores on generalized response score curves. Speed of Closure, Expressional Fluency, and Semantic Spontaneous Flexibility show only small trends, while Vocabulary is more strongly related with early scores (after trial 1).

The following example illustrates how correlations of abilities with generalized response score curves reflect trends in the correlations of abilities with trial-by-trial response measures. Consider, for the free recall group, the correlations of Associative Memory with generalized response score curves and with trial-by-trial response measures. For this group, Associative Memory has a significant positive correlation with the first generalized response score curve and significant negative correlations with the last three generalized response score curves. At the same time Associative Memory has positive correlations with response measures for all trials. The size of these correlations increases during the first four trials and then decreases. The positive correlation of Associative Memory with the first generalized response score curve reflects the initial increase in correlations with trial-by-trial response scores, while the negative correlations with the last three generalized response score curves reflect the gradual decrease after trial four.

To provide for each group a single measure of the degree of association of the set of abilities with learning performance (as measured by scores on generalized response score curves), the canonical correlation between the two sets of variables was computed for each group. The canonical correlations are reported in Table 32. The canonical correlations were significant for the free recall and clusters groups, but not for the serial anticipation group, reflecting the fact that under this condition, there was a single strong relationship with Associative Memory. This last relationship is undoubtedly due simply to the similarity of the First and Last Names Test, used to measure Associative Memory, with the present learning task.

To further investigate group differences in the dependence of measured abilities and response measures, regression tests were carried out using the Gulliksen-Wilks procedure. The results of these tests are

Table 32

Canonical Correlations between Abilities
and Generalized Response Score Curves

| Treatment Group | Canonical Correlation value | Canonical Correlation squared | Parameters for Heck's Charts s | m | n | p |
|---|---|---|---|---|---|---|
| Free Recall (FR) | .8044 | .6471 | 5 | 1/2 | 13 | < .01 |
| Clusters (C) | .8032 | .6451 | 5 | 1/2 | 13 | < .01 |
| Serial Anticipation (SA) | .5867 | .3442 | 5 | 1/2 | 13 | n.s. |

Canonical Weights

| | Treatment Group FR | C | SA |
|---|---|---|---|
| Predictors: Abilities | | | |
| Speed of Closure | -.116 | .297 | -.502 |
| Associational Fluency | .474 | .574 | .117 |
| Expressional Fluency | .065 | -.296 | -.380 |
| Associative Memory | .686 | .262 | .720 |
| Span Memory | .276 | -.105 | .016 |
| Vocabulary | .329 | .274 | .219 |
| Semantic Spontaneous Flexibility | -.554 | -.641 | .266 |
| Criteria: Generalized Response Score Curves | | | |
| I | 1.310 | 1.369 | 3.406 |
| II | .876 | .701 | 2.445 |
| III | .499 | 2.079 | 2.267 |
| IV | -.200 | 1.337 | 1.452 |
| V | .205 | -.005 | 1.279 |

summarized in Tables 33 and 34. The former table contains the multiple correlations of the seven abilities with scores on each of the five generalized response score curves. Significant multiple correlations occurred for the free recall and clusters groups, while none was significant for the serial anticipation group. The results of the significance tests investigating the hypothesis of equality of errors of estimate indicate that the groups differ significantly for scores on all except the first generalized response score curve. Since the treatment groups showed significant differences in variance on all except the first generalized response score curve, the test of equality of errors of estimate is a test of differential dependence only for the first criterion. The fact that no significant result was found for this criterion, indicates that the hypothesis of no differences among the multiple correlations cannot be rejected for the first generalized response score curve. The test of parallel regression planes for predicting the first generalized response score curve yielded an insignificant result, making possible the third test of equality of intercepts for predicting this criterion. The results of the test of equality of intercepts indicate a highly significant difference.

