AD-A031 105 NEW MEXICO STATE UNIV UNIVERSITY PARK DEPT OF PSYCHOLOGY F/G 5/8
COLOR RESEARCH FOR VISUAL DISPLAYS.(U)
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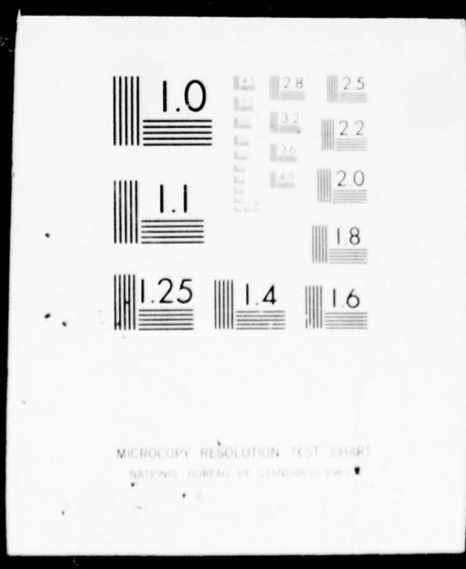

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REPORT ONR-CR213-102-3

(12)

COLOR RESEARCH FOR VISUAL DISPLAYS

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CONTRACT N00014-76-C-0306

ONR TASK 213-102

July 1975

FINAL REPORT

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PREPARED FOR THE

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19 REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: 18 ONR-CR213-102-3

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): 6 COLOR RESEARCH FOR VISUAL DISPLAYS.

5. TYPE OF REPORT & PERIOD COVERED: 9 Final Report,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): 10 Richard E. Christ, Gregory M. Corso

8. CONTRACT OR GRANT NUMBER(s): 15 ONR N00014-76-C-0306 NEW

9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Psychology, New Mexico State University, Univ Park, Las Cruces, New Mexico 88003

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 16 NR-213-102

11. CONTROLLING OFFICE NAME AND ADDRESS: Office of Naval Research, 800 N. Quincy Avenue, Arlington, Virginia 22209

12. REPORT DATE: 11 Jul[redacted]75

13. NUMBER OF PAGES: 108 — 12 110p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Color Coding, Visual Displays, Choice Reaction Time Task, Search/Locate Task, Identification Task, Human Performance, Engineering Psychology

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A series of experiments are reported which use highly practiced subjects to investigate the effectiveness of color coding relative to letters, digits, and familiar geometric shapes. These experiments were concerned with unidimensional and bidimensional displays and relatively simple single tasks (choice reaction time, search and locate, and multiple target identification). The results are presented in a format which may be used as a practical guide for when and where to use color in displays. In addition several issues of more general theoretical interest are discussed.

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NONTECHNICAL SUMMARY

A series of 10 experiments are reported which used highly practiced subjects to investigate the use of letters, digits, familiar geometric shapes, and color dots as coding dimensions in visual displays. These experiments were concerned with unidimensional and bidimensional displays and with relatively simple, single tasks (choice reaction, search and locate, and multiple target identification). The results of these experiments were analyzed in terms of absolute levels of performance for each coding dimension and in terms of the effectiveness of color relative to the achromatic codes. The most relevant relative scores were computed by determining the difference between performance with color as a target code and with an achromatic stimulus as a target code and dividing this difference by the results obtained with the achromatic target.

Table 1 shows the minimum and the maximum gain (or loss) that was found with color as a target code relative to each achromatic target code. These percent difference scores are shown separately for each type of task. The scores for the choice reaction and the search and locate tasks are based upon correct response time measures. The scores for the identification task are based upon both the average correct response times and the average levels of accuracy.

When the subject's task is to identify a single target as rapidly as possible, color produced relative losses in choice reaction time as large as -16 percent and relative gains as great as +36 percent. These percent difference scores varied as a function of the comparison achromatic code and as a function of whether the target stimulus appeared in isolation or in a field which also contained other nontarget background stimuli. The largest losses occurred when the target was presented by itself; the largest gains when the target was

TABLE 1

Range of Percent Difference Scores for the Use of Color[a]

Comparison Achromatic Code	Choice Reaction Task(Response Time)		Search/Locate Task(Response Time)		Identification Task(Response Time)		Identification Task(Accuracy)	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Letters	-11.8	+36.5	- 7.8	+27.3	+ 5.8	+27.4	-17.0	+ 2.9
Digits	-16.0	+29.2	- 6.7	+21.9	- 9.7	+17.3	-15.0	+ 0.2
Shapes	- 6.8	+16.4	- 2.8	+12.9	- 0.1	+15.7	-13.1	+ 1.1

[a] Positive scores indicate a gain, negative scores a loss with the use of color.

presented in a visually noisy (heterogeneous) stimulus display.

The use of color in search and locate tasks generally leads to a relative decrease in search/locate time. The gain in performance relative to when achromatic targets are used may be as great as 27 percent but there may also be a loss in performance as great as -8 percent. The greater gains are more likely to occur for the more dense displays (i.e., for displays containing many stimuli) and in bidimensional displays. The relative advantage of color is least for low density unidimensional displays.

When the subject is required to identify multiple targets from a briefly exposed display, color is less effective as a target code relative to achromatic stimuli if the primary objective is to maximize the accuracy of the responses. However, if the average correct response times are of primary importance, color coding leads to superior performance relative to letters, digits, or shapes. The effects in either case are never very large. The greatest relative loss associated with color for accuracy was only -17 percent; the greatest relative gain in the mean correct response times was about +27 percent. The larger relative scores were obtained with bidimensional displays; smaller scores were obtained with unidimensional displays.

In conclusion, it appears that color is most likely to benefit performance in any task if the subject must deal with more complex, multiple stimulus formats and when he must distinguish one class of stimuli (e.g., one stimulus dimension) from another. Presumably, color aids the subject in the requirement for organizing or reorganizing inputs from the display. The results of this research program also point out the importance of practice with any coding variable and with any task. Even when the different coding dimensions led to relatively large differences in performance, there was a tendency for practice to attenuate the differences. Finally, even when there were relative differences in performance attributable to color, it is not certain that color was the only coding variable or the best coding variable that could produce those results. In these present experiments familiar geometric shapes produced performance measures quite simular to that found for color. It is certainly possible to conceptualize other types of achromatic or monochromatic coding dimensions not tested here which may be more effective or less effective than color.

PREFACE

We wish to express our appreciation to Commander Donald C. Hanson, contract monitor, for his encouragement and understanding of the problems associated with this type of research. We are grateful as well to Nancy E. Hutchcroft, John B. Mocharnuk, M. Gregory Smith, and Michael J. Barnes who assisted in the collection of data. Special gratitude is owed to Nancy E. Hutchcroft who also prepared the figures used in this report and to Julie Goodrich who patiently typed several drafts of this report.

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INTRODUCTION

The concern with how to design visual displays to maximize the amount of information that can be presented effectively has a long history in engineering psychology. This concern has increased in magnitude with the development of automated facilities which impose an increasingly greater demand on the human operator for data acquisition and utilization.

A major consideration in display design has always been the selection of optimal symbolic coding variables. While a number of different coding variables, including color, have been examined extensively in the past, the relative efficiency of color as a coding variable has not been an issue until recently. Now, however, advances in hardware technology have made color a highly feasible coding dimension. As a result of these hardware developments, there is a need to know how much, if any, gain in human performance should be expected if color were utilized as a major coding variable. Quantitative information concerning the relative efficiency of color is needed so that decisions about when and how to use color can be considered meaningfully against such other system considerations as cost, training, and the like.

