71-7596

WILLIAMS, John Donald, 1941-
MEMORY ENSEMBLE SELECTION IN HUMAN
INFORMATION PROCESSING.

The Ohio State University, Ph.D., 1970
Psychology, experimental

University Microfilms, A XEROX Company , Ann Arbor, Michigan

MEMORY ENSEMBLE SELECTION
IN
HUMAN INFORMATION PROCESSING

DISSERTATION

Presented in Partial Fulfillment of the Requirements
for the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

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* * * * *

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ACKNOWLEDGMENTS

This research was carried out at the Human Performance Center and was sponsored in part by the National Science Foundation, through Grant GN-534.1 from the Office of Science Information Service to the Computer and Information Science Research Center, Ohio State University.

The author is pleased to acknowledge the assistance of Professors James R. Erickson, Dean H. Owen, and Harvey G. Shulman who read this dissertation and provided valuable suggestions. Professor George E. Briggs deserves special thanks for the time he devoted to reading early drafts and for the helpful ideas that he contributed to the research. Thanks are also extended to Dr. Michael W. Coon and the staff of the Ohio State University Optometry Clinic who contributed many hours to the screening of subjects for this study, and to Miss Janis Frye for her valuable suggestions during the preparation of the manuscript.

Finally, the author is particularly grateful to his wife, Norah, who gave birth to her first child and built a home while the author devoted nearly full time to the completion of the present research.

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INTRODUCTION

Many experimenters have studied the amount of time necessary for subjects (Ss) to respond to stimuli drawn from a preselected stimulus set. When S is familiar with the stimulus set, the results of these studies are consistent with the notion that S stores information about the stimuli in memory and that, upon stimulus presentation, he performs a systematic scan through the stored memory set in order to classify the displayed stimulus as a member of the preselected group (Sternberg, 1966). Investigations of the variables affecting reaction times in such memory search experiments have contributed to the development of the concept of a human information-processing system. Such a system describes the various steps necessary for subjects to generate the appropriate responses when stimuli are presented.

Recently some investigators (Briggs and Swanson, 1969; Forrin and Morin, 1967) have reported data suggesting that S may be able to organize his memory of stimuli into subsets or ensembles. Each ensemble appears to be characterized by a common attribute which S can recognize very quickly after a stimulus is presented. Such an organization allows S to avoid scanning his complete memory store in order to respond to a stimulus, but the strategy also requires that S somehow identify and select the smaller memory ensemble in which the necessary stimulus information is contained so that that ensemble may be scanned.

Although the selection of memory ensembles appears to be a very

important information-processing ability, no experiments have been conducted to systematically investigate the rate at which S can perform the selection process. This introduction, therefore, contains a discussion of the components of the human information-processing system which are involved in ensemble selection and a review of the relevant experimental literature.

Over the past 20 years, psychologists have increasingly viewed the human operator as an information-processing system. Pierce (1961) defined a system as a set of interrelated components or devices designed to perform an overall function. The idea of an information-processing system has been borrowed from computer technology and refers to the concept that information put into a system is subjected to various interrelated processing steps before it appears again as system output. The relationship between system input and output depends upon the number and type of processing steps that the input encounters while it is in the system. Early models of human information-processing systems were proposed by Broadbent (1958) and Welford (1960). Smith (1968) recently published an extensive review of human processing models.

Smith (1968) suggested that the human processing system is composed of four sequential stages. These stages are illustrated in Figure 1. The system input (stimulus) first encounters Stage 1, the encoding and preprocessing stage. Here, the stimulus is encoded and a representation of the encoded information is prepared for use by the subsequent stages in the sequence. At Stage 2 or central processing, the stimulus representation is compared with memorial representations of the stimuli contained in S's memory set. The results of the central

Figure 1. A model of human information processing (after Smith, 1968).

stage of processing are fed to Stage 3 or response decoding, and at this stage the appropriate way is selected to express the results of the prior stimulus comparisons. Stage 4, the response execution stage, controls the actual output or observable response of the system.

Two important assumptions about the human information-processing system are (1) that each stage takes some amount of time, and (2) that the times taken by the stages are additive (Donders, 1868). Because of these two assumptions, the total processing time between system input and output is assumed to be lawfully affected by the operation of the various processing stages in the system. Therefore, the total processing time or reaction time has been used by many psychologists in order to study human information processing.

Reaction times are measured from the onset of the stimulus to the beginning of the S's response. Since Stage 4 in the processing system is utilized for response execution, reaction time reflects the times utilized by the first three stages of the human processing system. One characteristic of reaction time experiments is that when each stimulus presented to S had its own unique response, mean reaction time often increases linearly with $\log_2 N$ (Hick, 1952; Hyman, 1953). The "N" refers to the number of stimuli which could have occurred on a particular trial. This increase in reaction time with N suggests that N has an effect on one or more of the relevant processing stages. Since the stimuli are usually presented to S individually, Sternberg (1967) has suggested that the Stage 1 encoding process is not affected by N. However, in Stage 2 the stimulus representation encounters memorial information concerning the N stimuli which could have been presented, and

during Stage 3 an appropriate response is selected from among the N responses which are possible. Therefore, since N is a factor which could affect both Stage 2 and Stage 3 when each stimulus has its own unique response, it is difficult to determine whether the increase in reaction time with N is attributable to the central processing or decoding stage of processing.

The confounding of Stage 2 and Stage 3 may be avoided by requiring S to select from only two responses instead of N responses. When Stage 3 always involves a selection between two responses, changes in reaction time which result from changes in N should reflect Stage 2 processing only. Sternberg (1966, 1967) required S s to respond "yes" if a presented test stimulus was a member of a predetermined set of digits which the S had stored in memory; he responded "no" if the stimulus was not a member of the set. Sternberg (1966) found that reaction time for both "yes" and "no" responses increased linearly with the size of the set of digits which the S had stored in memory. Since the slopes of the reaction time/memory load functions were the same for "yes" and "no" responses, Sternberg suggested that S makes an exhaustive search through the memory set during Stage 2 before decoding the appropriate response in Stage 3.

Sternberg provides a very useful methodology for studying human information processing. In this methodology one systematically changes the processing load on Stage 2 while maintaining a constant processing load on Stages 1 and 3. Since reaction time (RT) increases linearly with memory load (M), one may describe the relationship between RT and M by the equation

$$RT = A + B(M). \quad (\text{Eq. 1})$$

The intercept constant A is assumed to reflect the total time required for Stages 1 and 3 processing. The slope constant B presumably reflects the time required for memorial information to be compared with the stimulus representation in Stage 2 (Sternberg, 1966). Since the processing times required by the successive stages are assumed to be additive, experimental factors which do not interact with each other are assumed to affect different processing stages or component functions within stages (Sternberg, 1969). For example, Sternberg (1967) degraded the test stimulus by superimposing a checkerboard pattern on it, and found a 64-msec. increase in the intercept constant A in Equation 1 over that with a noise-free display. The slope constant B was relatively unchanged. Since degradation did not interact with M, Sternberg (1967) interpreted this result as indicating that degradation of the test stimulus increased Stage 1 time while leaving Stage 2 unaffected. Stage 3 was not affected because the same response alternatives were used with both the intact and degraded stimuli.

Sternberg's method has been most useful as a tool for investigating human information processing. However, it is probably only on rare occasions that Ss outside of the laboratory are called upon to respond to information related to a single, well-defined memory set. Also, considering the vast store of information contained in human memory, a serial search through the complete store would completely disallow any form of high-speed responding. For example, Oldfield (1966) estimated that the average university-educated person has a vocabulary of about 75,000 words. If, in order to identify or name an object or picture,

S searched his complete vocabulary at the rate of processing estimated by Sternberg (1966), his reaction time to produce a single word would be about 50 minutes! However, Oldfield and Wingfield (1965) have shown that the average latency for naming pictures of objects is about 800 msec.

To explain the obvious discrepancy between reaction time predicted by a serial memory search and the usual reaction time for naming pictures, Oldfield (1966) noted a result by Oldfield and Wingfield (1965) indicating that the reaction time for naming an object is inversely related to the log frequency of occurrence of the name in textual material. He then proposed that memory for names is organized in a number of subsets or ensembles, each ensemble being characterized by a common frequency of occurrence for the names that it contains. Utilizing a law formulated by Zipf (1935), Oldfield suggested that the size of each ensemble is inversely related to the log frequency of occurrence of the names within it; i.e., the largest ensemble contains the names utilized least while the smallest ensemble contains the most frequently used names in S's vocabulary. Oldfield conceived of the memory search as a two-step task: The appropriate ensemble is first selected and then the selected ensemble itself is scanned.

In order to test this hypothesis, Briggs and Swanson (1969) required that S learn four ensembles of random forms. Each form was assigned a unique name and the forms were arranged into four ensembles, each having forms with a common frequency of occurrence and a common number of sides (4-, 6-, 8-, or 10-sided forms). Frequency of occurrence of the individual forms and the number of forms (memory load)

within each ensemble (M) were maintained in accordance with Zipf's law. When the reaction time for naming the individual forms was measured, it was found that reaction time was a linear function of $\log_2 M$. Briggs and Swanson's (1969) results are illustrated in Figure 2. Finally, during a special session, the experimenter identified the ensemble from which each form was to be drawn. The information was spoken to S about 2 sec. prior to each stimulus presentation. As shown in Figure 2, reaction time under the special condition ($N|E$) was reduced by about 184 msec. from that without the prior ensemble information ($E+N$).

Since the amount of reduction in reaction time caused by early information concerning the specific ensemble to be used did not interact with the memory load within ensembles, it was assumed that preinformation and the memory load within ensembles affected different processing stages (Sternberg, 1969). Briggs and Swanson (1969) suggested that reaction time was reduced when ensemble information was provided to S because it was no longer necessary for S to select the appropriate memory ensemble from among the four which were stored in memory. In other words, they concluded that it took their Ss an average of 184 msec. to select the appropriate memory ensemble from among the four stored in memory.

Based upon the Briggs and Swanson (1969) data, Briggs (1969) revised Smith's (1968) original model of the human information-processing system. Briggs proposed that Stage 1, the preprocessing or encoding stage, contains a "Recognition Buffer Memory" (RBM) which keys the appropriate memory ensemble so that the items contained in it may be retrieved and compared with the encoded stimulus representation at

Figure 2. Mean reaction time as a function of the number of forms within each ensemble (M) for regular and for special testing (Briggs and Swanson, 1969).

Stage 2. Briggs' (1969) model is displayed in Figure 3. Briggs also added a new term to Equation 1 so that ensemble selection time could be taken into account in the linear RT equation. If stimuli are displayed individually to S and response decoding time is held constant, the constant A in Equation 1 may be broken into two components: a constant time C representing encoding plus response selection time, and the term F indicating the rate at which the RBM can select the appropriate memory ensemble. The term E reflects the number of ensembles contained in the total memory set. These changes are reflected in the following equation:

$$RT = C + F(E) + B(M)$$

where $B(M)$ represents the time necessary for Stage 2, given an ensemble of size M .

The supposition that S organizes his memory store into more than a single ensemble is not unique to Oldfield (1966). Morin and Forrin (1962) and Forrin and Morin (1967) also suggested that S uses a two-step process in order to search a memory ensemble. Utilizing a finding by Mowbray (1960) that the reaction time for naming digits is often unrelated to memory load when the memory set is composed entirely of digits, Morin and Forrin (1962) added some geometric symbols to their Ss' memory sets. They suggested that if numerals can be named without the use of the many processing stages in the human processing system, then numeral naming time should be unaffected by the presence of another class of stimuli in the memory set. Each symbol was assigned a numeral name. The authors found that reaction time for naming digits was unaffected by memory load when the memory set of possible stimuli contained only

Figure 3. An expanded model of human information processing (Briggs, 1969).

digits. When the set contained digits and symbols, the reaction time for naming the digits in the mixed set was increased by 100 msec. Because of their 1962 finding, Forrin and Morin (1967) proposed that S must first recognize the category to which a stimulus belongs. Once the decision concerning the stimulus category has been made, the subsequent speed of identification of elements within the category depends upon the characteristics of the items within the category set itself.