Group differences in the relationship of abilities to strategies

The results presented in Chapter V indicated that subjects' choices of strategies are to a very large degree higher-order responses to the characteristics of the three tasks. However, within-group variability, although small in relation to the between-groups, does exist and, thus, questions concerning within-group relationships between scores on measures of strategy choice and abilities can be asked, just as they were in

Table 33

Multiple Correlations of Abilities with Generalized Response Score Curves

| Criterion Generalized Response Score Curves | Treatment Group FR | C | SA | Within Groups | Total |
|---|---|---|---|---|---|
| I | .6005* | .4435 | .5054 | .4609* | .4188* |
| II | .3130 | .4187 | .4835 | .3040 | .2929 |
| III | .4256 | .5922* | .3204 | .3337 | .3644* |
| IV | .7197* | .6095* | .4247 | .4235* | .4047* |
| V | .3906 | .5557 | .5306 | .3769* | .3919* |

* = significant for $p < .05$

Table 34

Gulliksen-Wilks Regression Tests

| Criterion Variable | Chi-square | Degrees of Freedom | p |
|---|---|---|---|
| Tests of Equality of Errors of Estimate | | | |
| I | 1.1802 | 2 | n.s. |
| II | 9.6197 | 2 | < .01 |
| III | 11.9933 | 2 | < .01 |
| IV | 23.2075 | 2 | < .001 |
| V | 7.6898 | 2 | < .05 |
| Tests of Parallel Regression Planes | | | |
| I | 10.4824 | 14 | n.s. |
| Tests of Equality of Intercepts | | | |
| I | 52.2336 | 2 | < .001 |

the consideration of group differences in the relationships between strategies and response measures, the two sets of dependent variables.

The within-group correlations of abilities with strategy composites were computed for each treatment group, and are presented in Table 35. These correlations reflect covariation about the group means -- for abilities and strategies -- and are descriptive of within-group relationships which are small by comparison with the treatment differences in strategy mean vectors. Under the serial anticipation condition, organization by grouping is negatively correlated with Associative Memory and Vocabulary. Modification of strategies (changing strategies frequently and/or frequent shifting of words into different clusters) is correlated positively with Expressional Fluency and negatively with Associative Memory and Semantic Spontaneous Flexibility. The negative correlations of these strategies with Associative Memory perhaps occur because a person with a low score on the test measuring Associative Memory (First and Last Names) tends to be a poor performer on tasks involving learning a list of words and therefore, tends to try strategies other than those which best "fit" this task condition, i.e. sequential strategies. Semantic mnemonics correlates positively within this group with Associational Fluency.

Under the free recall condition, order preserving mnemonics correlates negatively with all seven abilities, indicating perhaps that persons of high "general" ability choose to learn early and late words in order using "sound" rather than an active order preserving mnemonic, and that this method facilitates recall during early trials. Organization by grouping correlates positively with Associational Fluency, Vocabulary, and Semantic Spontaneous Flexibility under the free recall condition, and semantic mnemonics correlates positively with Vocabulary.

Table 35

Correlations of Strategy Composites with Abilities

| Strategy Composites | Cs | Fa | Fe | Ma | Ms | V | Xs |
|---|---|---|---|---|---|---|---|
| Free Recall Group | | | | | | | |
| Organization by Grouping | .081 | .401* | .179 | .148 | .104 | .347* | .315* |
| Semantic Mnemonics | .035 | -.002 | -.213 | -.095 | .131 | .319* | .009 |
| Active Sequential Organization | -.022 | .207 | .002 | -.066 | -.021 | .144 | .182 |
| Order Preserving Mnemonics | -.263* | -.340* | -.297* | -.298* | -.339* | -.373* | -.393* |
| Modification of Strategies | .156 | .006 | .027 | -.345* | -.112 | .229 | -.020 |
| Clusters Group | | | | | | | |
| Organization by Grouping | -.129 | .081 | -.058 | .301* | -.082 | .047 | .061 |
| Semantic Mnemonics | .039 | .099 | .214 | .141 | -.190 | .179 | .278* |
| Active Sequential Organization | -.001 | .051 | -.034 | .285* | .156 | -.109 | -.097 |
| Order Preserving Mnemonics | -.046 | .026 | .053 | .265* | .142 | -.056 | .076 |
| Modification of Strategies | .026 | .247 | -.165 | -.079 | .184 | .130 | .234 |
| Serial Anticipation Group | | | | | | | |
| Organization by Grouping | -.069 | .070 | .072 | -.308* | -.030 | -.406* | -.078 |
| Semantic Mnemonics | .049 | .288* | .129 | .008 | .103 | -.187 | -.163 |
| Active Sequential Organization | .128 | -.106 | .002 | .050 | -.149 | -.250 | -.165 |
| Order Preserving Mnemonics | -.183 | -.192 | .052 | .030 | .123 | .103 | .021 |
| Modification of Strategies | .058 | .104 | .273* | -.288* | .004 | -.082 | -.260* |