Unfortunately, most research on the use of color as a stimulus variable has been directed toward investigating human sensory limitations as dependent upon the energy characteristics of the stimulus (e.g., sensory threshold) or toward investigating theoretical concepts concerning information processing. As a result, the bulk of the color research literature does not present data in a form that allows the quantitative effects of color to be isolated.

A recent review of the literature quantitatively analyzed the results of those few studies which could be used to determine the relative effectiveness of color codes (Christ, 1975). That review suggested that color can be a very effective target code under some display and task conditions, but also that it may yield no advantage and might even be detrimental under other conditions relative to various types of achromatic codes.

While the information derived from the literature review permitted the generation of a tentative guide for the use of color in displays, an equally valuable outcome was the identification of those gaps in knowledge which have prevented a definitive evaluation of color coding. The major limitation of the published studies is the complete absence of data necessary for making some color versus achromatic code comparisons. Furthermore, those few comparative values which are available in the literature have generally been obtained under highly restricted conditions. Of particular importance, these restrictions include the fact that published experimental results are, with few exceptions, based on the performance of essentially unpracticed subjects, i.e., subjects who participated in one, usually short, experimental session. In addition, the published data were obtained under conditions in which the subjects could devote their full attention to a single display for the purpose of accomplishing a single, relatively simple task. These two restrictions, more than anything else, severely limited the design guides that were established. (Christ, 1975).

The present report describes a series of experiments designed to provide a revised (where needed) and expanded table of gains and losses associated with the use of color in visual displays relative to achromatic coding variables. Table 2 summarizes the purposes and major independent variables of each of 10 experiments. The overall concern of most of these experiments was to provide a single group of subjects long term practice with each of four coding variables (Letters, Digits, Familiar Geometric Shapes, and Colors) in each of three types of relatively simple tasks, Choice Reaction Time (CRT), Search and Locate, and

TABLE 2

A Chronological Summary of Experiments

Completed From December 1, 1974, to May 8, 1975

Experiment	Brief Description
1	An experiment designed to develop practice for subjects with each of four unidimensional target codes in a choice reaction task and to familiarize these subjects with the apparatus.
2	An experiment using naïve subjects designed to investigate the effects of variations in stimulus-response mapping, size of color stimuli, and average luminance of each of four unidimensional codes in a choice reaction task.
3	A replication of Experiment 1 designed primarily to establish a baseline level of choice reaction time performance for the long-term subjects.
4-5	Two experiments using the long-term subjects designed to investigate the effects of peripheral viewing, stimulus position uncertainty, and visual noise on choice reaction time, with single stimulus and with multiple stimulus bidimensional displays.
6-7	Two experiments designed to give long-term subjects practice with each of four unidimensional displays and each of six possible bidimensional displays in a search/locate task. These experiments utilized displays containing stimuli from only one stimulus dimension or from each of two stimulus dimensions.
8	A second replication of Experiment 1 designed to reevaluate baseline performance in the choice reaction task.
9	An experiment designed to give long-term subjects practice with each of four unidimensional stimuli and each of six possible bidimensional displays in a multiple target identification task. In the latter case the full report of targets in both stimulus dimensions was investigated.
10	A third, partial replication of Experiment 1 designed to reevaluate baseline performance in the choice reaction task.

Identify. A subsequent report will describe studies designed to determine the relative effects of color coding in more complex multiple task conditions.

General Methodology

The apparatus used for these studies consisted of a multiple display-multiple task system designed specifically for this research program. Since this system has been described in detail in an earlier report (Christ, Stevens, and Stevens, 1974), only a brief description will be given here.

The overall configuration of the displays and controls is illustrated in Figure 1 which shows a photographic view of the apparatus from over the left shoulder of a subject. Figure 2 shows a more detailed photograph of the display and control consoles.

Displays

The displays used for the present series of experiments used IEE Series 00100 single plane rear-projection readouts. Each IEE unit consists of 12 projection lamps and 12 film messages. When one of the lamps is lighted it illuminates the corresponding film message, focuses it through a lens system, and projects it onto a non-glare viewing screen.

Figure 3 illustrates the types of films used with these display units. Films C through H were designed so that any one of four target codes (Letters, Digits, Familiar Geometric Shapes, and Color Dots) or any one of the six two-way combinations of these four codes could be used in a given experimental session. The colored dots were produced by placing Roscolene color filters in front of the solid circles shown on Films F, G, and H. The type style of the single letter and single digits used in Films C through H was Alternate Gothic

Figure 1. A photographic view of the apparatus as seen over the left shoulder of a subject.

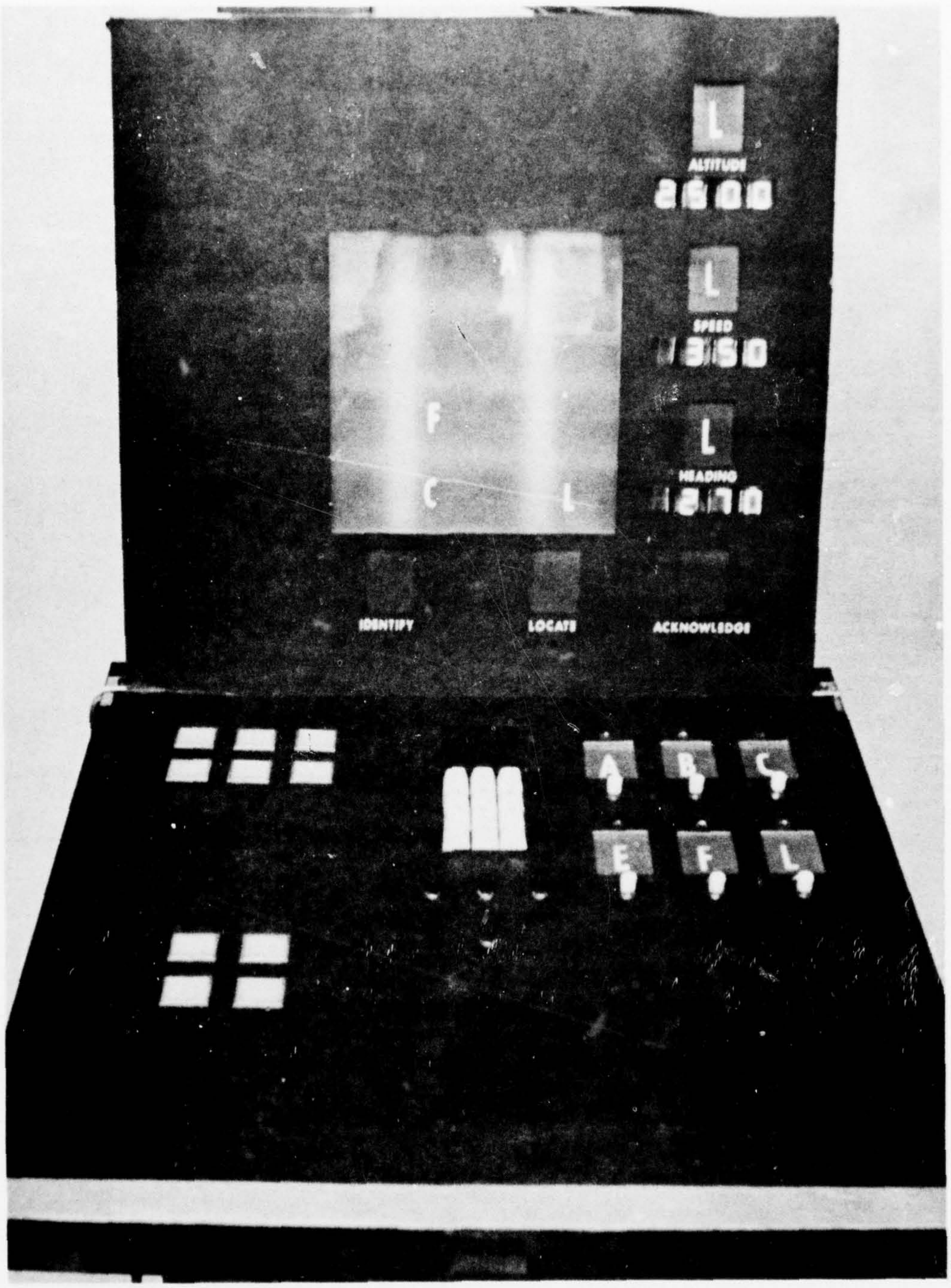

Figure 2. A photographic view of the display and control consoles.