In an attempt to explore their hypothesis in greater detail, Forrin and Morin (1967) varied orthogonally the number of numerals and symbols making up the set of possible stimuli in an experimental condition. Their stimulus sets contained eight combinations of zero, two, or four numerals and symbols. For example, one condition utilized a set of four numerals and four symbols, while in another condition the set of possible stimuli contained four numerals and two symbols. Numeral names were assigned to the symbols and the reaction times for naming the individual stimuli were measured. The Ss were rotated through all eight experimental conditions and they always were informed of the set of stimuli to be used.

Forrin and Morin (1967) again found that the presence of symbols in the stimulus set increased the reaction time for naming numerals. When the stimulus set contained both numerals and symbols, the reaction time for naming symbols was strongly affected by the number of symbols in the set, but reaction time for naming numerals was unaffected by the size of the numeral set. These findings further support the hypothesis that the identification of elements within a category depends upon the characteristics of the items within the category itself. In addition,

if S conducted a serial search through the entire memory store of numerals and symbols, the reaction time for symbol naming would be very much affected by the number of numerals in the set. Since symbol naming time was unaffected by the number of numerals greater than two in the stimulus set, the data suggest that S may have avoided searching the numeral ensemble when the displayed stimulus was a symbol.

It seems clear that an S in an information-processing task is able to organize memory information into distinct independent subunits. His task then becomes one of identifying the ensemble membership of a stimulus and searching the identified ensemble for the appropriate information. Such a strategy reduces the Stage 2 processing load when S must utilize large amounts of stored information. It is surprising, therefore, that no studies have been conducted in an attempt to investigate the rate at which the human information-processing system can select an appropriate ensemble in memory. In each of the studies reviewed in this paper, S selected memory ensembles from a fixed number of stored memory sets. However, just as the rate of scanning within an ensemble must be investigated by varying the memory load within the ensemble, ensemble selection rate must be studied by varying the number of ensembles from which S must select in his processing task.

The present research was designed to study the selection of memory ensembles in an information-processing task. In order to obtain an estimate of the rate of selection of memory ensembles, the number of ensembles contained in S's total memory set was systematically varied. In addition, the memory load within ensembles was varied in order to study S's scanning of information within a selected ensemble. It was

anticipated that these two variables (the number of ensembles in memory and the memory load within ensembles) would not interact with each other in the experiment, reflecting the independence of the two information-processing steps of ensemble selection and subsequent scanning of the selected ensemble. Finally, it was anticipated that S's ability to scan only the selected ensemble instead of his entire memory set would produce considerable savings in information-processing time.

METHOD

Procedure

Experimental groups. Three groups of 10 Ss each were formed. Each group contained five males and five females and, with this restriction, the Ss were assigned to groups in a random fashion. The memory ensembles used by Group M₂ always contained two letters. Group M₃ used ensembles containing three letters, and Group M₄ used ensembles of size four. Therefore, memory load within ensembles (M) was a between-Ss variable. Memory load within ensembles was maintained as a between-Ss variable because such a procedure allowed the S to use the same ensembles throughout the experiment. If memory load within ensembles were a within-Ss variable, the number of letters contained in the ensembles used by the S would have varied for each experimental condition. It was anticipated that frequent changing of the composition of the S's memory ensembles would produce considerable confusion.

Half of the Ss in Group M₂ learned ensembles made up of the letters "N K," "L V," and "J W." The remaining M₂ Ss learned "F S," "R D," and "B P." Five Ss in Group M₃ learned ensembles containing the letters "N K F," "L V R," and "J W B," while the remaining five Ss learned "K F S," "V R D," and "B W P." All Ss in the M₄ group learned the three ensembles "N K F S," "L V R D," and "J W B P." The ensembles used during the experiment are outlined in Table 1.

Ensemble learning. During the first two days of the experiment

Table 1
Memory Ensembles Learned by Three Subjects
during Days 1 and 2

Group M ₂		
Ensemble Green	Ensemble Purple	Ensemble Blue
N or F K or S	L or R V or D	J or B W or P
Group M ₃		
Ensemble Red	Ensemble Gray	Ensemble Brown
N K K or F F S	L V V or R R D	J B W or P B W
Group M ₄		
Ensemble Purple	Ensemble Green	Ensemble Red
N K F S	L V R D	J W B P

each S learned three different ensembles. The size of each ensemble was two, three, or four letters depending upon the group to which S had been assigned, and each of the letters in a particular ensemble had a common background color. The three different ensembles, however, were characterized by different colors. This arrangement is also outlined in Table 1. The three colors used to characterize the different memory ensembles were counterbalanced across Ss.

The S learned the ensembles by performing two sorting tasks during the first two days of the experiment. To prepare for the tasks, each S was given three colored cards when he started the experiment, each card displaying the letters and color to be used in a single ensemble. The letters in the "green" ensemble (for example) were listed on a green card, the letters in the "blue" ensemble were listed on a blue card, etc. After S had studied the ensemble cards for a few minutes, the ensemble cards were removed and the S was handed a pack of 78 white sorting cards. Each card contained a single letter and the pack was made up of three complete alphabets of 26 letters each. Three colored squares were then placed on the table in front of S—the colors being those which characterized the three memory ensembles to be used during the experiment. During the first sorting task, S placed letters which were ensemble members face down on top of the color defining the appropriate ensemble. Letters which were not ensemble members were placed in a separate pile elsewhere on the table. The pack of cards was reshuffled after each trial. Each S performed the sorting task to a criterion of three perfect sequential trials during the first day of the experiment. A criterion of five perfect sequential trials was used

during the second day.

The second sorting task was conducted using sorting cards made up on the six colors to be used in the experiment. Three of the colors characterized ensembles which the S had learned, and three were "irrelevant" colors for which S had not learned letters. The S was handed a pack of 18 colored cards and he held the cards face down. As he turned the cards over one at a time, he was required to repeat the letters which were members of the ensemble defined by the color of the card which he encountered. If the color of the card did not define a memory ensemble which he had learned, he said "no." Each S performed this sorting task to a criterion of five perfect sequential trials during the first day of the experiment, and to a criterion of five perfect sequential trials during the second day.

Experimental task. After two days of ensemble learning, the Ss began the actual experimental task. During this task the Ss were instructed to respond as quickly and as accurately as possible to test stimuli which were back-projected before them on a ground-glass screen. The stimuli were letters surrounded by a background color. The task consisted of three experimental conditions (E_1 , E_2 , and E_3) and two control conditions (Colors-Only and Letters-Only).

During the experimental task, S was told to respond "yes" if the test stimulus displayed before him was a letter contained in one of the memory ensembles which he had previously learned. In order to respond "yes" to a test slide, the stimulus had to have a background color which characterized one of the three ensembles which the S had learned, and the letter presented had to be one of the letters which was a

member of the defined ensemble. The total memory set used by S during the experimental conditions consisted of one ensemble (E_1), two ensembles (E_2), or three ensembles (E_3), and S worked under each of the three conditions during the experiment.

When the S was working with only one memory ensemble (E_1), he was informed of the ensemble which he was to be using at the beginning of the block of trials for that condition. He was also informed that he would not see the two remaining colors which characterized the two ensembles not in use during the block of trials. However, he did see stimuli which contained the three background colors to which he had not learned letters. When the S was working with two memory ensembles (E_2) and with three ensembles (E_3), he was also informed of the ensembles which he was to be using. In the E_2 condition, as in the E_1 condition, S was told that he would not see the remaining color which characterized the one ensemble not being used in that block of trials. He did see stimuli which contained background colors to which he had not learned letters. Of course, in the E_3 condition, S worked with test stimuli drawn from a population containing all of the colors to which he had learned letters. These three conditions define the number of memory ensembles from which S must select in the information-processing task.

To illustrate, consider an S in Group M_3 who has learned the ensembles "N K F," "L V R," and "J W B." Under the E_2 condition, when S was told to respond "yes" to the test stimuli contained in the red or gray ensembles, a test stimulus which was a red N, K, or F required a "yes" response. A test stimulus which was a gray L, V, or R also required a "yes" response. Any other stimulus presented required a

negative response because it was not a member of one of the two designated memory ensembles. The S always knew that in the E₂ condition he would not see a stimulus with a blue background and therefore he could eliminate the blue ensemble from his memory set.

When the S was working under the Colors-Only condition, he viewed test stimuli which were of solid color and contained no letters. The S was required to respond "yes" whenever he saw one of the colors to which he had learned letters, i.e., a color which designated a memory ensemble. During this special testing, the S's memory set was composed of one, two, or three of the colors used in the experiment. When the S was working with only one color (C₁), he was informed at the beginning of the condition of the color to which he was to respond "yes." He was also informed that he would not see the two remaining colors which had characterized memory ensembles, but that he would see the three irrelevant colors for which he had never learned letters. These irrelevant colors always required a "no" response. When S was using two colors (C₂), he was told that he would not see the one remaining color which characterized an ensemble of letters, and, of course, when working with the three colors (C₃), he viewed all three of the ensemble-defining colors. Since color was the attribute defining the ensembles used by S in the E₁, E₂, and E₃ conditions, it was hypothesized that S would select the appropriate memory ensembles for processing by scanning a memory set of colors characterizing the ensembles in his letter memory set. This control condition was designed to provide data concerning the memory scanning for color in a color recognition task.

When working in the Letters-Only condition, the S viewed stimuli

containing a letter and a background color. These were the same stimuli used in the three experimental conditions. However, during this condition the S was informed that every stimulus presented would have the same background color—the color being one which defined an ensemble which he had learned. He was also informed of the color to be used. Therefore, the S could ignore the background color of the stimuli and respond utilizing only the letter presented on the display. The S was instructed to respond "yes" if the letter presented to him was one which he had learned with the color in use at the time, and to respond "no" if the letter was not a member of the ensemble which he was using. This condition was designed to provide data concerning the memory scanning for letters in a letter recognition task when there was no ensemble selection uncertainty. It was anticipated that the results of this condition would be quite similar to those obtained by Sternberg (1966).

The S served in the experiment for nine daily sessions, each a half-hour in length. Following every half-hour session, each S performed the two sorting tasks again to demonstrate that he thoroughly knew the memory ensembles in use during the experiment. Errors were recorded and the time required to complete each task was also measured. Errors and sorting-time records were also maintained during the two days of ensemble learning.

Design

During a single half-hour session, each S experienced three of the five conditions of the experiment. Each condition was preceded by a 1-min. rest and a brief instructional period during which S was informed

of the condition under which he would be working. During this instructional period, the S was always reminded to respond as quickly and as accurately as possible.

Each S provided 72 reaction times under each condition, half of which were "yes" and half "no" responses. When working with one ensemble (E_1), all of the stimuli to which S responded "yes" were drawn from the ensemble in use at the time. When two ensembles were being used, 18 stimuli were drawn from one ensemble and 18 from the other. Twelve stimuli were presented from each ensemble when all three ensembles were in the memory set.

The stimuli which required a "no" response were of two types. Half of the negative stimuli contained background colors which characterized one of the memory ensembles in use at the time. However, the letter displayed was not a member of the memory ensemble defined by the color presented. The "no" response generated in this case will be designated a No_1 response. The remaining half of the negative responses were generated by stimuli which did not contain a background color defining an ensemble in use during the condition under which the S was working. The colors presented in this case were equally distributed between the three irrelevant hues for each S. These "no" responses will be designated No_2 responses. While the No_1 responses should require the selection of an ensemble and the search of the letters contained within that ensemble, it was hypothesized that S could produce a No_2 response without searching any memory ensemble of letters because he had never learned letter sets for the three irrelevant colors.