$Pr(r > .257) = .05$ ; $Pr(r > .358) = .01$

Within the clusters group, three strategies correlate positively with Associative Memory -- organization by grouping, active sequential organization, and active order preserving mnemonics (a positive score indicating use of "sentences or phrases" more than "sound") -- indicating, if high scores on Associative Memory are taken as indicative of general success in learning lists of words, that subjects who are "good learners" tend to do more grouping and to use "sentences or phrases" more than "sound" as order preserving mnemonics than do those who are "poor learners".

A single measure of the degree of relationship between the set of measured abilities and strategy choice for each treatment group was found by computing, for each group, the canonical correlations between these two sets of variables. These canonical correlations are found in Table 36. The canonical correlations indicate that the greatest amount of dependence of abilities and strategy choice occurs under the serial anticipation condition and the least occurs under the clusters condition. However, only for the serial anticipation group can the hypothesis of independence be rejected on the basis of samples of forty subjects.

Group differences in the dependence of strategy choice and abilities were investigated statistically using the Gulliksen-Wilks technique for comparing regression planes for several samples. Under consideration was the regression of each strategy measure on the set of abilities for each treatment group. The multiple correlations of abilities with each strategy composite were computed separately for each group and are reported in Table 37. None of these multiple correlations is significant for samples of size forty. The within-groups multiple correlations were also computed as were the total multiple correlations obtained by pooling the

Table 36

Canonical Correlations between

Abilities and Strategy Composites

| Treatment Group | Canonical Correlation value | Canonical Correlation squared | Parameters for Heck's Charts s | m | n | p |
|---|---|---|---|---|---|---|
| Free Recall (FR) | .6885 | .4740 | 5 | 1/2 | 13 | n.s. |
| Clusters (C) | .5368 | .2882 | 5 | 1/2 | 13 | n.s. |
| Serial Anticipation (SA) | .7624 | .5813 | 5 | 1/2 | 13 | < .025 |

Canonical Weights

| | Treatmen Group FR | C | SA |
|---|---|---|---|
| Predictors: Abilities | | | |
| Speed of Closure | .304 | -.292 | -.452 |
| Associational Fluency | .103 | .290 | -.811 |
| Expressional Fluency | .070 | -.377 | -.328 |
| Associative Memory | -.429 | .308 | -.012 |
| Span Memory | .044 | -.567 | .400 |
| Vocabulary | .755 | .151 | .452 |
| Semantic Spontaneous Flexibility | .252 | .874 | .814 |
| Criteria: Strategy Composites | | | |
| Reorganization by Grouping | .107 | .478 | .333 |
| Semantic Mnemonics | .342 | .770 | -.753 |
| Active Sequential Organization | .346 | -.391 | -.536 |
| Order Preserving Mnemonics | -.679 | -.078 | .432 |
| Modification of Strategies | .584 | .462 | -.478 |

Table 37

Multiple Correlations of Abilities with Strategy Composites

| Criterion Strategy Composites | Treatment Groups FR | C | SA | Within Groups | Total |
|---|---|---|---|---|---|
| Reorganization by Grouping | .5215 | .4220 | .5753 | .3521* | .3616* |
| Semantic Mnemonics | .5520 | .3213 | .4646 | .2179 | .1815 |
| Active Sequential Organization | .3052 | .3384 | .4111 | .1926 | .3018 |
| Order Preserving Mnemonics | .4724 | .4171 | .5223 | .1537 | .1575 |
| Modification of Strategies | .4711 | .4433 | .5303 | .2768 | .1909 |