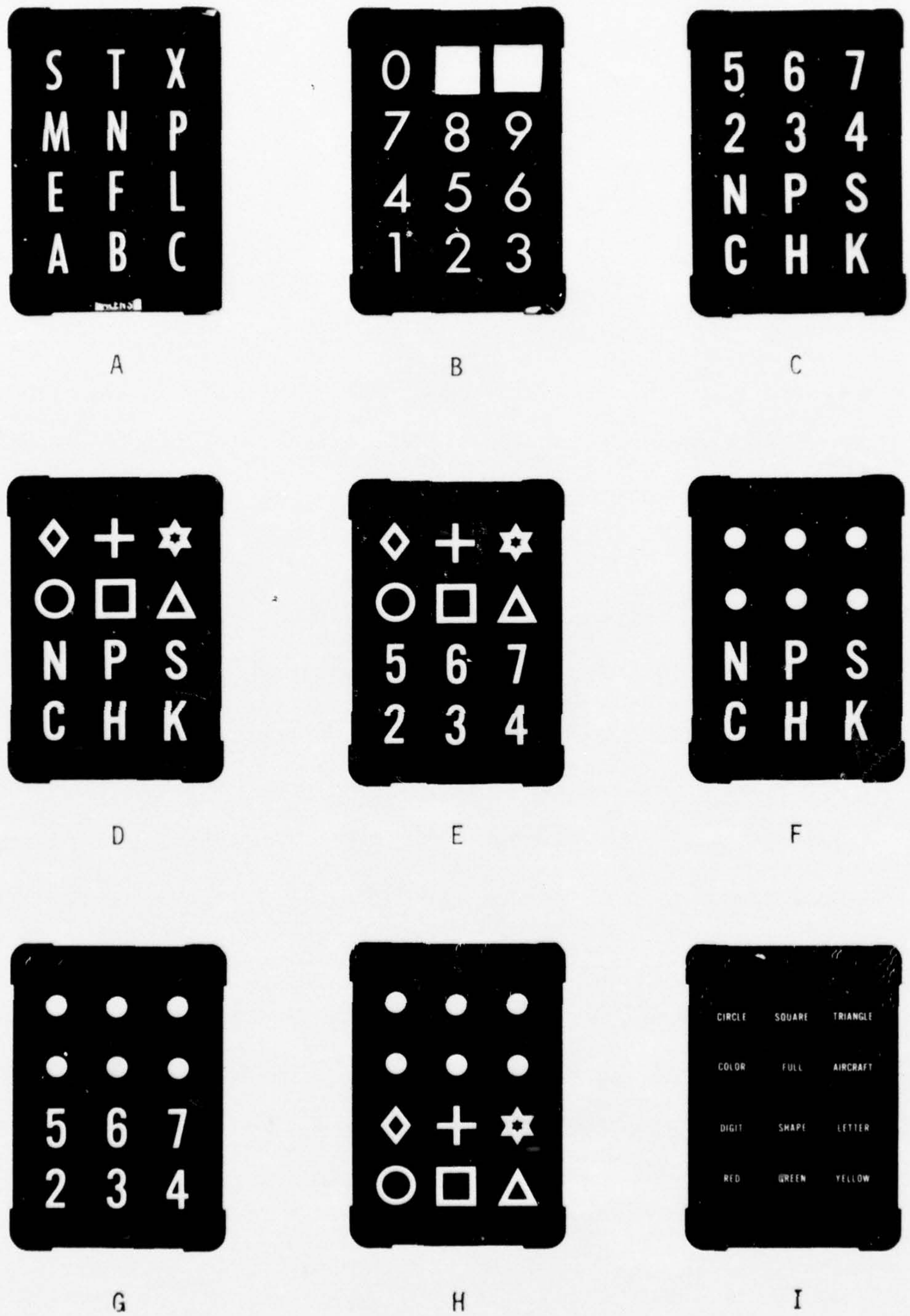

Figure 3. Photographs of nine films used with single plane readouts

#3. The projected height of the single letters and digits was 0.94 inch (2.39 cm) and the projected diameter of the dots was 0.50 inch (1.27 cm). Film I was used only in the Identify Task and then only the message, "FULL", was used. The type style of the words shown in Film I was also Alternate Gothic #3, but the projected height of these letters was only 0.185 inch (0.47 cm). Only one message per readout was illuminated at any given time and all messages were projected to the center of the viewing screen for that readout.

The six color filters used to produce the color coding dimension gave colors designated as purple, blue, green, yellow, orange, and red. The manufacturer's numbers for these filters were 843, 850, 871, 806, 817, and 821, respectively. The total transmission of these filters, as a percent of an incandescent light source is 18, 30, 31, 88, 56, and 16, respectively. These transmission measurements were provided by the manufacturer and based on measurements taken with a General Electric photometer. The average brightness of the alphanumeric messages in an IEE readout, using standard lamp No. 1820, was 16.0, 8.0, and 4.5 foot-lamberts (54.9, 2714, and 15.4 cd/m^2*) at rated voltages of 24, 18, and 14 volts, respectively. These latter values were derived using conversion tables provided by Industrial Electronic Engineers, Inc. Combining the transmission characteristics of the color filters and the rated brightness of the normal white messages, it may be seen that at any given voltage setting the average brightness computed over the six colors was not equal to the brightness of the achromatic stimuli. Specifically, the average brightness of the color messages was 6.39, 3.19, and 1.78 foot-lamberts (21.9, 10.9, and 6.1 cd/m^2) at rated voltages of 24, 18, and 14 volts. Of course, the exact spectral density function of the different filters, as well as the corresponding hues reported

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* candela per square meter

by an observer viewing the colored dots, varied as a function of rated voltage. No attempt was made to measure these density functions since the hues reported did not differ appreciable as a function of brightness. There also was no attempt made to equate the brightnesses of the six different colors; neutral density filters were not available when the research was initiated and there were no facilities for directly and accurately measuring the actual brightness obtained.

The display console used for all 10 experiments reported here was designed to hold one large multiple stimulus display and three smaller single stimulus displays. The large multiple stimulus display is shown in Figure 2 in the center of the display console. This display consisted of 16 IEE single plane readouts arranged in a four x four matrix. This matrix display was mounted behind a common viewing screen. While all six of the smaller peripheral displays shown in Figure 2 were visible to the subjects in this series of experiments, only those three at the bottom of the display console were used and then, no more than one at a time. Only the single IEE unit labeled ACKNOWLEDGE was used in Experiments 1, 2, 3, 8, and 10. Only the large matrix display was used in Experiments 4 and 5. The single IEE unit labeled LOCATE and the matrix display were used in Experiments 6 and 7. The single IEE unit labeled IDENTIFY and the matrix display were used in Experiment 9.