The conditions of the experiment were presented in a Latin Square

arrangement of the following order: E₁, E₂, E₃, Colors-Only, Letters-Only. The sessions during which S experienced the experimental conditions for the first time were considered practice sessions and the data collected during these sessions were not analyzed. After the practice sessions, the S experienced each condition three additional times during the course of the experiment. The ensembles used for the conditions were counterbalanced within Ss, and the three exposures to the conditions were treated as three blocks in the analysis of the experiment. An outline of the order of presentation of the experimental conditions is contained in Table 2. In this table, C₁ designates the Colors-Only condition when S had one color in his memory set; C₂ and C₃ signify the Colors-Only condition with two and three colors respectively in the memory set. Median reaction times were calculated for the last 60 trials for each S at each block under the five conditions. Median reaction times for Yes, No₁, and No₂ responses were computed separately and the data for the last five of the nine sessions were analyzed.

Stimuli and Responses

The stimuli were single letters photographed on Kodachrome II Professional-A film and mounted as 35-mm. slides. The slides were back-projected on a ground-glass screen. Surrounding each letter was a background color selected from a pool of six hues equated for brightness and chromaticity before photographing. A check of color brightness was also conducted after the slides were developed, and the hues were still of equal intensity. The six colors were chosen from Color Match paper (Craftint Manufacturing Company, Cleveland, Ohio) and were

Table 2
Order of Presentation of Conditions for
One Subject during Sessions 1 to 9

Session	Conditions Presented
1	Sorting
2	Sorting
3	E ₁ , E ₂ , E ₃
4	C ₁ , L ₀ , E ₁
5	E ₂ , E ₃ , C ₂
6	L ₀ , E ₁ , E ₂
7	E ₃ , C ₃ , L ₀
8	E ₁ , E ₂ , E ₃
9	C ₁ , L ₀

selected to be as close as possible in hue and chromaticity to Munsell colors: 5R 10/5, 5YR 8/5, 5G 8/5, 5B 8/5, 5P 6/5, and gray of value 5 (Newhall, Nickerson, and Judd, 1943). Color selections were made from the Munsell Book of Color (1969). These colors, with their Color Match numbers, are: red (65), brown (40), green (191), blue (138), purple (98), and gray (G 11).

The memory ensembles used by S were ensembles of letters, and each of the separate ensembles was characterized by one of the six background colors. The color specific to each ensemble was the stimulus attribute which the S needed to utilize in order to select the relevant memory set for processing.

The total extent of the stimulus slide (letters and background color) subtended a visual angle of 10 deg. The letter in the center of the slide was about 1 cm. square, producing a visual angle of .90 deg. Each letter was actually placed in the center of a 2.5X1.6-cm. colorless rectangle so that all characters would be equally discriminable regardless of the background color of the slide.

The S indicated his response to a test stimulus by pressing one of two response buttons placed before him. One of the buttons indicated a "yes" response, meaning that the stimulus presented to S was a member of one of his memory ensembles. The other button designated a "no" response and signified that the stimulus presented was not a member of one of the memory ensembles. Half of the Ss used the right button for the Yes response and half used the left button for the Yes response.

Apparatus

Two Kodak RA-950 Carousel random access slide projectors were

employed to display the stimulus material. The interval between the presentation of stimuli was controlled by interval timers and was maintained at 2.5 sec. throughout the experiment. Each stimulus was displayed for a period of 2.5 sec. Immediately upon the presentation of the stimulus, a Hewlett-Packard 5222L timer began accumulating the time and continued to do so at a rate of 10,000 counts per sec. until S initiated a response. The reaction time and the response made were printed out automatically after each trial.

The S worked in a sound-treated booth and was seated about 2 ft. before the ground-glass screen upon which the stimuli were back-projected. Each S wore a headset through which he heard constant-intensity white noise at 87 db. The headset was part of an intercom system with which the S and experimenter could communicate, and the white noise was interrupted when the intercom was in use. The white noise was also momentarily interrupted 1 sec. prior to each stimulus presentation as a warning signal for the subject. A 1-sec. interval was chosen because it has been shown that S may achieve maximum readiness to respond with a 1-sec. warning (Telford, 1931; Klemmer, 1956).

Subjects

The Ss were 30 Ohio State University undergraduates, 15 males and 15 females. Each S served in the experiment for nine days and was paid \$1.25 for each half-hour session. Color vision tests were administered to Ss by the Ohio State Optometry Clinic utilizing HRR Pseudoisochromatic Plates (Hardey, Rand, and Rittler, 1945) and the Farnsworth Dichotomous Test (Farnsworth, 1943). Every S was color normal.

RESULTS

Analysis of the sorting times for letter and color sorting indicated that the Ss were thoroughly familiar with the memory ensembles by the fourth session of the experiment. The sorting times for letter and color sorting are illustrated in Figure 4. Analyses of variance were conducted separately for the letter and color sorting data, and neither of these analyses revealed group differences in sorting times (Tables 5 and 6 of Appendix A). An interaction between groups and sessions was found in both sets of data ($F = 1.94$, $p < .05$ for letter sorting, and $F = 2.79$, $p < .01$ for color sorting), and an analysis of simple effects (Winer, 1962) on these data revealed that there was a significant difference between groups only during Session 1 for both tasks ($p < .01$). A Tukey-B (Winer, 1962) test of the session means indicated that performance improved in the color sorting task only during the first two sessions ($p < .01$), while significant improvement in letter sorting time was evident only during the first three sessions ($p < .01$). Since the error rate for letter sorting was .04% during the last five sessions of the experiment, it may be concluded that the memory ensembles were well learned by all Ss.

Because of the extent of the analysis performed on the experimental data, the remaining results will be presented within the organization outlined below.

1. Analysis of variance of Yes and No₁ data for the experimental

Figure 4. Sorting speed as a function of sessions for letter and color sorting tasks.

task. This analysis was performed to investigate the relationship between ensemble selection and the memory load within the selected ensembles. The important finding in this analysis was that reaction time did not increase in a linear fashion with the number of items within the selected ensembles. The finding was verified by the nonlinear relationship between reaction time and the number of letters in memory found in the Letters-Only condition.

2. Analysis of variance of the Colors-Only control condition.

This analysis indicated that Group M₃ provided somewhat slower reaction times than Groups M₂ and M₄, and suggested that the nonlinear relationship between reaction time and the number of letters within the individual ensembles was due to the presence of slower Ss in Group M₃.

3. Analysis of covariance of Yes and No₁ data for the experimental task. This analysis used the individual S's scores on the Colors-Only task as a covariate and thereby corrected the individual subject differences for the three groups suspected from Analysis 2, above. The important finding of this analysis was that ensemble selection is a process independent of the subsequent scanning of the selected ensemble.

4. Analysis of covariance of Yes, No₁⁻, and No₁⁺ responses for the experimental task. This analysis was performed in order to investigate an interaction between the number of ensembles in S's memory set and response type. The interaction was originally found during Analysis 3, above. The results indicated that S may have been able to generate a No₁ response without first selecting a memory ensemble or scanning the selected letter set.

5. Analysis of variance of the Colors-Only control conditions.

This analysis was performed to inspect S's memory scanning for colors. It was anticipated that the processing rate for color information would be similar to the memory ensemble selection rate based upon colors. The data revealed that color processing in the Colors-Only condition was slower than anticipated and it was hypothesized that the slow processing might have been caused by the relative lack of practice on the three levels of the Colors-Only task.

6. Analysis of variance of the Special Colors-Only control condition. This analysis was performed on the data from a second Colors-Only experiment conducted at the conclusion of the main study. The data for this analysis were collected because it was suspected that the processing rates found in Analysis 5 would be artificially low. The results indicated a faster processing rate for colors than was found in the Colors-Only control condition.

7. Analysis of covariance of the Letters-Only control condition. This analysis was performed to investigate S's processing performance when there was no ensemble selection uncertainty. It was demonstrated that S's letter processing rate under the Letters-Only condition did not differ significantly from the letter processing rates found when S was required to select a letter ensemble from an increasing number of memory ensembles.

8. Analysis of covariance of Yes, No₁, and No₂ data for the experimental task. This analysis compared S's performance when ensemble selection was performed during processing (Yes and No₁ responses) with performance when S could respond accurately without selecting an

ensemble for letter search (No_2 responses). The results indicated that S may generate a No response with a shorter reaction time when the background color of the stimulus does not characterize an ensemble in memory.

Analysis of Variance for Yes and No₁ Data for the Experimental Task

An analysis of variance was performed on the Yes and No₁ data for the last five sessions of the experimental task. The results of this analysis are displayed in Figure 5, and a summary of the analysis is contained in Table 7 of Appendix A. As anticipated, there was a significant effect of memory load within ensembles ($F = 6.06$, $p < .05$) and the number of ensembles which S had in his memory set ($F = 90.75$, $p < .001$). A Tukey-B test of the main effect of ensembles revealed that there was a significant rise in reaction time when S increased his memory set from one to two ensembles ($q = 17.54$, $p < .01$). However, there was no significant change in reaction time when the S's memory set was increased to include three ensembles ($q = .58$, $p > .25$). The mean reaction times for the main effects of the number of ensembles were 459 msec., 520 msec., and 518 msec. for the E_1 , E_2 , and E_3 conditions, respectively. The interaction between the number of ensembles and memory load within ensembles did not attain statistical significance ($F = 2.04$, $p > .10$), thereby indicating that ensemble selection and subsequent ensemble search are independent, additive processes. The interactions which did attain significance in this analysis will be discussed when the data are reconsidered in a later portion of this paper.

The data displayed in Figure 5, however, are not as straightforward

Figure 5. Reaction time as a function of the memory load within ensembles (M) and the number of ensembles in the memory set (E)—Yes and No₁ responses combined.

as one would expect. The main effect of the number of letters within each ensemble does not appear to be linear even though there is sufficient evidence in previous literature (Sternberg, 1966, 1967; Wingfield and Branca, 1970) to suggest that reaction time should increase linearly with the memory load within each ensemble. The data in the Letters-Only condition (Figure 6) also do not appear to be fitted well by a straight line, although an analysis of variance conducted on the control data did reveal a significant effect of memory load within ensembles ($F = 4.43$, $p < .05$). The summary table for the analysis of variance for the Letters-Only condition is contained in Table 8 of Appendix A.

Analysis of Variance of the Colors-Only Control Condition

Because memory load within ensembles was a between-groups variable in this study, it was suspected that the reaction times for Group M₃ might be due to slower Ss in that group in addition to the treatments received by the group. This hypothesis was confirmed when the reaction times for the Colors-Only control condition were subjected to an analysis of variance. The analysis (Table 9 of Appendix A) revealed no significant differences between groups ($F < 1.00$), which was desirable since all Ss received the same treatments under the Colors-Only condition. However, as Figure 7 illustrates, the mean reaction time for Group M₃ was 23 msec. higher than the reaction times for Groups M₂ and M₄.

Analysis of Covariance of Yes and No₁ Data for the Experimental Task

The finding of higher reaction times for Group M₃ in the Colors-Only condition indicated that the linear relationship between reaction

Figure 6. Reaction time as a function of memory load (M) for the Letters-Only control condition—Yes and No responses combined.

Figure 7. Reaction time as a function of groups for the Colors-Only control condition.

time and the number of letters within ensembles might be obscured because of individual S differences. Therefore, an analysis of covariance was performed on the experimental task data (Winer, 1962), utilizing the individual S 's mean scores across all conditions of the Colors-Only task as the covariate. A summary table of the analysis of covariance for the Yes and No₁ responses is contained in Table 10 of Appendix A. Figure 8 displays the adjusted reaction times of the analysis summed across Yes and No₁ responses. Memory load within ensembles and the number of ensembles in the memory set both had significant effects on reaction time ($F = 7.45$, $p < .005$; and $F = 90.75$, $p < .001$, respectively). Inspection of Figure 8 reveals that the effect of memory load within ensembles does indeed appear to be linear in accordance with previous studies (Sternberg, 1966, 1967; Wingfield and Branca, 1970). Equations for the best-fitting straight lines (least-squares solutions) are also presented in Figure 8.