* = significant for $p < .05$

Table 38

Gulliksen-Wilks Regression Tests

| Criterion Variable | Chi-square | Degrees of Freedom | p |
|---|---|---|---|
| Tests of Equality of Errors of Estimate | | | |
| Reorganization by Grouping | 8.9495 | 2 | < .025 |
| Semantic Mnemonics | 19.6789 | 2 | < .001 |
| Active Sequential Organization | 10.9487 | 2 | < .005 |
| Order Preserving Mnemonics | 7.0313 | 2 | < .05 |
| Modification of Strategies | 34.4651 | 2 | < .001 |

three samples. These are also reported in Table 37. The generally small multiple correlations in Table 37 are probably due to the fact that (1) strategy choice is largely a response to instructions and (2) within groups, strategies seem to be correlated with specific abilities.

Results from the tests of equality of errors of estimate are presented in Table 38. The significance tests indicate that for predicting scores on all five strategy composites from abilities, there is a significant difference between groups with respect to errors of estimate in fitting the regression planes. Since the three treatment groups differed significantly in variance on each of the strategy composites (Table 15), the condition under which a test of differences in degree of association (measured by the within-group multiple correlations) was not met for these data. Thus, the tests of differences in error of estimate variance do not provide any evidence for group differences in degree of association in this case.

# Chapter VII

# Discussion

In an attempt to integrate results obtained from studies of the relationships of learning measures to abilities and those obtained from studies of the functioning of retrieval mechanisms in verbal learning, it was suggested that cognitive strategies, functioning as higher order responses to the characteristics of a learning task, provide a mechanism of transfer from abilities to learning performance. To investigate the plausibility of this model, an experiment was performed in which a task characteristic, cluster size, was varied in order to influence subjects' choices of strategies. Specific experimental hypotheses concerned possible differences among treatment group centroids for response measures and strategy measures, group differences in the relative dependence of measured abilities and response measures, group differences in the relative dependence of measured abilities and strategy choice, and treatment group differences in relationships of specific abilities to response measures. In this section, experimental results pertaining to each of these hypotheses are discussed, together with some additional observations not corresponding to any explicit hypothesis.

## Differences among treatment group centroids

Hypotheses concerning differential relationships among measured abilities, strategy choices, and response measures under different treatment conditions are conditional upon the effectiveness of the manipulated task characteristic in influencing strategy choice. These hypotheses presuppose that the three learning situations elicit widely differing patterns of strategy choice. The results of the multivariate analysis of variance of scores on the sixteen strategy statements indicated that the three groups differed considerably in their mean strategy choices. An examination of the mean strategy statement vectors for the three treatment groups indicated that the clusters and serial anticipation groups differed considerably, despite the fact that their mean response score curves were virtually identical. Results from an analysis of variance of scores in the reduced strategies space also support strongly the conclusion that the manipulated treatment condition effectively influences strategy choice.

The observation that two treatment groups differed considerably in mean strategy choice while at the same time showing virtually identical response measures is well illustrated by a comparison of the mean discriminant scores obtained for each group from an analysis of scores on generalized response score curves (Table 14), with those obtained from an analysis of scores on strategy composites (Table 15). In the former case, the clusters and serial anticipation groups fall together on a single discriminant dimension, while in the latter case they are well separated in the two dimensional discriminant space. This result suggests that the amount of information about human learning obtainable from the behavior of learning curves may be limited, and that precise prediction of learning performance curves may not be the most important function of a learning theory.

## Differential association of abilities with response measures

The consideration of learning tasks as complex problems eliciting higher order tactical responses or strategies led to predictions of differential degrees of relationship between measured abilities and response measures for each treatment condition. If abilities function through mediating strategies, then those abilities which best predict performance for a particular learning task should be those functioning through strategies which are effective for that task. The number of different abilities which are strongly related to learning performance for a particular learning task should depend on the range of strategies which are effective for that task. Since the three learning tasks used in the present experiment represented different degrees of required order (from no order for the free recall condition to perfectly reproduced order for the serial anticipation condition), and since it was expected that the range of possible effective strategies would be inversely related to degree of task-specified order, the hypothesis that the free recall group should show the strongest relationship between the set of measured abilities and response measures was suggested.