The same film was used in all of the IEE readouts relevant for any given experiment. The design of the films made it possible for all projected messages to be coded identically (unidimensional display) or for the messages to be coded by two coding variables (bidimensional display). Figure 4 presents examples of these two types of display conditions as they applied to the matrix display. It may be seen that the displays labeled B and D in Figure 4 are unidimensional shape and unidimensional letter displays, respectively. The displays labeled A and C in Figure 4 are bidimensional digit-shape and

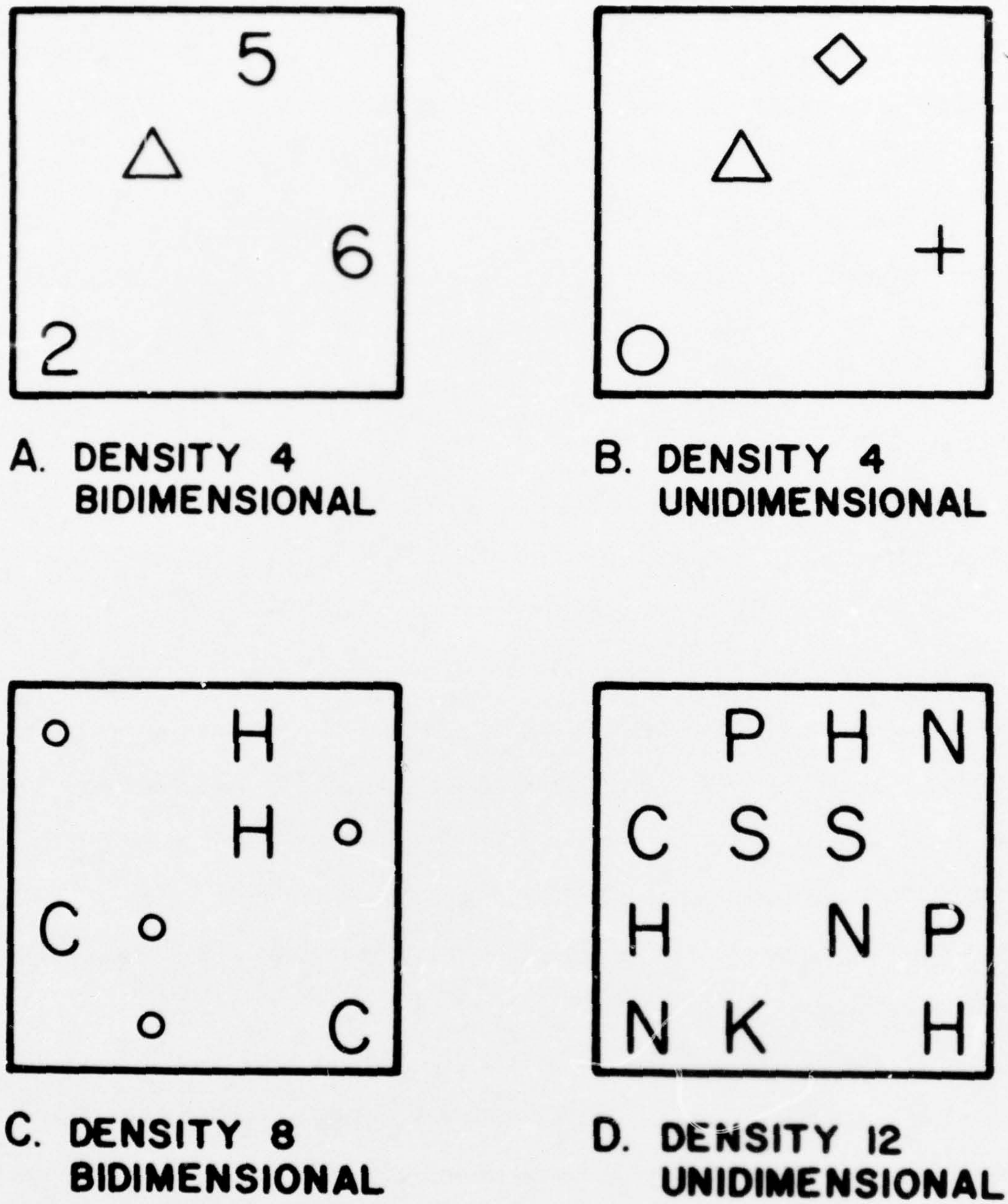

Figure 4. Examples of the types of matrix displays used in Experiments 4, 5, 6, 7, and 9. The small circles in C represent the location of color dots in the display.

bidimensional letter-color displays, respectively. The messages in each display were lighted and shown against a dark gray background. Color filters were used in conjunction with the dots shown in the display labeled C. in the figure. More complete descriptions of the different types of displays will be given while describing the experiments in which they were used.

Controls

The control console shown in Figures 1 and 2 consisted of four clusters of buttons. Each cluster of buttons was designed to receive a subject's responses for a different task. The six IEE units and associated buttons in the upper right corner of the control console shown in Figure 2 were used to identify stimuli in the CRT and Identify tasks. In the former case, either all six response units or only the top or bottom three units were used. When only three units were used the three buttons and IEE units not used were covered by an aluminum panel. The standard arrangement used in all but Experiment 2 was consistent for each of the four types of stimulus codes. Specifically for letters, the arrangement from left to right, top to bottom row was C, H, K, N, P, S; for digits, 2, 3, 4, 5, 6, 7; for shapes, circle, square, triangle, diamond, cross, star; and for color dots, purple, blue, green, yellow, orange, red. These particular samples of values within each dimension and the sequencing of values over the six response units were purposely chosen in an attempt to approximate equal stimulus-response compatibility across codes.

The same arrangement of six response units within a coding dimension were used in the unidimensional Identify task as were used in the CRT task. In the bidimensional Identify task the first three values of one target code were combined with the second three values of another target code. For example, in the letter-digit bidimensional Identify condition the arrangement of response units was either 2, 3, 4, N, P, S or C, H, K, 5, 6, 7.

The Search and Locate response units consist of four momentary contact buttons arranged in a two x two matrix which was placed in the lower left corner of the control console shown in Figure 2. The subject used this response unit to specify the location (quadrant) of a target in the matrix display.

The only other response button used in this series of experiments was the lowest button of the set of four buttons shown centered in the control console in Figure 2. This button was used to terminate the trial in the Identify task. The numeric keyboard shown in Figure 2 and the three buttons in the row immediately below the keyboard were removed from the control console and that entire area was covered by an aluminum panel. The six buttons in the upper left of the control console were exposed to the subject but they were never used.

Programming

The entire system shown in Figures 1 and 2 was interfaced with a PDP8/e minicomputer. The software developed for this computer controlled all programmable sequences of display events. The experimental program and up to 100 stimulus sequences of 20 to 48 trials each were written onto one auxiliary magnetic tape (Dectape) and the results were stored on a second tape.

Long-term Subjects

Except for Experiment 2, the same set of eight male subjects was used in all experiments. These subjects were paid a fixed sum per experimental session for their participation and were also given a monetary incentive based upon their performance. All subjects were between the ages of 19 and 24, and they were all right-handed. In addition, subjects all had a visual acuity of at least 20/15 in each eye as measured with the Snellen chart and normal color vision in each eye as determined by the American Optical H-R-R Pseudoisochromatic Plates.