Again, as in the analysis of variance of the experimental task data, the interaction between memory load within ensembles and the number of ensembles in the memory set was not statistically significant ($F = 2.04$, $p > .10$), indicating once more that ensemble selection and ensemble search are independent processes. A Tukey-B test indicated that there was a significant rise in reaction time when the memory set was increased from one to two ensembles ($q = 17.54$, $p < .01$), but that there was no significant change in reaction time when the memory set was augmented to include three ensembles ($q = .58$, $p > .25$).

The analysis of the experimental task also revealed a significant effect of response type ($F = 47.95$, $p < .001$). It will be recalled

Figure 8. Reaction time as a function of memory load within ensembles (M) and the number of ensembles (E)—Yes and No₁ responses combined.

that a Yes response was generated when the background color of a test stimulus characterized one of the ensembles which S had in memory and the stimulus letter matched one of the letters contained in the appropriate ensemble. A No₁ response was generated when the stimulus color characterized a memory ensemble but the stimulus letter did not match one of the letters in the defined ensemble. The significant effect of response type agrees with many previous studies in which it has been noted that reaction times for negative responses are longer than those for positive responses (Briggs and Blaha, 1969; Sternberg, 1969). The analysis also indicated that response type interacted with the number of ensembles in the memory set ($F = 12.50$, $p < .001$). This interaction is illustrated by Figure 9. It may be seen that the difference in reaction times for Yes and No₁ responses decreased as the number of ensembles in memory was increased from one to three ensembles. A Tukey-B test of the effects of ensembles for positive and negative responses indicated that there was a significant increase in reaction time between the E₁ and E₂ conditions for both Yes and No₁ responses ($p < .01$). Neither response showed a significant change between the E₂ and E₃ conditions. Analysis of the simple effects of response type at each of the three ensemble levels (Winer, 1962) revealed that there were significant differences between positive and negative responses at all three E levels ($p < .05$ for E₁ and E₂; $p < .01$ for E₃). The Ensemble X Response interaction, therefore, seems to indicate that the difference between positive and negative responses was reduced when S had three ensembles in his memory set.

The analysis of the Yes and No₁ responses also showed an Ensembles

Fig. 9. Reaction time as a function of Yes and No responses for the memory load within ensembles (M) for one (E₁), two (E₂), and three (E₃) ensembles in memory conditions.

X Blocks interaction ($F = 3.00$, $p < .05$). This interaction is displayed in Figure 10 and suggests that practice may not have affected all three ensembles-in-memory conditions equally. A Tukey-B test of the effects of ensembles for each of the three blocks indicated that, for each block, $E_1 < E_2 = E_3$ ($p < .01$). However, a test of the effects of block at the three ensemble levels resulted in the following differences:

$$E_1: B_1 = B_2, B_2 = B_3, B_1 > B_3 \quad (p < .01)$$

$$E_2: B_1 = B_2, B_2 > B_3, B_1 > B_3 \quad (p < .01)$$

$$E_3: B_1 > B_2, B_2 = B_3, B_1 > B_3 \quad (p < .01)$$

With one ensemble in memory, practice reduced the mean reaction time by 26 msec., and reaction time decreased 46 msec. over the three blocks when S had three ensembles in his memory set.

Analysis of Covariance of Yes, No₁⁺, and No₁⁻ Responses for the Experimental Task

It had not been expected that reaction time for No₁ responses would be reduced relative to Yes responses when S had two and three ensembles in his memory set (see Figure 9). To understand the cause of the Ensembles X Response interaction, the reader should recall the experimental procedure. The No₁ response was generated when the background color of a slide designated a letter set which S had learned, but the letter presented on the slide was not a member of the designated set. Some of the letters on a No₁ slide, however, could be members of other ensembles (i.e., a green W in Table 1). The responses generated in such a case will be called No₁⁺ responses. The majority (77%) of the letters presented on the No₁ slides were never ensemble

Figure 10. Reaction time as a function of blocks (B) and memory load within ensembles (M)—Yes and No₁ responses combined.

members (e.g., the letter Z). The No_1 responses generated in this case will be called No_1^- responses. It was felt that the processing of No_1^- letters might be somewhat faster than that for letters which had been members of other ensembles (i.e., those letters producing a No_1^+ response). Since the reaction time for No_1 responses is a weighted function of both No_1^+ and No_1^- reaction times, faster processing of No_1^- letters would reduce the mean reaction time for the No_1 data in general.

Median reaction times for the No_1^+ and No_1^- for each S under each condition were computed. However, an analysis of covariance using the No_1^+ response data was not performed because the No_1^+ medians were based upon an extremely small number of reaction times and were therefore considered to be quite unreliable. For example, in Group M_2 only six out of the total 26 letters in the alphabet were No_1^+ letters; and of 72 stimulus presentations under each of the E_1 , E_2 , and E_3 conditions, on the average, only three stimuli were No_1^+ letters. Nevertheless, means of the median reaction times summed across all S s and conditions were computed for the No_1^+ and the No_1^- responses, and the data indicated that No_1^+ letters produced significantly longer reaction times than No_1^- letters ($t = 15.2$, $p < .001$). The mean reaction time for No_1^+ responses was 620 msec. while that for the No_1^- responses was 501 msec.

The median reaction times for No_1^- letters were based upon a larger number of responses than were the No_1^+ data, and were considered to be somewhat more reliable than the No_1^+ reaction times. Therefore, an analysis of covariance was performed on the E_1 , E_2 , and E_3 data using the Yes and No_1^- responses. Individual S 's mean scores on the Colors-Only condition constituted the covariate. The analysis is contained

in Table 11 of Appendix A. As in the analysis utilizing the Yes and No₁ data, an Ensembles X Response interaction again was significant ($F = 16.39$, $p < .001$). The processing rates for Yes and No₁ responses at each of the three ensemble conditions are illustrated in Figure 11. These data suggest that the processing rates for No₁ responses remained constant at about 24 msec. per item for each level of E. However, when S had two or three ensembles in his memory set, the processing rate for Yes responses was reduced by approximately 10 msec. per item. A comparison of the No₁ response data in Figures 9 and 11 illustrates the change in mean reaction time which took place when the No₁ reaction times were analyzed separately. The failure of the processing rates for No₁ stimuli to increase along with the rates for stimuli which were members of the designated ensembles (Yes responses) in the E₂ and E₃ conditions accounts for the reduction in No₁ reaction time relative to Yes reaction time in the E₂ and E₃ conditions, illustrated in Figure 9. However, the present author is unaware of any factors which might explain why the apparent differences between No₁ and Yes response processing rates appeared in the E₂ and E₃ conditions, but did not appear when S had only one ensemble in memory.

The apparent higher rate of processing for No₁ letters suggests that S may have occasionally been able to classify the No₁ stimuli without selecting and searching memory ensembles because he recognized that the displayed letter was not contained in any of the letter sets. It appears, then, that the No₁ data may not veridically reflect ensemble selection and scanning behavior. If so, the best index of ensemble selection and scanning performance is the Yes response data.

Figure 11. Reaction time as a function of Yes and No responses and the memory load within ensembles for the one (E_1), two (E_2), and three (E_3) ensembles in memory conditions.

Analysis of Variance of the Colors-Only Control Condition

This control condition was discussed earlier in order to illustrate that Group M_3 performed more slowly than Groups M_2 and M_4 . The present discussion is, in effect, a continuation of the previous Colors-Only analysis and deals with the number of colors which S had in his memory set in the Colors-Only condition.

The letter ensembles used in this study were defined such that S could select the appropriate memory ensemble from his memory set based upon the background color of the test slide presented to him. A Colors-Only control condition was used in the study because it was anticipated that S's ensemble selection rate would be similar to the rate of processing of colors in the Colors-Only condition. An analysis of variance performed on the Colors-Only data (Table 9 of Appendix A) revealed a significant effect of the number of colors which S had in his memory set ($F = 58.61$, $p < .001$). The reaction times from this analysis are displayed in Figure 12. Of particular interest is the rather slow processing rate suggested by these data (a least-squares fit results in a processing rate of 47 msec. per color). The processing rate was slower than the slowest case found for letters in the present experiment (see Figure 9). Earlier studies (Woodworth, 1938) have shown that the disjunctive reaction times to colors are considerably faster than reaction times for Arabic numerals, suggesting that the processing of color information should be conducted at higher rates than the processing of letters and digits. These data suggest that the processing of color information was conducted at a rate no faster than the processing of letters.

Figure 12. Reaction time as a function of the number of colors in memory (M) and responses (R)—Colors-Only control condition.

The design of the present experiment dictated that S serve under each experimental condition three times during the last five sessions. Therefore, S experienced each of the conditions E_1 , E_2 , and E_3 three times during the course of the study. Although each S also experienced the Colors-Only condition three times during the experiment, this condition consisted of three different levels, C_1 , C_2 , and C_3 . Therefore, S worked under each level of the Colors-Only condition only once during the last five sessions. This arrangement may be seen by inspecting Table 2. The reduced practice with the levels of the Colors-Only processing rate displayed in Figure 12.

Analysis of Variance of the Special Colors-Only Control Condition

Because of the possibility that the processing rate for colors might be too low, a Special Colors-Only data collection session was conducted at the conclusion of the main study. The procedure was identical to that used in the Colors-Only condition of the main experiment and each of 12 Ss produced 18 reaction times under each level of the condition. The Ss had also served in the main experiment and the special session was conducted immediately after the Ss had concluded their final experimental sessions.

Median reaction times were computed for positive and negative responses under each level of the number of colors in memory and these data were subjected to an analysis of variance. The summary table of the analysis is contained in Table 12 of Appendix A. The data are displayed in Figure 13. The fitted constants for the data are also presented in Figure 13, and one can see that the processing rate for colors in the Special Colors-Only condition was considerably faster than the

Figure 13. Reaction time as a function of the number of colors in memory (M) and responses (R)—Special Colors-Only control condition.

.045 sec. per color found in the earlier Colors-Only condition. It is also apparent in Figure 13 that the slope constants for Yes and No responses are nearly identical. These data suggest that S conducts a serial, exhaustive search through a memory set of colors in a similar manner to that used for the central processing of digits (Sternberg, 1966) and letters (Wingfield and Branca, 1970).

Analysis of Covariance of the Letters-Only Control Condition

In order to obtain an estimate of the processing rate for letters, a control condition was designed such that S could effectively ignore the color information presented on the test slide. The Letters-Only condition provided an estimate of the letter processing rate at a time when S was not required to select a memory ensemble based upon color information. An analysis of covariance was performed on the Yes and No data for the Letters-Only condition utilizing individual S's reaction times in the Colors-Only test as the covariate.

The summary table for the analysis of covariance for the Letters-Only condition is contained in Table 13 of Appendix A. The data are presented graphically in Figure 14, together with the equations for the best-fitting straight lines. The number of letters which S had in memory was again a significant variable ($F = 9.09$, $p < .01$).

It was pointed out earlier that Briggs (1969) proposed an ensemble selection process prior to and independent of the scanning of a selected ensemble. The scanning of letters within the selected ensemble is required regardless of the uncertainty concerning the memory ensemble to be selected. It follows, then, that the processing rate for the Letters-Only condition (during which there was no uncertainty concerning the

Figure 14. Reaction time as a function of memory load (M) and responses (R)—Letters-Only control condition.

ensemble to be selected) should be similar to the search rate for letters in the E_1 , E_2 , and E_3 conditions (during which there was uncertainty concerning the ensemble to be selected for further processing). Therefore, a Tukey-B comparison of the Yes response slope constants for the Reaction Time X Memory Load within Ensembles functions in the Letters-Only and the E_1 , E_2 , and E_3 conditions was performed. These slope constants are illustrated in Figures 9 and 13. The results indicated that the letter processing rates for the E_1 , E_2 , and E_3 conditions did not differ significantly from the rate found in the Letters-Only (L_0) condition.

$$E_1 = L_0 \quad (q = .59, p > .25)$$

$$E_2 = L_0 \quad (q = 1.37, p > .25)$$

$$E_3 = L_0 \quad (q = .67, p > .25)$$

The similarity of the processing rates under all levels of ensemble selection uncertainty suggests that the search of the letters within a selected ensemble is the same regardless of the uncertainty concerning the ensemble to be selected.