The results tend to support this hypothesis. Significant canonical correlations between the set of measured abilities and response measures (Table 32) were obtained for the free recall and clusters conditions but not for the serial anticipation condition. However, since the treatment groups differed significantly with respect to the variance of scores on all except the first generalized response score curve, a statistical evaluation of treatment group differences in the degree of association of abilities with scores on individual generalized response score curves was possible only for the first generalized response score curve.

The first generalized response score curve (representing early performance increments) was predictable from abilities within groups (the largest significant within-groups multiple correlation occurred for this criterion) but there was no significant group difference with respect to standard errors of estimate or slopes of the regression planes (Table 34). There was, however, a significant difference for this criterion with respect to predicted level of score on the first generalized response score curve. These results suggest that early performance increments can be predicted from either knowledge of an individual's abilities or knowledge of his treatment group membership, but that no significant interaction between abilities and task constraints occurred for predicting this criterion.

Differential association of abilities with strategy choice

In addition to being a response to the characteristics of the task and a response to the preceived effectiveness of a strategy, an individual's strategy choice was also considered to be a function of his particular abilities. An individual may tend to choose strategies corresponding to his particular abilities or highly practiced skills. Since the three task situations used in the present experiment varied with respect to strategy-choice specificity, the hypotheses that the ability tests should predict strategy choice differently for different treatment conditions and that the within-group relationship between abilities and strategy choice should be strongest under the free recall condition were proposed.

The results from the correlations and canonical analyses tend to support the notion that strategy choice is in part a function of abilities and that learning tasks differ with respect to the degree to which strategy choice is a function of abilities, but the ordering of the learning tasks with respect to the degree of this association was not as expected. The highest canonical correlations was found for the serial anticipation group. The generally small multiple correlations of abilities with each strategy composite are probably due to the fact that strategy choice is largely a response to instructions and, within groups, individual strategy composites tend to be correlated with <u>specific</u> abilities. These specific relationships have been described in Chapter VI (Table 35).

Since the serial anticipation group showed a stronger relationship between abilities and strategy choice than was expected, it is interesting to consider the serial anticipation group separately. The highest canonical correlation between abilities and strategy choice was obtained under this condition, while at the same time, the group learning under this condition showed the lowest canonical correlation between abilities and response measures. These two results become explicable when they are considered in terms of the predominating strategy for the serial anticipation condition.

The decidedly most popular strategy choice for the serial anticipation condition was "Associations" (see Table 4). In addition, the discriminant function coefficients for "Associations" were both found to be large, indicating that this strategy represents a variable contributing greatly to observed treatment group differences. In the reduction of the strategies space, the strategy "Associations" did not define a separate dimension in addition to those defined by other strategy measures, but instead fell within the space defined by other strategy measures, projecting on all five principal axes. Thus, it may be that individuals in the serial anticipation group tend to associate each word with the one immediately preceding it in the list, using other strategies to organize the words into clusters and build "associative links" (see Table 11). There is, then, evidence indicating that the serial anticipation task, which is highly structured with respect to order, requires individuals to use a strategy of making associations, but that the means by which individuals accomplish this are relatively unconstrained. The result that abilities and strategy choice are related under the serial anticipation condition may indicate that an individual tends to make associations in ways that are easy for him given his particular abilities. The result that abilities are not highly related to response measures for the serial anticipation group is probably due to the fact that <u>how</u> an individual forms his associations affects performance very little.

<u>Relationships of specific abilities to response measures under each treatment condition</u>

The final hypothesis of Chapter III suggested that relationships between individual abilities and response measures should occur in a unique pattern for each treatment condition, if indeed the three conditions are distinct in terms of cognitive functioning. The correlations between individual abilities and trial-by-trial response measures described in Chapter VI (Tables 28, 29, and 30) show <u>distinct patterns</u> for each condition. The pattern of correlations with trial-by-trial response measures obtained for each condition has been described in detail in Chapter VI.