These eight subjects were assigned to one of two groups primarily on the basis of scheduling convenience. In general, subjects in Group A ran in sessions scheduled for Monday through Thursday. Subjects in Group B ran in sessions scheduled for Wednesday through Saturday. This scheduling was used to enable optimal use of facilities and experimenters, and to allow at least a minimum degree of counterbalancing of conditions over successive sessions.

CHOICE REACTION TASKS

General Method

As shown in Table 2, six different CRT experiments were run using the long-term subjects and one CRT experiment was run using groups of relatively naïve subjects. In all seven of those CRT experiments the subjects were presented a stimulus display and were required to identify a single target alternative from a specified target dimension as rapidly as possible. The display was illuminated for 4 seconds or until the subject made a response whichever was shorter. There was a 100 msec* interval between the offset of one display and the onset of the next. The trials were paced by the subject's rate of responding. There were always 48 trials per sequence and, depending upon the specific experiment, from eight to twenty sequences per experimental session. The number of possible targets (three or six) was constant over a sequence of 48 trials, but varied over successive sequences. When there were three such target alternatives, they were either the stimuli corresponding to the top or to the bottom three response buttons. The target dimension was constant over successive sequences, but, in some experiments, varied over successive blocks of sequences within an experimental session. The subject was always told in advance what the target dimension would be and how many and which particular alternatives were to serve as possible targets during a sequence of trials.

There were three different variations of the CRT task. The CRT task used in Experiments 1, 2, 3, 8, and 10 will be called a simple CRT task. In the simple CRT task, a single stimulus was presented as the target on each trial. That stimulus was presented in the small display panel labeled ACKNOWLEDGE in Figure 2. That display panel was located in the lower right part of the display

* milliseconds

console just above the identification buttons. In the simple CRT task there was no uncertainty about where the stimulus would appear and it was assumed that the subject would be looking directly at the stimulus when it did appear.

The CRT task used in Experiment 4 and during the initial part of each half-session of Experiment 5 also used the presentation of a single target alternative as the stimulus for each trial. Unlike the simple CRT task, the exact location of that target varied over trials. Specifically, one of three- or one of six-alternative targets was presented on each trial in a randomly selected position in the 16-cell matrix display. This second type of CRT task therefore included the factor of stimulus position uncertainty. This task will be called a single stimulus matrix CRT task. The rationale for this task was based upon the notion that subjects would generally not be looking directly at the location of a target in the matrix when the target was presented. Hence, this task would determine the relative efficiency of identifying stimuli from the different target dimensions when the stimuli were presented initially in the periphery of the visual field.

The third type of CRT task was used only during the latter part of each half-session of Experiment 5. This CRT task maintained the factors of a single target stimulus and of target position uncertainty but added a visual noise factor. Specifically, on each trial, in addition to a single target stimulus, the matrix display contained either three or eleven stimuli drawn from one of the nontarget dimensions. In the former case, any three of the six nontarget stimuli could occur as noise stimuli. In the latter case, one of the nontarget stimuli would occur once, two would occur twice, and two would occur three times as noise stimuli. The sample matrix shown in Figure 4A represents a display which occurred when the total display density was four stimuli. In this example, the target dimension was shapes and the background dimension was digits. Figure 4A shows that only one target stimulus (viz., a triangle) occurred in the matrix and that three nontarget stimuli (viz., the digits 2, 5, and 6) also occurred in this particular display. The locations of the target stimulus and the three or eleven background stimuli were randomly chosen for each display with the restriction that over the forty-eight trials in a sequence the target occurred in each position three times. Furthermore, the total display configuration was such that one stimulus (for the case where density was four) or one blank cell (for the case where density was twelve) occurred once in every row and once in every column. We call this third type of CRT task the multiple stimulus matrix CRT task. The subject in this task had first to search for a stimulus from the target dimension and then identify this stimulus. The task was specifically designed to examine possible interaction effects between stimulus dimensions in bidimensional displays.

More detailed discussion of the methods and the results of each of these CRT experiments will be presented below. For ease of organization, Experiment 2 will be presented first even though it was the second experiment run. It was the only experiment which did not use the eight long-term, well-practiced subjects.

Experiment 2

This experiment was designed to provide information which might be used to establish some basic task parameters for use in subsequent studies. The experiment was used as a basis for comparison with the results obtained with the long-term, highly practiced subjects. In particular, we wished to determine whether or not such task variables as target luminance and the configuration of response buttons were important potential sources of variation in the CRT tasks.

Method

Subjects. A total of forty male and forty female students served as subjects for this experiment. These students were all enrolled in introductory psychology classes at New Mexico State University and volunteered to participate in this experiment for partial fulfillment of the requirements for that course. The subjects ranged in age from 18 to 38. They all claimed to be right-handed and they all did, in fact, use their right hand to write their names on a sign-up sheet for the experimenter. Each subject was tested for visual acuity and color vision. The criterion for participating in the experiment was a visual acuity of at least 20/15 in each eye as tested with the Snellen Chart and a passing score on the American Optical H-R-R Pseudoisochromatic test.

Procedure. Five male and five female subjects were tested under each combination of four target dimensions (letters, digits, shapes, color) and two arrangements of buttons (normal and scrambled). The normal arrangement of buttons was described in an earlier section of this report. The scrambled arrangement was constructed by rearranging the stimulus-response orders. Hence, the arrangement of buttons, from left to right, top row to bottom row was as follows: N, H, P, C, S, and K for letters; 5, 3, 6, 2, 7, 4 for digits; diamond, square, cross, circle, star, triangle for shapes; and yellow, blue, orange, pruple, red, green for colors. The output voltage of the power supply used to light the IEE lamps was varied between conditions of target dimension to approximately equate the average brightness of stimuli. Specifically, the average brightness of the color dots was maintained at 6.39 foot-lamberts (21.9 cd/m^2) and the average brightness of the letters, digits, and shapes was set at 4.5 foot-lamberts (15.4 cd/m^2).

The subjects were given one practice and sixteen experimental sequences of forty-eight trials each. There were thirty seconds between successive experimental sequences and a three-minute rest between the first and last blocks of eight experimental sequences. Each block of eight sequences consisted of four six-alternative sequences and four three-alternative sequences. The latter consisted of two sequences in which only the stimuli corresponding to the top three buttons were used and two sequences in which only the stimuli corresponding to the bottom three buttons were used. The order of six- and three-alternative sequences was randomized within and between subjects.

Results

Omission error. An error of omission was recorded if the subject did not respond during the four-second maximum response interval. Over all eighty subjects, only 0.2 percent of the trials were scored as omissions. These 150 errors (out of a total of 61,440 trials) were made by only thirty-three subjects. Male subjects committed 67 percent of the omissions and 59 percent of the omissions occurred in the normal button arrangement condition. Since so very few omissions occurred, these data were not further analyzed.

Commission errors. Errors in choice were tallied for each subject as a function of sex, target dimension, number of target alternatives, button arrangement, and practice. These data were transformed by adding .5 to each score and then taking the square root of that sum. These transformed error scores were then used in an analysis of variance. The results of this analysis showed that the only significant source of variation was due to the main effect of practice, $\underline{F}(1, 74) = 17.96$, $\underline{p} < .01$. A reversed transformation of the mean levels of error showed that subjects made 4.25 errors per 192 trials during the first half of the experiment and 2.98 errors per 192 trials during the second half of the experiment. These values correspond to error rates of 2.2 and 1.6 percent.