Analysis of Covariance of the Yes, No₁, and No₂ Data for the Experimental Task

In order to inspect performance when $\underline{S}$ could generate a negative response without selecting an ensemble for processing, an analysis of covariance was also performed on the experimental task data for Yes, No₁, and No₂ responses. The summary table of the analysis is contained in Table 14 of Appendix A. Again, as in the analysis of the Yes and No₁ responses, there were significant effects of the number of ensembles from which $\underline{S}$ must select ($F = 101.76, p < .001$) and the memory load

within ensembles ($\underline{F} = 10.05$, $p < .001$). The analysis also revealed a significant interaction between memory load within ensembles and response type ($\underline{F} = 3.29$, $p < .05$). The data making up this interaction are displayed in Figure 15. Tests of the slope differences revealed that the slope constant for No₂ responses was significantly lower than the constants fitting the No₁ and Yes response data:

$$\text{No}_2 < \text{No}_1 \quad (\underline{t} = 2.54, p < .01)$$

$$\text{No}_2 < \text{Yes} \quad (\underline{t} = 3.06, p < .005)$$

In addition, a Tukey-B comparison of the mean reaction times for each of the three responses indicated that the reaction times for No₂ responses were significantly lower than both the No₁ and Yes latencies:

$$\text{No}_2 < \text{No}_1 \quad (\underline{q} = 21.19, p < .01)$$

$$\text{No}_2 < \text{Yes} \quad (\underline{q} = 11.78, p < .01)$$

$$\text{Yes} < \text{No}_1 \quad (\underline{q} = 9.43, p < .01)$$

An analysis of the simple effects showed that, while the memory load within ensembles had a significant influence upon reaction time for Yes and No₁ responses ($\underline{F} = 3.67$, $p < .05$; $\underline{F} = 3.17$, $p < .05$, respectively), there was no effect of within-ensemble memory load for No₂ responses ($\underline{F} = .97$). Nevertheless, a best-fitting line for the No₂ responses produced a slope constant of 17 msec. and a regression analysis revealed that this slope was significantly greater than zero ($\underline{F} = 16.83$, $p < .001$). The data indicate, therefore, that S may generate a negative response with a shorter reaction time when the background color of the stimulus does not characterize an ensemble in S's memory set.

A test of intercept differences (McNemar, 1962) for the Memory Load within Ensembles X Response functions revealed that the intercepts

Figure 15. Reaction time as a function of memory load within ensembles (M) and responses (R)—one (E_1), two (E_2) and three (E_3) ensembles in memory conditions combined.

of the Yes and No₁ functions were different from each other ($t = 1.91$, $p < .05$), while the intercepts for No₁ and No₂ did not differ significantly ($t = 1.13$, $p > .10$). Sternberg (1967) and Briggs (1969) have argued that the intercept of the reaction time function reflects Stage 1 encoding time plus Stage 3 decoding time. Since the No₁ and No₂ responses are identical in nature and should therefore require equal decoding time, the finding of no differences between the two intercepts reflects equal encoding times for the two conditions.

The analysis of covariance for the Yes, No₁ and No₂ responses also showed a significant interaction ($F = 13.28$, $p < .001$) between the number of ensembles in memory and response type. The data are displayed in Figure 16. Tukey-B tests of the effects of E for the three responses showed the following differences:

$$\text{No}_1: E_1 < E_2 = E_3 \quad (p < .01)$$

$$\text{Yes}: E_1 < E_2 = E_3 \quad (p < .01)$$

$$\text{No}_2: E_1 < E_2 = E_3 \quad (p < .05)$$

A test of the effects of responses for the three levels of ensembles in memory indicated that:

$$E_1: \text{No}_2 < \text{Yes} < \text{No}_1 \quad (p < .01)$$

$$E_2: \text{No}_2 < \text{Yes} < \text{No}_1 \quad (p < .01)$$

$$E_3: \text{No}_2 < \text{Yes} \quad (p < .01); \quad \text{Yes} < \text{No}_1 \quad (p < .05)$$

As in the analysis of the Yes and No₁ responses (Table 10 of Appendix A and Figure 9), these data suggest that the differences between Yes and No₁ responses were reduced when $\underline{S}$ had two and three ensembles in his memory set. The data also seem to imply that the effect of E was somewhat reduced for the No₂ responses.

Figure 16. Reaction time as a function of the number of ensembles in memory and responses.

Figure 17. Reaction time as a function of the number of ensembles in memory, responses, and blocks.

A three-way interaction between the number of ensembles in memory, blocks, and responses was also found during the analysis of Yes, No₁, and No₂ data ($F = 2.20$, $p < .05$). The interaction is shown in Figure 17. It should be recalled that the analysis of Yes and No₁ responses (Table 10 of Appendix A) revealed a two-way Ensembles X Blocks interaction, suggesting that practice had a greater effect when S had three ensembles in memory than when his memory set contained only one ensemble (see Figure 10). The present results show that the differences in practice effects were specific only to the Yes and No₁ responses, thereby resulting in a three-way interaction of ensembles, blocks, and responses.

DISCUSSION

The data provided by the Letters-Only condition of this study (Figure 14) clearly support Sternberg's (1966, 1967) contention that S conducts a serial scan through his memory set in order to classify a stimulus' status as to set membership. The linear increase in reaction time found when the number of letters in S's memory set was increased in the Letters-Only condition suggests that the Ss in this study were able to scan the memory set of letters at a rate of 32.2 letters per second (the reciprocal of .031 seconds per letter illustrated in Figure 14).

Sternberg's (1966) demonstration of ensemble scanning was extended considerably by the work of Briggs and Swanson (1969) and of Forrin and Morin (1967). These researchers all demonstrated that S may utilize a two-step process—first selecting the appropriate ensemble for search, and then searching the selected ensemble. The present study was designed to investigate S's ensemble-selection behavior in an information-processing task similar to that employed by Sternberg (1966).

Three questions are relevant to the present discussion:

1. Is ensemble selection time lengthened as S is required to choose from among an increasing number of letter-ensembles in his memory set?
2. Is the selection of a memory ensemble during Stage 1 preprocessing similar to the central processing of the attribute upon which selection is based?

3. Does the organization of memory information into subsets or ensembles reduce S's processing time when compared with the time necessary for him to make a serial scan of all the information in his total memory set?

First, consider ensemble selection performance. The analysis of Yes and No₁ responses (Figures 9 and 11, and Tables 7 and 8 of Appendix A) indicated that there may have been some inherent differences between the processing conducted for positive and negative responses in the present study. The S appeared to be able to process No₁ stimuli at a faster rate than he could process stimuli which produced a Yes response. It was proposed that this faster processing rate for No₁ responses might indicate an ability of S to generate negative responses without performing ensemble selection and search when the S recognizes a displayed stimulus as being one which does not belong to any of the ensembles that he has learned. The ability to produce a negative response with a faster reaction time for some types of stimuli, but not others, has not, to the present author's knowledge, been reported in the experimental literature. Since the individual No₁ letters were always presented to S less frequently than were the Yes and No₁⁺ letters (letters producing Yes responses were presented on 50% of the trials), it is possible that frequency of occurrence of the individual letter stimuli might have been a cue which allowed S to respond "no" without selecting a memory ensemble and scanning the selected ensemble. This notion gains support from Briggs and Swanson (1969) and Oldfield (1965), who have proposed that the S may use the frequency of occurrence of individual stimuli as an aid in information processing. Since S might be able to avoid ensemble selection, it follows that the combined No₁

responses do not provide a reliable index of S's ensemble selection and scanning performance.

In each previous experiment concerned with ensemble selection behavior, the experimenter utilized a naming task in which S was required to identify the stimuli presented to him (Briggs and Swanson, 1969; Forrin and Morin, 1967; Oldfield and Wingfield, 1965). In the identification experiments a stimulus presented was always a member of one of S's memory ensembles. It may be argued, therefore, that the naming response reliably reflected S's memory search strategy because the test stimulus always matched an item contained in memory and the response was generated following a search of S's store of memory information. The identical argument may be applied to the Yes responses of the present study. Therefore it is clear that the best index of ensemble selection is the Yes response data.

As a first step, it is necessary to inspect the central processing rates found under each ensemble level. The processing rates for Yes responses were presented in Figure 9 and are listed again in Table 3 in the format

$$RT = A + B(M). \quad (\text{Eq. 1})$$

The slope constant B reflects the rate at which S may search memorial information during central processing. The intercept constant A indicates Stage 1 encoding and ensemble selection, plus Stage 3 processing. Since Stage 1 encoding and Stage 3 decoding are the same for each of the three ensemble conditions, it follows that differences in A must reflect changes in the time necessary for ensemble selection at Stage 1.

By inspecting Table 3 one may see that the intercept constant A

Table 3
Best-Fit Equations Relating RT to M
for Each Level of Ensembles-in-Memory
(Yes Responses)

E	RT = A + B(M)
1	RT = .355 + .028(M)
2	RT = .384 + .041(M)
3	RT = .404 + .036(M)

increases with the number of ensembles which S had in memory. Figure 18 displays the A constants as a function of the number of ensembles in memory. These constants were fitted by a straight line of the form

$$A = C + F(E). \quad (\text{Eq. 2})$$

The best-fit equation based upon the data in Table 3 is

$$C = .332 + .025(E).$$

Note that the slope constant F of the function in Figure 18 is in units of seconds per ensembles in memory. This indicates, therefore, that, for Yes responses, 25 msec. additional processing time was required for each additional ensemble which S had in memory.

We may now substitute Eq. 2 into Eq. 1 and obtain Eq. 3.

$$RT = C + F(E) + B(M) \quad (\text{Eq. 3})$$

With constants fitted, Eq. 3 is of the form

$$RT = .332 + .025(E) + .035 (M).$$

The B constant of 35 msec. is the average of the three slopes in Table 3.

The above equation indicates that S spent 332 msec. encoding and selecting the appropriate response (Stage 1 encoding and Stage 3 decoding). The S then selected the appropriate memory ensemble for further processing at a rate of 40 ensembles per second. (The selection rate is determined by computing the reciprocal of 25 msec. per ensemble.) This linear increase in ensemble selection time with the number of ensembles in memory suggests that S performed a serial search of a memory set of ensemble-defining colors in order to select the appropriate ensemble for further processing. After ensemble selection, S scanned the chosen ensemble at a rate of 28.5 letters per second (the reciprocal

Figure 18. The intercept constant A of the relationship $RT = A + B(M)$ as a function of the number of ensembles in memory.

of 35 msec. per letter).

The Letters-Only condition was included in the present study to obtain an estimate of information processing performance when there was no uncertainty about the ensemble to be scanned during central processing. The data for Yes responses in the Letters-Only condition were fitted in the form of Eq. 1 and the best-fit constants produced the equation

$$RT = .344 + .031 (M).$$

This is the same equation displayed in Figure 14 and indicates that Stage 1 encoding and Stage 3 decoding required 344 msec. while Stage 2 central processing could be performed at a rate of 32.2 letters per second. The estimate of 344 msec. for Stage 1 and Stage 3 decoding is quite close to the 332 msec. obtained from Eq. 3. In addition, the Stage 2 processing rates are reasonably close when estimated from either the Letters-Only or the experimental task data.

The Colors-Only data were obtained in an effort to compare the process of ensemble selection based upon colors with the central processing of color information. The Yes data from the Special Colors-Only condition, displayed in Figure 13, were fitted in the form of Eq. 1 and the best-fit constants produced the line

$$RT = .343 + .025(M).$$

As in the previous two equations, the intercept constant indicates that 343 msec. were required for Stage 1 encoding and Stage 3 decoding. This estimate is nearly identical to the estimate provided by the Letters-Only data and is quite close to that found when ensemble selection rate was calculated in Eq. 2 using the data from the experimental task. The

40 colors per second processing rate (the reciprocal of 25 msec. per color in memory) found in the Colors-Only data is identical to the rate of ensemble selection based upon color in Eq. 2.