The view of a strategy as a means by which an individual structures a learning problem to facilitate recall, suggests that relationships between individual abilities and response measures can be understood by considering the manner in which subjects restructured the learning problem under each treatment condition. Although any relationship between ability and learning performance depends upon two factors -- (1) what strategies are used for the particular learning conditions, and (2) how effective these strategies are in the particular learning situation -- if with practice subjects gravitate to strategies which are effective, then relationships between specific abilities and performance for a particular condition can be understood by considering which strategies predominate for that condition. The assumption that subjects discard ineffective strategies and gravitate to optimal ones must be regarded here as an hypothesis requiring empirical verification.

A noteworthy example of an interaction between treatment condition and a specific ability in predicting learning performance is provided by the results concerning relationships of Semantic Spontaneous Flexibility with trial-by-trial response measures under each treatment condition (Tables 29, 30, and 31). This ability, which involves changing set spontaneously in as many different ways as possible, was positively (though slightly) related to response measures under the free recall condition, significantly negatively related to response measures under the clusters condition (the absolute value of the negative correlations increasing from trial five), and negatively (though slightly) under the serial anticipation condition. If it is hypothesized that transfer from Semantic Spontaneous Flexibility occurs through strategies involving frequently shifting words into new clusters or changing strategies in response to their preceived effectiveness, then the above relationships become explicable. Under the clusters condition, frequently modifying the assignment of words into clusters should be detrimental to performance, while flexible use of strategies might be helpful in the free recall situation. Thus, individuals learning in the clusters condition who are best able to use this strategy (i.e. who are high in Semantic Spontaneous Flexibility) should perform more poorly than individuals low in this ability. An opposite result should obtain under the free recall condition.

The author knows of only one other instance in which a negative relationship between an ability and performance in a problem solving task has been found. Murray (1963) investigated performance on a functional fixedness problem under conditions of continuous work on the problem and interpolation of unrelated activity for subjects of low and high problem solving ability. He found a significant interaction between treatment condition and ability level: individuals of high ability performed better in the continuous work situation than those of low ability, while the opposite result occurred for the interpolated activity condition.

The distinct patterns of correlations of individual abilities with trial-by-trial response measures under different treatment conditions which were found in the present experiment suggest that, despite the fact that the learning tasks were identical except for differences with respect to the amount of reproduced order required of the subject, relationships of learning performance to abilities may be greatly influenced by changing parameters of the task, while learning performance itself may be affected very little. This result further suggests that it may be important to include some manipulated task characteristic in studies such as those of Fleishman and his co-workers of the temporal relations of abilities with performance on learning tasks, in order to ascertain the degree of invariance of such results with small changes in the task. It appears that subjects' "cognitive" responses to task characteristics are easily influenced by characteristics of the task, and that these strategies determine to a great extent, through a mediation mechanism, what abilities will be related to response measures, and how they will be related.

The fact that the experimental results demonstrated an interaction of treatments and abilities in predicting learning performance and strategy choice makes plausible the view that the three learning situations used in the present experiment represent functionally distinct tasks, a result first suggested by the differences in mean strategy profiles obtained for the three learning conditions. Not only do the treatment groups learning under the three different conditions show distinct mean profiles of strategy choice, but they differ with respect to the functioning of abilities in relation to response measures and strategy choice. It is particularly striking that such results were obtained for groups learning under the clusters and serial anticipation conditions, groups which showed virtually identical response score curves.