Choice reaction time. The mean CRT over all correct responses was determined for each subject. An analysis of variance of these data showed that alternatives, $\underline{F}(1, 64) = 1327.8$, practice, $\underline{F}(1, 64) = 218.47$, and the Alternatives x Practice interaction, $\underline{F}(1, 64) = 17.44$ were all significant at the .01 level. The only other significant effect was due to the three-way interaction among target dimensions, sex, and practice, $\underline{F}(1, 64) = 3.10$, $\underline{p} < .05$. It was determined that subjects responded faster when there were three alternatives than six alternatives (666 msec vs. 833 msec) and that performance improved as a function of practice (775 msec vs. 724 msec). The interaction of practice with alternatives was due to a larger practice effect for the three-alternative condition (60 msec) than for the six-alternative condition (42 msec).

Figure 5 illustrates the form of the interaction between target code, sex, and practice. Neuman-Kuels tests for pairwise differences showed that during the first stage of practice males were faster than females when the targets were letters or digits, and that females were faster than males when the targets were shapes or colors. However, during the second stage of practice sex differences were not significant except for when the targets were colors, and then, females were still faster than males. Looked at from a different perspective, male subjects were consistently faster with digits than with letters and were consistently faster with letters than with colors or shapes. Response times for the latter two codes were not different. On the other hand, while females showed a consistently faster CRT to colors than to letters, they showed no difference in CRT between shapes and digits until the second stage of practice. For females there was never any significant difference between letters and shapes or between

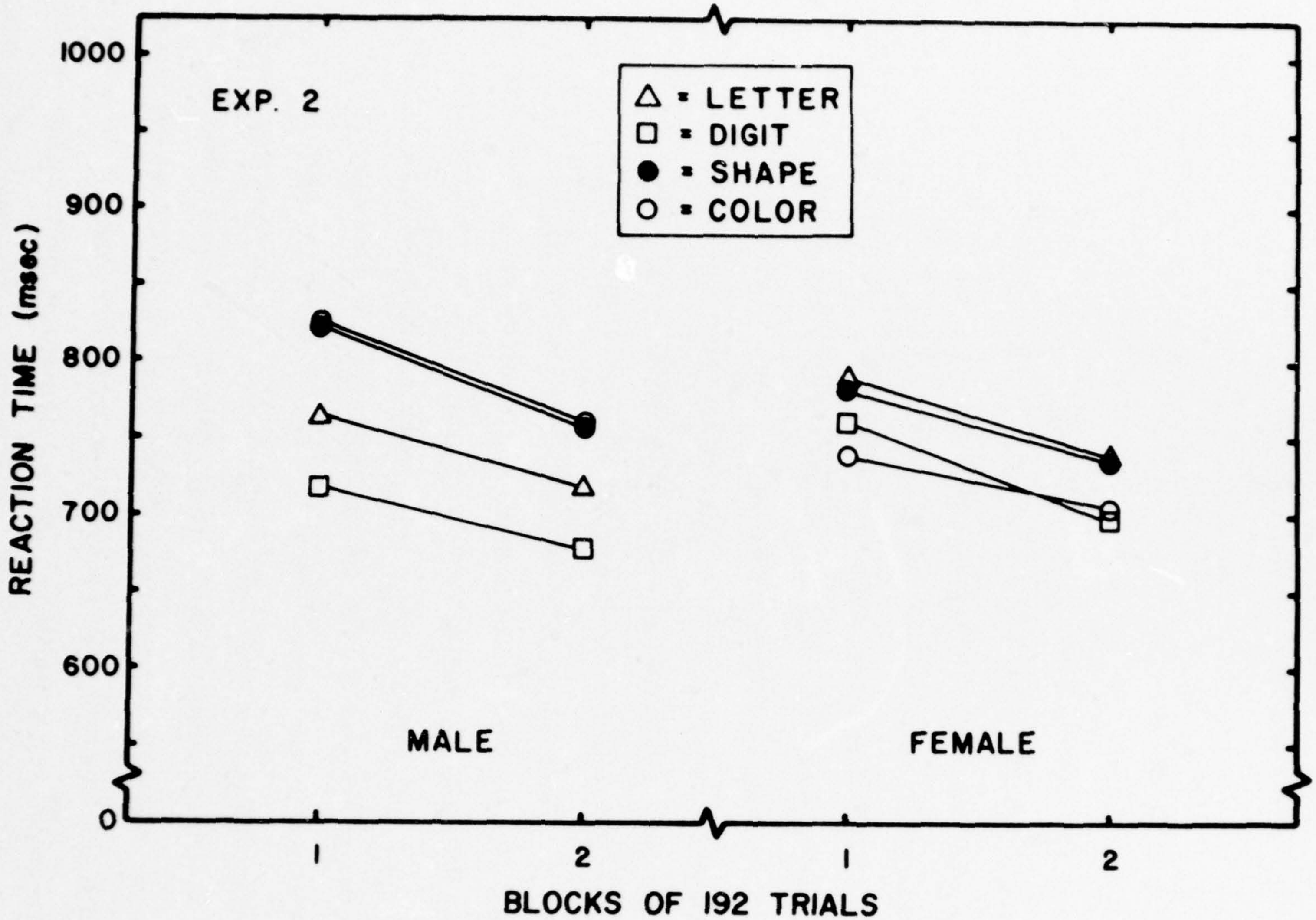

Figure 5. Reaction time as a function of practice, target code, and sex of the subjects in Experiment 2.

digits and colors.

Experiments 1, 3, 8, and 10

A series of four simple CRT experiments was conducted with the long-term subjects. These experiments had several purposes. Experiments 1 and 3 were designed to provide some initial information about the effects of different unidimensional target codes on choice reaction performance, to familiarize the subjects with the apparatus, and to evaluate the reliability of the hardware and software systems under actual experimental conditions. In addition, those two experiments and Experiments 8 and 10 were used to evaluate the effects of extended practice on choice reaction performance. The data from those studies also were used as a continuing baseline for interpreting the subjects' overall orientation to the experimental program. The latter was deemed necessary by the relatively long time interval over which these studies took place.

Method

The major independent variables in each of Experiments 1, 3, 8, and 10 were target code (all four target codes were used in Experiments 1, 3, and 8, but only letters and shapes in Experiment 10), number of target alternatives, and practice.. The major differences between experiments were the number of experimental sessions, the number of 48-trial sequences per session, and the number of different target codes run per session. The average brightness of color targets (6.39 foot-lamberts or 21.9 cd/m^2) was less than the average brightness of achromatic targets (16.0 foot-lamberts or 54.9 cd/m^2) in Experiment 1 but those values were approximately matched in Experiments 3 and 8 (6.39 foot-lamberts or 21.9 cd/m^2) for colors and 4.5 foot-lamberts or 15.4 cd/m^2 for achromatic codes.)

Experiment 1. In Experiment 1 each subject was run through 12 daily sessions. Each of the four target code conditions occurred once in each block of four successive sessions. The order of codes within and across blocks of sessions was counterbalanced over subjects. Each session consisted of one 48-trial practice sequence and eight 48-trial experimental sequences. The latter was divided into four sequences with six-alternative targets and four sequences with three-alternative targets. The eight subjects competed among themselves for awards of $10.00 and $5.00 which were given to the two subjects with the shortest overall mean response time.