It can be argued that the processing rate for the Special Colors-Only data is not comparable to the rate of ensemble selection found in the experimental sessions because the Ss served under the Special Colors-Only condition after they had completed all of the experimental sessions. The extra practice could serve to decrease the Ss' reaction times under all conditions of the experiment, including the Colors-Only task. However, the extremely close agreement between the intercept constants A calculated from the experimental task, the Letters-Only condition, and the Special Colors-Only condition argue that the performance displayed under the Special Colors-Only condition is comparable to performance in the other conditions of the experiment. The important point supported by the Special Colors-Only condition is that S did perform a serial search through a memory set of colors, and that he was capable of performing the search at a rate similar to the rate of ensemble selection found in the experimental task.

To this point we have determined that ensemble selection based upon the colors is similar to the processing of color information in a color recognition task. The similarity of the two functions hints strongly that S selected the appropriate ensemble by performing a serial scan of his memory set of colors in order to choose the appropriate ensemble for subsequent search. It remains to determine whether or not S's scan of his memory set of colors during ensemble selection was also an exhaustive search similar to the scanning of a memory set

of digits (Sternberg, 1966) and letters (Wingfield and Branca, 1970).

It was stated earlier that the evidence supporting an exhaustive search could be found by inspecting the relationship between positive and negative responses. It will be recalled that during the ensemble selection process Yes responses always indicated that at some time during the information processing a match had been obtained between the background color of the test stimulus and S's memory set of colors defining the ensembles in use at the time. No₂ responses, however, were generated when the color of the test stimulus did not match one of the colors in the memory set. Since the changes in intercept constants A in Eq. 2 reflect ensemble selection rate, the comparison of ensemble selection rates for Yes and No₂ responses is provided by considering A separately for each response type. Changes in the intercept constants A in Eq. 2 for No₂ responses at the three ensembles-in-memory levels will expose the ensemble selection rate for nonmatch cases. The equations for No₂ responses at each ensemble level (E) are presented in Table 4.

The constants for No₂ responses of the form

$$A = C + F(E) \quad (\text{Eq. 2})$$

produce the line

$$A = .356 + .021(E).$$

A comparison of the intercept constants A for Yes and No₂ responses at the three levels of ensembles is displayed in Figure 19.

The slope constant reflecting ensemble selection rate when no match was found was quite similar to the rate of selection when a match was obtained (47.5 ensembles per second vs. 40 ensembles per second).

Table 4

Best-Fit Equations Relating RT to M
for Each Level of Ensembles-in-Memory
(No₂ Responses)

E	RT = A + B(M)
1	RT = .370 + .017(M)
2	RT = .412 + .016(M)
3	RT = .412 + .019(M)

Figure 19. The intercept constant A of the relationship $RT = A + B(M)$ as a function of the number of ensembles in memory for Yes and No₂ responses.

Since a self-terminating search would produce a No_2 rate of about 20 ensembles per second (half of 40 ensembles per second), the data suggest that S performed an exhaustive, serial search of his memory set of colors in order to choose the appropriate ensemble for subsequent scanning.

In retrospect, two of the three questions posed earlier in this discussion have been answered as follows:

Ensemble selection time increases in a linear fashion when S is required to choose from among an increasing number of letter-ensembles in his memory set.

In addition, the selection of memory ensembles during preprocessing appears to be serial and exhaustive, and is therefore similar to the central processing of the attribute upon which ensemble selection is based.

It is of interest to investigate the savings in processing time gained by S when his memory set may be organized into smaller ensembles. A serial comparison of each letter contained in the combined memory set of ensembles would require the scanning of considerably more letters than would be compared with the test stimulus if only a single ensemble were scanned. To illustrate: When S had two ensembles of three letters each in his memory set (the E_2 condition for Group M_3), the ability to select the appropriate ensemble for processing means that he must scan only three letters. However, if S scanned all of the letters in the combined memory set instead of first selecting an ensemble, he would need to scan six letters (three letters X two ensembles). When three ensembles containing four letters each are used (the E_3 condition

Figure 20. Reaction times predicted from a serial, exhaustive search of the combined memory set of letters (solid lines) compared with the reaction times observed under the E₁, E₂, and E₃ conditions (dashed lines).

for Group M₄), a serial search of the combined memory set would require the scanning of 12 letters (four letters X three ensembles). Wingfield and Branca (1970) demonstrated that S can indeed perform a serial, exhaustive scan of up to 12 letters when his memory set is not organized into smaller ensembles.

Using the slope constant of 35 msec. per letter computed from the data in Table 3 and the intercept constant A of 332 msec. derived from the same table, predicted reaction times for Yes responses resulting from a serial, exhaustive search of the combined memory set of letters were computed for all nine experimental conditions. The equation $RT = .332 + .035(M)$ was used. The predicted reaction times were then plotted as a function of memory load within ensembles. These predicted reaction times are displayed as solid lines in Figure 20. As Figure 20 illustrates, the predicted reaction time is 752 msec. for a serial, exhaustive search of the letters in the combined memory set of 12 letters (the E₃ condition for Group M₄). The dashed lines in Figure 20 display the actual reaction times for Yes responses for the three groups in the experimental task. The actual mean reaction time was 543 msec. for the Group M₄ Ss under the E₃ condition. It is clear that the ability to organize the memory set into smaller ensembles and search only a smaller selected ensemble resulted in a savings of 209 msec. of processing time under the most extreme experimental condition.

SUMMARY

In summary, the present experiment provided the following data about the human information-processing system when S has memory information organized in ensembles which are defined by a common attribute:

1. The S may reduce his memory search load by performing a two-step scanning process:
 - A. Scanning the memory set of ensemble cues in order to select the appropriate memory ensemble for further use.
 - B. Scanning the items contained in the selected memory ensemble to determine if the stimulus is a member of the chosen set.
2. The two scanning steps are independent of each other.
3. The scan of ensemble-defining cues is serial, exhaustive, and was performed at a rate of 40 ensembles per second.
4. The scan of letters within the selected ensemble is serial and was performed at a rate of 28 letters per second.

The data have also demonstrated that the intercept constant A of the function relating reaction time to memory load within ensembles reflects not only stimulus encoding and response decoding times, but also an exhaustive, serial scan of a memory set of the attribute defining the memory ensembles which S is using in his processing task. Finally,

it has been shown that the organization of S's memory set into smaller ensembles provides considerable savings in processing time when S must work with relatively large amounts of memory information.

APPENDIX A
ANALYSIS OF VARIANCE TABLES

Table 5

Analysis of Variance for Letter Sorting Times

Source	df	MS	F	p
Between	29			
Groups (G)	2	1727.62	1.01	
Error	27	1707.05		
Within	240			
Sessions (S)	8	4610.94	38.97	.001
G x S	16	229.88	1.94	.05
Error	216	118.30		

Table 6

Analysis of Variance for Color Sorting Times

Source	df	MS	F	p
Between	29			
Groups (G)	2	70.18	<1.00	
Error	27	160.05		
Within	240			
Sessions (S)	8	888.49	83.66	.001
G x S	16	29.70	2.79	.01
Error	216	10.62		

Table 7
Analysis of Variance of Experimental Task (Yes and No₁)

Source	df	MS	F	p
Between	29			
Memory load within ensembles (M)	2	.2549	6.06	.05
Error (Ss/G)	27	.0420		
Within	510			
Ensembles (E)	2	.2179	90.75	.001
M x E	4	.0049	2.04	
E x Ss/G	54	.0024		
Blocks (B)	2	.0777	23.54	.001
M x B	4	.0017	<1.00	
B x Ss/G	54	.0033		
Responses (R)	1	.1055	47.95	.001
M x R	2	.0004	<1.00	
R x Ss/G	27	.0022		
E x R	2	.0100	12.50	.001
M x E x R	4	.0002	<1.00	
E x R x Ss/G	54	.0008		
B x R	2	.0009	1.00	
M x B x R	4	.0015	1.66	
B x R x Ss/G	54	.0009		
E x B	4	.0054	3.00	.05
M x E x B	8	.0016	<1.00	
E x B x Ss/G	108	.0018		
E x B x R	4	.0009	1.50	
M x E x B x R	8	.0005	<1.00	
E x B x R x Ss/G	108	.0006		

Table 8

Analysis of Variance for Letters-Only Control Condition

Source	df	MS	F	p
Between	29			
Memory load within ensembles (M)	2	.0576	4.43	.05
Error (Ss/G)	27	.0130		
Within	150			
Blocks (B)	2	.0182	10.11	.001
M x B	4	.0046	2.55	.05
B x Ss/G	54	.0018		
Response (R)	1	.0306	34.00	.001
M x R	2	.0007	<1.00	
R x Ss/G	27	.0009		
B x R	2	.0001	<1.00	
M x B x R	4	.0002	<1.00	
B x R x Ss/G	54	.0003		

Table 9

Analysis of Variance for Colors-Only Control Condition

Source	df	MS	F	p
Between	29			
Groups (G)	2	.0090	<1.00	
Error (Ss/G)	27	.0148		
Within	150			
Colors in memory (C)	2	.1231	58.61	.001
G x C	4	.0012	<1.00	
C x Ss/G	54	.0021		
Response (R)	1	.0235	19.58	.001
G x R	2	.0009	<1.00	
R x Ss/G	27	.0012		
C x R	2	.0018	6.00	.005
G x C x R	4	.0004	1.33	
C x R x Ss/G	54	.0003		

Table 10

Analysis of Covariance of Experimental Task (Yes and No₁)

Source	df	MS	F	p
Between	28			
Memory load within ensembles (M)	2	.2210	7.45	.005
Error (Ss/G)	26	.0297		
Within	510			
Ensembles (E)	2	.2179	90.75	.001
M x E	4	.0049	2.04	
E x Ss/G	54	.0024		
Blocks (B)	2	.0777	23.54	.001
M x B	4	.0017	<1.00	
B x Ss/G	54	.0033		
Responses (R)	1	.1055	47.95	.001
M x R	2	.0004	<1.00	
R x Ss/G	27	.0022		
E x R	2	.0100	12.50	.001
M x E x R	4	.0002	<1.00	
E x R x Ss/G	54	.0008		
B x R	2	.0009	1.00	
M x B x R	4	.0015	1.66	
B x R x Ss/G	54	.0009		
E x B	4	.0054	3.00	.05
M x E x B	8	.0016	<1.00	
E x B x Ss/G	108	.0018		
E x B x R	4	.0009	1.50	
M x E x B x R	8	.0005	<1.00	
E x B x R x Ss/G	108	.0006		

Table 11

Analysis of Covariance of Experimental Task (Yes and No₁)

Source	df	MS	F	p
Between	28			
Memory load within ensembles (M)	2	.1867	9.33	.001
Error (Ss/G)	26	.0207		
Within	510			
Ensembles (E)	2	.1974	94.10	.001
M x E	4	.0024	1.14	
E x Ss/G	54	.0021		
Blocks (B)	2	.0754	25.99	.001
M x B	4	.0021	<1.00	
B x Ss/G	54	.0029		
Responses (R)	1	.0364	13.48	.001
M x R	2	.0053	1.96	
R x Ss/G	27	.0027		
E x R	2	.0131	16.39	.001
M x E x R	4	.0005	<1.00	
E x R x Ss/G	54	.0008		
B x R	2	.0007	<1.00	
M x B x R	4	.0016	2.00	
B x R x Ss/G	54	.0008		
E x B	4	.0032	2.00	
M x E x B	8	.0013	<1.00	
E x B x Ss/G	108	.0016		
E x B x R	4	.0006	1.20	
M x E x B x R	8	.0008	1.60	
E x B x R x Ss/G	108	.0005		