## Relationships between strategy choice and performance

Strategy choice is for the most part a response to the characteristics of a learning task, both directly and through feedback from the observed effectiveness of each strategy in facilitating recall. However, one can consider residual variation in strategy choice within each treatment group, and ask, "Can I predict performance from knowledge of the strategies a person is using within a treatment condition?" The answer to this question seems to be that one can improve the prediction slightly, and that the amount of improvement is directly related to the degree to which the task specifies an individual's choice of strategies, directly and through feedback from recall performance. Accordingly, the canonical correlation between strategy composites and scores on generalized response score curves is least for the clusters condition and greatest for the free recall condition (Table 22). Controlling ability differences statistically showed that the improvement in prediction, slight as it was, was not due only to regression of both sets of dependent variables (strategy choice and response measures) on abilities (Table 24).

The results of the analysis of group differences in the regression of scores on each generalized response score curve considered individually on the set of strategy composites suggest that the prediction of response measures can be improved somewhat by knowledge of an individual's strategy choices (Tables 25 and 26). The within multiple correlations are all small and insignificant while the total multiple correlations, which are increased by treatment effects, are significant for the first three criteria. The Gulliksen-Wilks regression tests indicate that the treatment groups differed significantly with respect to standard error of estimate for all except the first generalized response score curve. The groups differed only with respect to the intercepts of the regression planes for predicting scores on the first generalized response score curve. This result is similar to that found for predicting response measures from abilities, and probably has a similar explanation.

The three treatment groups showed unique patterns of correlations of strategy composites with trial-by-trial response measures (Tables 19, 20, and 21). A description of these relationships has been presented in Chapter VI. These relationships, although they are small relative to treatment effects, contribute to an understanding of cognitive functioning in learning tasks by showing how strategy choices, functioning within a treatment condition, affect performance.

The reliability and validity of verbal reports

Although the strongest test of the model was contained in hypotheses involving only the interaction of treatments and abilities in predicting response measures, subjects' reported use of strategies was an important source of data for this investigation. The reliability and validity of such reports are thus of concern, both to the present study and for possible future use of such measures. The report method used here made relatively few demands on the individual, only that he be able to remember how he learned a particular word and that he be able to indicate with a set of binary decisions which of a set of statements best describe the method he used. Conservatively obtained reliability estimates for the strategy statements were as large as those obtained for the ability tests administered to this sample.

Given that the strategy assessment procedure is reliable and thus that the subject can, in fact, remember how he learned each word, the validity of the verbal reports must also be demonstrated. The validity of verbal reports can be ascertained through the notion of construct validity (Cronbach and Meehl, 1955). A claim that a test measures a construct ("is valid") is a claim that the test score can be linked to a theoretical network, entering into systematic relationships with other variables. It is through this network that the test scores generate predictions about observations. The results of this study provide evidence, of a construct validity nature, for the validity of the strategy measures employed.

While experimental results involving strategy measures support strongly the notion of strategies as mediators, the model is well supported by results concerning only the interaction of treatments and abilities in predicting response measures. These results require the inclusion of cognitive strategies as information retrieval mechanisms for their adequate explanation, and imply that models for verbal learning must recognize the importance of cognitive factors.

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13. ABSTRACT

In order to integrate results obtained from studies of the relationships of learning measures to abilities and those obtained from studies of the functioning of retrieval mechanisms in verbal learning, a model was suggested in which cognitive strategies, functioning as higher-order responses to the characteristics of a learning task, provide a mechanism of transfer from abilities to learning performance. To investigate the plausibility of this model, a multivariate verbal learning experiment was performed in which a task characteristic, cluster size, was varied in order to influence subjects' choices of strategies. Specific experimental hypotheses concerned possible differences among treatment group centroids for learning and strategy measures, treatment group differences in the relative dependence of measured abilities and learning performance, in the relative dependence of measured abilities and strategy choice, and in relationships of individual abilities to learning performance. The results obtained supported the hypotheses. It was concluded that each of the treatment conditions represents a functionally distinct learning problem and that the results obtained conform to the model. It was further concluded that : (1) verbal reports can constitute a reliable and valid source of data, (2) the amount of information about human learning obtainable from the behavior of learning curves may be limited, (3) it may be important to include some manipulated task characteristic in studies of the temporal relations of abilities with performance on learning tasks to ascertain the degree of invariance of such results with small changes in the task, and (4) models for verbal learning must recognize the importance of cognitive factors.

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