Experiment 3. Each subject was run through four sessions in Experiment 3. Each session consisted of one practice sequence and eight experimental sequences with one target code followed by one practice and eight experimental sequences with a second target code. All four target codes were used once each in Sessions 1 and 2 and then used again, in reverse order of occurrence in Sessions 3 and 4. The order of target codes within and between sessions was counterbalanced over subjects. A five-minute rest was given between the two halves of each session. As always, one-half of the experimental sequences had six-alternative targets and the other half had three-alternative targets.

Experiment 8. Experiment 8 was conducted during one experimental session. Each subject received one practice and four experimental sequences per target code condition. A two-minute rest was given between the first and second, and between the third and fourth code conditions. A ten-minute break was given between the second and third code conditions. Half of the sequences within each code condition were six-alternative trials and half were three-alternative trials. The order of codes was counterbalanced over subjects.

Experiment 10. This last simple CRT experiment was a partial replication of the first three simple CRT studies. The four subjects in Group A received one practice and four experimental sequences with only the shape target code. The four subjects in Group B received the same treatments but with only the letter target code. The five simple CRT sequences were run immediately after the subjects had completed an experimental session concerned with another type of performance task.

Results

Omission errors. During the twelve sessions of Experiment 1 all eight subjects made a total of only twenty-five omissions. Hence, fewer than 0.1 percent of all trials were omitted. Since the number of omitted trials was so small in Experiment 1, and was even smaller in subsequent CRT experiments, these data were not analyzed further.

Commission errors. The number of error responses mady be each subject was determined in each experiment as a function of target code and the number of alternatives. These data were analyzed for each session of Experiment 1 but for only the last two sessions of Experiment 3. After the data were transformed using a square root transformation they were used in analyses of variance. In terms of the percentage of trials on which an error response occurred, performance generally increased from Experiment 1 (2.1%) to Experiment 3 (4.6%), and then remained fairly constant over Experiment 8 (4.8%) and Experiment 10 (4.1%).

The effect of practice was significant in Experiment 1, $F(2, 14) = 9.32$, $p < .01$. The mean error rates for each of three successive stages of practice were 1.4 percent, 2.7 percent, and 2.4 percent, respectively. The only other significant effect in Experiment 1 was the Code by Target Alternative interaction

$F(3, 21) = 3.9$, $p < .05$. This effect was due to the fact that there were no differences between codes when there were six possible targets but that more errors were made with color targets (5.6%) than with digit targets (2.9%) when there were three alternative targets.

Only the effect of code was significant in Experiment 3, $F(3, 21) = 3.28$, $p < .05$. The percentage of trials on which an error occurred with color targets (5.6%) was greater than the percentage of errors with letters and digits (4.0% in each case), but not different from the errors made with shapes (4.8%). In Experiment 8, the only significant effect was due to the number of target alternatives $F(1, 7) = 8.62$ $p < .05$. The error rate was 5.4 percent for three alternatives and 4.0 percent for six alternatives. There were no significant effects found for commission errors in Experiment 10.

Choice reaction time. The main reaction time for correct responses was determined for each subject as a function of target code, target alternatives, and practice. Practice effects were based on 192 trial blocks and were determined only for Experiments 1 and 3. The data of each experiment were used in separate analyses of variance; repeated measures analyses were used for Experiments 1, 3, and 8, and mixed model analysis was used for Experiment 10.

The main effect of practice was significant at the .01 level in both Experiments 1 and 3, $F(2, 14) = 83.23$ and 16.40, respectively, but no other effects involving practice were significant in either experiment. The effect of target code was significant in Experiment 1 at the .01 level and in Experiments 3 and 8 at the .05 level, $F(3, 21) = 8.35$, 4.54, and 4.74, respectively. Target code was not significant in Experiment 10. The number of target alternatives was significant at the .01 level in all four experiments, $F(1, 7) = 1826.3$, 188.56, and 146.83, for Experiments 1, 3, and 8 respectively, and $F(1, 6) = 85.81$ for

Experiment 10. The only other significant sources of variation were due to the Code x Number of Alternatives interaction in Experiments 1 and 8, $F(3, 21) = 15.11$ and 7.10, $p < .01$ in both cases.

The overall effects of practice and target codes are illustrated in Figure 6. This figure shows the effects of practice for the male subjects using the normal button arrangement in Experiment 2, as well as the effects of practice within and between Experiments 1, 3, and 8. Recall that in Experiment 2 a different group of five relatively naïve subjects were run under each level of target code. It may be seen that, in general, the reaction times were quite long for those subjects. Neuman-Keuls tests showed that the performance of all four groups of subjects improved with practice and that there were large and consistent differences among the target codes. The single group of long-term subjects used in Experiments 1, 3, and 8 also showed large effects due to practice both within and between experiments. While there were no differential effects of practice on target codes within Experiments 1, 3, and 8, it is clear that the absolute differences among target code conditions decreased over successive experiments. Neuman-Keuls tests showed that within each of Experiments 1, 3, and 8, CRT for digit targets was shorter than for shapes, colors, or letters and that there were no overall differences among the latter three target conditions.

The form of the significant effects due to target code and target alternatives is shown in Figure 7 for each of the four simple CRT experiments which used the long-term subjects. It may be seen that within any given study the subjects always took longer to respond in the six-alternative condition than in the three-alternative condition. It may also be seen that while subjects always responded faster to digits, the order of CRT to letters, shapes and colors