Table 12

Analysis of Variance of Special Colors-Only
Control Condition

Source	df	MS	F	p
Colors in memory (C)	2	.0150	21.42	.001
Response (R)	1	.0087	4.84	.05
Subjects (S)	11	.0092		
C x S	22	.0007		
R x S	11	.0018		
C x R	2	.0009	3.00	
C x R x S	22	.0003		

Table 13

Analysis of Covariance for Letters-Only Control Condition

Source	df	MS	F	p
Between	28			
Memory load within ensembles (M)	2	.0473	9.09	.01
Error (Ss/G)	26	.0052		
Within	150			
Blocks (B)	2	.0182	10.11	.001
M x B	4	.0046	2.55	.05
B x Ss/G	54	.0018		
Response (R)	1	.0306	34.00	.001
M x R	2	.0007	< 1.00	
R x Ss/G	27	.0009		
B x R	2	.0001	< 1.00	
M x B x R	4	.0002	< 1.00	
B x R x Ss/G	54	.0003		

Table 14

Analysis of Covariance of Experimental Task
(Yes, No₁, and No₂ Responses)

Source	df	MS	F	p
Between	28			
Memory load within ensembles (M) ^a	2	.2250	10.05	.001
Error (Ss/G) ^a	26	.0224		
Within	780			
Ensembles (E)	2	.2646	101.76	.001
M x E	4	.0049	1.88	
E x Ss/G	54	.0026		
Blocks (B)	2	.1018	26.10	.001
M x B	4	.0033	< 1.00	
B x Ss/G	54	.0039		
Responses (R)	2	.2629	109.54	.001
M x R	4	.0079	3.29	.05
R x Ss/G	54	.0024		
E x R	4	.0093	13.28	.001
M x E x R	8	.0009	1.28	
E x R x Ss/G	108	.0007		
B x R	4	.0010	1.10	
M x B x R	8	.0011	1.37	
B x R x Ss/G	108	.0008		
E x B	4	.0041	1.86	
M x E x B	8	.0022	1.00	
E x B x Ss/G	108	.0022		
E x B x R	8	.0011	2.20	.05
M x E x B x R	16	.0003	< 1.00	
E x B x R x Ss/G	216	.0005		

APPENDIX B

TABLES OF MEDIAN REACTION TIMES FOR ALL SUBJECTS
UNDER ALL EXPERIMENTAL AND CONTROL CONDITIONS

Table 15

Median Reaction Times (in Sec.) for All Ss under
Three Blocks of E₁, E₂, and E₃ Conditions

M	<u>S</u>	E	B	Yes	No ₁	No ₂
2	1	1	1	.5186	.5266	.5340
2	1	1	2	.4837	.4632	.4417
2	1	1	3	.4134	.4233	.3966
2	2	1	1	.4025	.5481	.4682
2	2	1	2	.4314	.5028	.4737
2	2	1	3	.3841	.4692	.4273
2	3	1	1	.4984	.5145	.4412
2	3	1	2	.4903	.4576	.3904
2	3	1	3	.4506	.4729	.4083
2	4	1	1	.4195	.4635	.4395
2	4	1	2	.4155	.4834	.3883
2	4	1	3	.3725	.4278	.3963
2	5	1	1	.4356	.4798	.4380
2	5	1	2	.4346	.4131	.3974
2	5	1	3	.3304	.4170	.3885
2	6	1	1	.3582	.3883	.3615
2	6	1	2	.3478	.4146	.3360
2	6	1	3	.3340	.4221	.3669
2	7	1	1	.3563	.3881	.3529
2	7	1	2	.3504	.3815	.3702
2	7	1	3	.3540	.4385	.3657
2	8	1	1	.3514	.4186	.3587
2	8	1	2	.3387	.4059	.3640
2	8	1	3	.3619	.4236	.3427
2	9	1	1	.4076	.5086	.4454
2	9	1	2	.3613	.4020	.3810
2	9	1	3	.3367	.3980	.3737
2	10	1	1	.5100	.4828	.4200
2	10	1	2	.4111	.4535	.3911
2	10	1	3	.3821	.4735	.3612
3	1	1	1	.5144	.5466	.5148
3	1	1	2	.5698	.6261	.5618
3	1	1	3	.4646	.5382	.4737
3	2	1	1	.5504	.5171	.4713
3	2	1	2	.5041	.5596	.5186
3	2	1	3	.4551	.4994	.4033

Table 15 (Cont'd)

M	<u>S</u>	E	B	Yes	No ₁	No ₂
3	3	1	1	.4178	.4465	.3758
3	3	1	2	.3510	.4367	.3584
3	3	1	3	.3766	.3930	.3374
3	4	1	1	.5376	.5635	.5662
3	4	1	2	.4621	.5179	.4480
3	4	1	3	.5027	.5000	.3731
3	5	1	1	.4900	.4912	.3795
3	5	1	2	.4940	.5116	.4579
3	5	1	3	.4857	.5014	.3993
3	6	1	1	.3993	.4652	.3982
3	6	1	2	.3640	.4093	.3699
3	6	1	3	.3515	.4610	.3787
3	7	1	1	.3929	.4596	.3449
3	7	1	2	.3922	.4484	.3739
3	7	1	3	.4004	.4317	.3593
3	8	1	1	.5413	.5725	.5156
3	8	1	2	.4354	.5121	.4362
3	8	1	3	.4566	.4791	.4370
3	9	1	1	.4716	.5555	.4265
3	9	1	2	.4311	.4833	.4494
3	9	1	3	.4761	.5028	.4420
3	10	1	1	.4140	.4385	.4398
3	10	1	2	.4224	.4841	.4538
3	10	1	3	.4741	.5503	.4896
4	1	1	1	.4647	.5095	.4577
4	1	1	2	.4358	.4957	.4394
4	1	1	3	.4325	.4700	.4225
4	2	1	1	.4201	.4417	.4313
4	2	1	2	.4105	.4563	.4131
4	2	1	3	.4588	.5057	.4229
4	3	1	1	.4636	.5306	.4025
4	3	1	2	.4613	.4866	.4031
4	3	1	3	.4200	.4543	.3619
4	4	1	1	.5303	.6081	.4879
4	4	1	2	.5509	.5795	.5135
4	4	1	3	.5137	.5317	.4654
4	5	1	1	.4196	.4794	.4714
4	5	1	2	.4676	.5267	.4520
4	5	1	3	.4805	.5289	.4757
4	6	1	1	.5763	.5788	.5485
4	6	1	2	.5586	.5712	.5056
4	6	1	3	.5308	.4760	.4689

Table 15 (Cont'd)

M	<u>S</u>	E	B	Yes	No ₁	No ₂
4	7	1	1	.3888	.3831	.3626
4	7	1	2	.4148	.4315	.3944
4	7	1	3	.4271	.4592	.3837
4	8	1	1	.4088	.4221	.3357
4	8	1	2	.4018	.4681	.3551
4	8	1	3	.3784	.4248	.3529
4	9	1	1	.5408	.5761	.5148
4	9	1	2	.4165	.4538	.4458
4	9	1	3	.4461	.4900	.4306
4	10	1	1	.4029	.4570	.4107
4	10	1	2	.4377	.5682	.4771
4	10	1	3	.4543	.5451	.4671
2	1	2	1	.6014	.6066	.5536
2	1	2	2	.4846	.4817	.4726
2	1	2	3	.4734	.4882	.4656
2	2	2	1	.4981	.5317	.5036
2	2	2	2	.4809	.6213	.4807
2	2	2	3	.5280	.5148	.4955
2	3	2	1	.5105	.4903	.4294
2	3	2	2	.5012	.4664	.4054
2	3	2	3	.4717	.4330	.4137
2	4	2	1	.4675	.5257	.4254
2	4	2	2	.4726	.5100	.4099
2	4	2	3	.4403	.4763	.4095
2	5	2	1	.4996	.5334	.4863
2	5	2	2	.4575	.4664	.4426
2	5	2	3	.3966	.4481	.4068
2	6	2	1	.3882	.4274	.4504
2	6	2	2	.3844	.4274	.3933
2	6	2	3	.3946	.4336	.4013
2	7	2	1	.4645	.5071	.4078
2	7	2	2	.4243	.4441	.3708
2	7	2	3	.3331	.3798	.3315
2	8	2	1	.4177	.4383	.3822
2	8	2	2	.3946	.4299	.3811
2	8	2	3	.3905	.4311	.3896
2	9	2	1	.4737	.4955	.4607
2	9	2	2	.4642	.4624	.4214
2	9	2	3	.3895	.4577	.4483
2	10	2	1	.5271	.5320	.4622
2	10	2	2	.4502	.4707	.4492
2	10	2	3	.4252	.5098	.4118

Table 15 (Cont'd)

M	<u>S</u>	E	B	Yes	No ₁	No ₂
3	1	2	1	.5960	.6485	.5605
3	1	2	2	.6435	.7557	.5897
3	1	2	3	.4969	.5736	.5177
3	2	2	1	.6455	.7282	.5863
3	2	2	2	.6833	.6687	.5617
3	2	2	3	.5937	.5808	.5232
3	3	2	1	.4937	.5098	.4373
3	3	2	2	.4432	.4484	.3914
3	3	2	3	.4466	.4564	.4456
3	4	2	1	.5527	.6334	.5096
3	4	2	2	.5430	.5649	.5174
3	4	2	3	.5546	.5433	.4803
3	5	2	1	.6346	.6192	.4842
3	5	2	2	.6413	.6166	.5148
3	5	2	3	.5116	.6164	.4758
3	6	2	1	.4236	.4700	.3845
3	6	2	2	.4384	.5216	.4457
3	6	2	3	.3997	.4473	.4087
3	7	2	1	.4830	.5247	.4307
3	7	2	2	.4672	.4446	.3898
3	7	2	3	.4168	.4189	.3875
3	8	2	1	.5193	.5389	.4739
3	8	2	2	.4862	.5560	.4918
3	8	2	3	.5103	.5033	.4921
3	9	2	1	.6204	.5699	.5438
3	9	2	2	.5523	.5258	.5077
3	9	2	3	.5576	.5216	.4685
3	10	2	1	.4655	.5393	.4552
3	10	2	2	.5625	.7356	.6062
3	10	2	3	.5776	.6252	.4703
4	1	2	1	.5661	.4867	.4205
4	1	2	2	.5729	.5534	.4681
4	1	2	3	.5772	.5267	.4301
4	2	2	1	.5370	.6743	.5071
4	2	2	2	.4998	.6178	.4881
4	2	2	3	.4780	.4627	.4100
4	3	2	1	.4610	.5181	.4105
4	3	2	2	.5327	.5196	.4418
4	3	2	3	.4960	.4695	.4094
4	4	2	1	.6454	.6681	.5072
4	4	2	2	.7583	.7203	.5945
4	4	2	3	.5773	.6056	.4849

Table 15 (Cont'd)

M	<u>S</u>	E	B	Yes	No ₁	No ₂
4	5	2	1	.5746	.5911	.5450
4	5	2	2	.6146	.6148	.4826
4	5	2	3	.5276	.5911	.5199
4	6	2	1	.5684	.6702	.5392
4	6	2	2	.5569	.5669	.4971
4	6	2	3	.5269	.5295	.4964
4	7	2	1	.5444	.5556	.4979
4	7	2	2	.4942	.4732	.4289
4	7	2	3	.4433	.4103	.3865
4	8	2	1	.4783	.5055	.3928
4	8	2	2	.4463	.4627	.3689
4	8	2	3	.4653	.4943	.3782
4	9	2	1	.5299	.5815	.4953
4	9	2	2	.5108	.6838	.4690
4	9	2	3	.4697	.4878	.4361
4	10	2	1	.5544	.6390	.5064
4	10	2	2	.5746	.4893	.4477
4	10	2	3	.5016	.5220	.4608
2	1	3	1	.5994	.6507	.5560
2	1	3	2	.5134	.4699	.4474
2	1	3	3	.4867	.4418	.4237
2	2	3	1	.4902	.5472	.5050
2	2	3	2	.4819	.5239	.4954
2	2	3	3	.5167	.5312	.5128
2	3	3	1	.5386	.5050	.4627
2	3	3	2	.5231	.5322	.4368
2	3	3	3	.4864	.4715	.4264
2	4	3	1	.4924	.5052	.4386
2	4	3	2	.4674	.4975	.4125
2	4	3	3	.4178	.4631	.3947
2	5	3	1	.4907	.4882	.4608
2	5	3	2	.4622	.4805	.4600
2	5	3	3	.3687	.4268	.3918
2	6	3	1	.4544	.4625	.4394
2	6	3	2	.4333	.4257	.4151
2	6	3	3	.4120	.4307	.4091
2	7	3	1	.3916	.4322	.3772
2	7	3	2	.4351	.4283	.4269
2	7	3	3	.3890	.4145	.3993
2	8	3	1	.4068	.4181	.3793
2	8	3	2	.4374	.4466	.4002
2	8	3	3	.4007	.4273	.3966

Table 15 (Cont'd)

M	S	E	B	Yes	No1	No2
2	9	3	1	.5089	.5733	.4856
2	9	3	2	.4368	.4995	.4373
2	9	3	3	.4493	.4579	.4205
2	10	3	1	.5559	.5252	.4914
2	10	3	2	.4710	.5256	.4743
2	10	3	3	.4762	.4979	.4498
3	1	3	1	.5760	.6186	.5346
3	1	3	2	.5629	.5968	.5394
3	1	3	3	.5850	.5830	.5522
3	2	3	1	.6876	.7127	.5549
3	2	3	2	.6357	.6038	.5871
3	2	3	3	.6099	.5017	.4914
3	3	3	1	.5428	.5064	.4578
3	3	3	2	.5150	.4847	.4570
3	3	3	3	.4199	.4342	.4085
3	4	3	1	.5742	.5839	.5215
3	4	3	2	.5274	.5347	.4986
3	4	3	3	.5953	.5748	.5249
3	5	3	1	.6127	.5794	.5063
3	5	3	2	.6127	.6135	.5005
3	5	3	3	.5490	.6015	.4479
3	6	3	1	.4608	.4937	.4360
3	6	3	2	.4182	.4724	.4134
3	6	3	3	.4121	.4372	.3728
3	7	3	1	.4528	.5234	.4369
3	7	3	2	.4366	.4526	.4057
3	7	3	3	.4571	.4632	.4173
3	8	3	1	.4714	.5505	.5352
3	8	3	2	.4711	.5131	.4785
3	8	3	3	.5573	.6005	.5523
3	9	3	1	.5155	.5218	.4824
3	9	3	2	.5527	.5453	.5254
3	9	3	3	.5011	.4704	.4734
3	10	3	1	.4931	.5381	.4876
3	10	3	2	.5571	.5767	.5892
3	10	3	3	.4871	.4779	.4488
4	1	3	1	.6769	.5936	.5807
4	1	3	2	.5644	.5935	.4136
4	1	3	3	.5898	.5059	.4741
4	2	3	1	.5120	.5624	.4477
4	2	3	2	.4819	.4752	.4716
4	2	3	3	.5286	.5329	.4553

Table 15 (Cont'd)

M	<u>S</u>	E	B	Yes	No ₁	No ₂
4	3	3	1	.5904	.6543	.5700
4	3	3	2	.5408	.5727	.4614
4	3	3	3	.5503	.5521	.4421
4	4	3	1	.6454	.7021	.5381
4	4	3	2	.6189	.5811	.5457
4	4	3	3	.6527	.5973	.4971
4	5	3	1	.5038	.4984	.5382
4	5	3	2	.5360	.5680	.4985
4	5	3	3	.4882	.5678	.4717
4	6	3	1	.5965	.7164	.5746
4	6	3	2	.5779	.6199	.5129
4	6	3	3	.5040	.5259	.5613
4	7	3	1	.5349	.5465	.4221
4	7	3	2	.5043	.4675	.4421
4	7	3	3	.4439	.4490	.3934
4	8	3	1	.4551	.4783	.3851
4	8	3	2	.4859	.5010	.4257
4	8	3	3	.4575	.4431	.3885
4	9	3	1	.5131	.6169	.4892
4	9	3	2	.5146	.4879	.4805
4	9	3	3	.4866	.5024	.4572
4	10	3	1	.5370	.5414	.5061
4	10	3	2	.5340	.5060	.4456
4	10	3	3	.5342	.6177	.4996

Table 16

Median Reaction Times (in Sec.) for All Ss under
Three Blocks of the Letters-Only Condition

M	<u>S</u>	B	Yes	No
2	1	1	.4628	.4960
2	1	2	.4683	.4615
2	1	3	.3674	.3900
2	2	1	.4285	.5441
2	2	2	.4001	.4972
2	2	3	.3708	.4005
2	3	1	.5233	.5040
2	3	2	.4644	.4626
2	3	3	.4354	.4420
2	4	1	.4384	.4889
2	4	2	.4032	.4328
2	4	3	.3570	.4124
2	5	1	.4633	.4587
2	5	2	.4300	.4616
2	5	3	.3847	.3929
2	6	1	.3633	.4092
2	6	2	.3424	.3927
2	6	3	.3250	.3690
2	7	1	.3310	.3918
2	7	2	.3680	.4048
2	7	3	.3629	.3872
2	8	1	.3388	.3949
2	8	2	.3521	.3791
2	8	3	.3334	.3767
2	9	1	.4090	.4721
2	9	2	.3471	.3865
2	9	3	.3602	.4309
2	10	1	.5155	.4842
2	10	2	.4742	.4500
2	10	3	.3850	.4145
3	1	1	.4867	.5856
3	1	2	.4386	.5316
3	1	3	.5067	.5271
3	2	1	.5713	.5393
3	2	2	.5259	.5088
3	2	3	.4344	.5030

Table 16 (Cont'd)

M	<u>S</u>	B	Yes	No
3	3	1	.3981	.4231
3	3	2	.3538	.3940
3	3	3	.4456	.4682
3	4	1	.5320	.5715
3	4	2	.5316	.5007
3	4	3	.4783	.4688
3	5	1	.4669	.4375
3	5	2	.5273	.5329
3	5	3	.4399	.4753
3	6	1	.3660	.4195
3	6	2	.3601	.3900
3	6	3	.3319	.3777
3	7	1	.4012	.4100
3	7	2	.4105	.4137
3	7	3	.3782	.4057
3	8	1	.4846	.4942
3	8	2	.3340	.3927
3	8	3	.4780	.4801
3	9	1	.5132	.5248
3	9	2	.4829	.4882
3	9	3	.5357	.5351
3	10	1	.4520	.5069
3	10	2	.4576	.5293
3	10	3	.5033	.5703
4	1	1	.4653	.4632
4	1	2	.4488	.4561
4	1	3	.4104	.4336
4	2	1	.4248	.4571
4	2	2	.4382	.4379
4	2	3	.4348	.4542
4	3	1	.4653	.4870
4	3	2	.4470	.4739
4	3	3	.4297	.4412
4	4	1	.5271	.5171
4	4	2	.5792	.5824
4	4	3	.5015	.5011
4	5	1	.5329	.5892
4	5	2	.4760	.5057
4	5	3	.4531	.5011
4	6	1	.5604	.5818
4	6	2	.5088	.5816
4	6	3	.4626	.4548

Table 16 (Cont'd)

M	<u>S</u>	B	Yes	No
4	7	1	.3943	.4278
4	7	2	.3917	.4258
4	7	3	.3724	.3862
4	8	1	.3903	.4418
4	8	2	.4194	.4404
4	8	3	.4183	.4069
4	9	1	.5189	.5035
4	9	2	.4889	.4851
4	9	3	.5113	.4935
4	10	1	.4281	.5150
4	10	2	.5052	.5251
4	10	3	.4870	.5075

Table 17

Median Reaction Times (in Sec.) for
All Ss in the Colors-Only Condition

M	<u>S</u>	Yes	No
1	201	.3085	.3294
2	201	.4689	.4712
3	201	.5806	.5454
1	202	.3141	.4323
2	202	.4173	.5041
3	202	.3976	.4850
1	203	.4199	.4073
2	203	.4393	.4226
3	203	.4900	.4147
1	204	.3108	.3677
2	204	.4542	.4102
3	204	.5079	.4745
1	205	.3056	.3260
2	205	.2870	.3326
3	205	.3590	.3563
1	206	.4026	.4277
2	206	.3486	.3819
3	206	.4146	.4382
1	207	.2716	.3163
2	207	.3684	.4081
3	207	.3404	.3851
1	208	.3018	.3168
2	208	.3628	.3835
3	208	.4074	.4245
1	209	.2990	.3982
2	209	.4226	.4799
3	209	.4893	.5514
1	210	.4020	.3949
2	210	.3695	.4110
3	210	.4173	.4902
1	301	.3048	.3850
2	301	.4274	.4856
3	301	.4485	.5019
1	302	.4122	.4281
2	302	.4946	.5037
3	302	.4196	.4675

Table 17 (Cont'd)

M	<u>S</u>	Yes	No
1	303	.3119	.3503
2	303	.3545	.3830
3	303	.3596	.4159
1	304	.4334	.4297
2	304	.5172	.5052
3	304	.5085	.5370
1	305	.3892	.4201
2	305	.5412	.4942
3	305	.5503	.5382
1	306	.2974	.3139
2	306	.3298	.3669
3	306	.3404	.4285
1	307	.2757	.3102
2	307	.3809	.4018
3	307	.3502	.3826
1	308	.3702	.3668
2	308	.4859	.4633
3	308	.4315	.4497
1	309	.4010	.4792
2	309	.4629	.4782
3	309	.4630	.4829
1	310	.3636	.4297
2	310	.3972	.4178
3	310	.4871	.5144
1	401	.2981	.3318
2	401	.3562	.3795
3	401	.4362	.4543
1	402	.2880	.3605
2	402	.4168	.4363
3	402	.4332	.4396
1	403	.4071	.3861
2	403	.4330	.4047
3	403	.4046	.4022
1	404	.3827	.4074
2	404	.5092	.4982
3	404	.5275	.5039
1	405	.3471	.3983
2	405	.3766	.4434
3	405	.4604	.4904
1	406	.4143	.4419
2	406	.4938	.5059
3	406	.5207	.5457

Table 17 (Cont'd)

M	<u>S</u>	Yes	No
1	407	.2381	.2643
2	407	.3267	.3289
3	407	.3236	.3545
1	408	.3060	.2962
2	408	.3693	.3760
3	408	.4072	.3978
1	409	.3617	.3803
2	409	.4314	.4062
3	409	.4212	.4448
1	410	.3456	.3694
2	410	.3821	.4755
3	410	.3982	.4522

Table 18
Median Reaction Times (in Sec.)
for All Ss in the Special
Colors-Only Condition

M	<u>S</u>	Yes	No
1	207	.3340	.3113
2	207	.3451	.3734
3	207	.3537	.3405
1	208	.3311	.3770
2	208	.3744	.4462
3	208	.4312	.4163
1	209	.3029	.3846
2	209	.3755	.4528
3	209	.3765	.4380
1	210	.3265	.3303
2	210	.3622	.4220
3	210	.3924	.4266
1	304	.4599	.4169
2	304	.4812	.4637
3	304	.4611	.4694
1	308	.4958	.4639
2	308	.4737	.4231
3	308	.5036	.4369
1	309	.3740	.4601
2	309	.3887	.4377
3	309	.4684	.4762
1	310	.3720	.3864
2	310	.3839	.4056
3	310	.4201	.4360
1	406	.3979	.4355
2	406	.4203	.4404
3	406	.4431	.5080
1	408	.3133	.3218
2	408	.3392	.3841
3	408	.3592	.4042
1	409	.3608	.3478
2	409	.3937	.4346
3	409	.4119	.3725
1	410	.3566	.3916
2	410	.3844	.4681
3	410	.4091	.4660

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