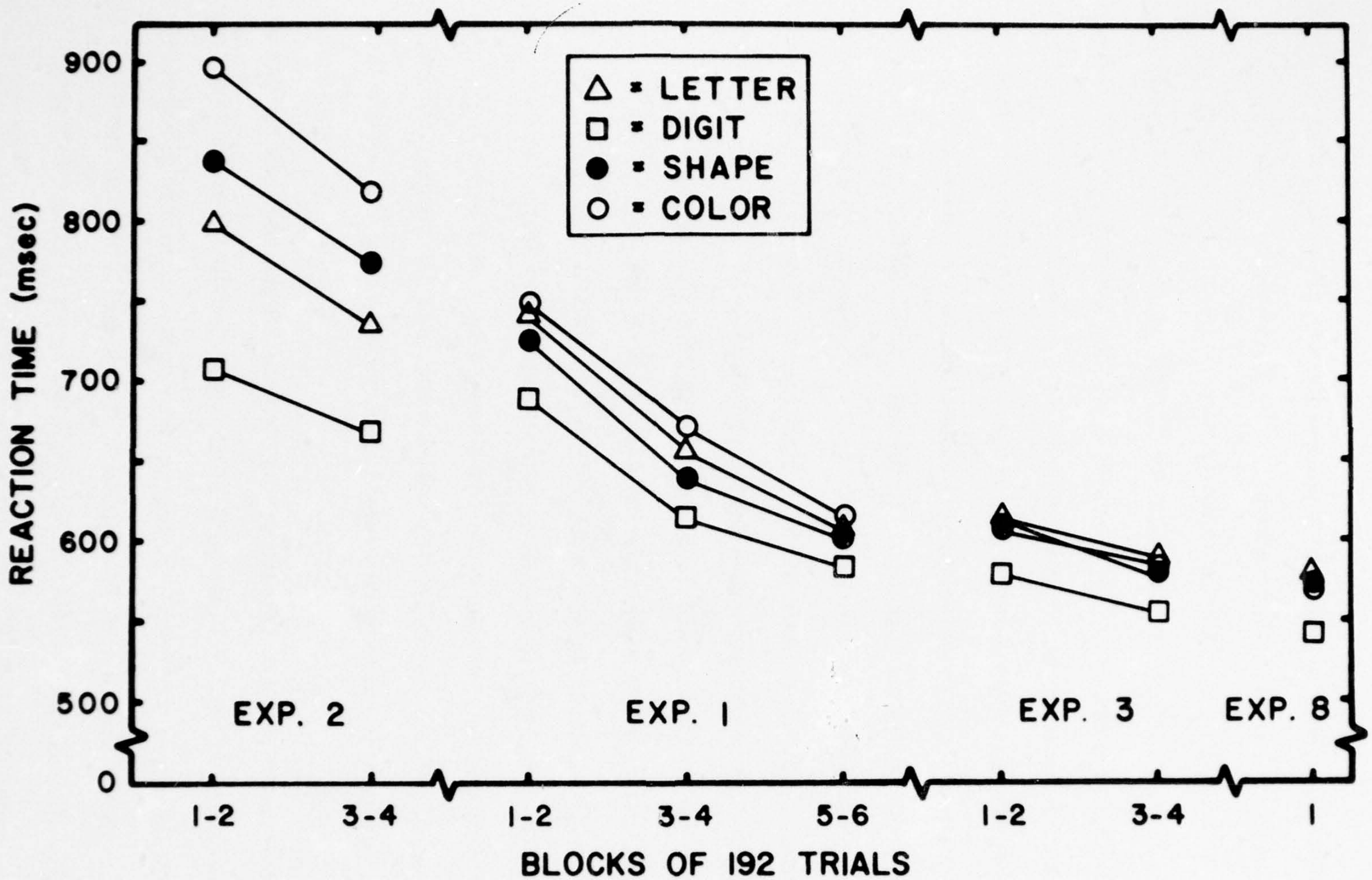

Figure 6. Reaction time as a function of practice and target code across Experiments 1, 2, 3, and 8.

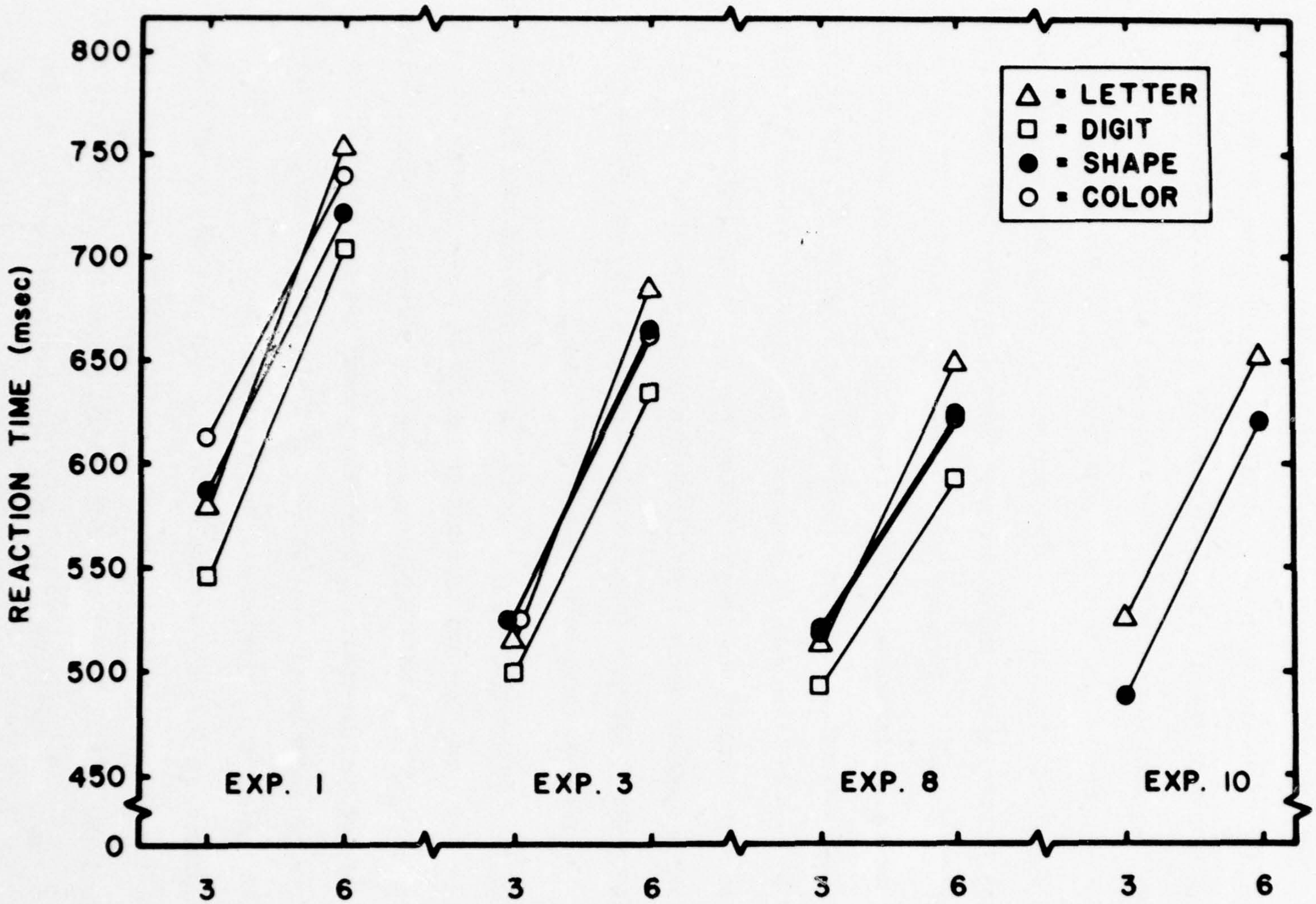

Figure 7. Reaction time as a function of target code and number of target alternatives in Experiments 1, 3, 8, and 10.

varied as a function of the number of target alternatives. Pairwise comparison between target code conditions showed that for Experiment 1 the CRT for letters and shapes were not different from one another but both were shorter than for colors when there were three-alternative targets but that CRT for shapes was less than CRT for colors, and that both were less than CRT for letters when there were six-alternative targets. In Experiment 8, there were no differences in CRT among letters, shapes and colors when there were only three-target alternatives but CRT for both shapes and colors were shorter than the CRT for letters when there were six-alternative targets. Though the interaction between target code and target alternatives was not significant for Experiment 3, the same trends may be seen in those data as were found for Experiments 1 and 8. Hence, while CRT to digit targets was always shorter than CRT to non-digit targets, the CRT to colors and shapes were not different from or slightly longer than the CRT to letters when there were three-target alternatives but were shorter than the CRT to letters when there were six-alternative targets.

Information transmission scores. Using the data from the last four sessions of Experiment 1 and the last two sessions of Experiment 3, an attempt was made to derive an overall index of information processing efficiency. Specifically, the amount of information transmitted by each subject was determined within each of those two experiments as a function of target code and target alternatives. Each subject's performance was thus determined over blocks of 192 trials. Separate analyses of variance of the information transmission scores showed that the number of alternatives was significant at the .01 level in both Experiments 1 and 3, $F(1, 7) = 1848.8$ and 2698.3, respectively. The only other significant source of variation in the data of either experiment was a main effect for target code in Experiment 3, $F(3, 21) = 3.1345$, $p < .05$.

The effect of the number of alternatives is exactly as would be predicted from an understanding of the information metric. The amount of information transmitted increased as the number of alternatives increased, from 1.42 to 2.41 in Experiment 1, and from 1.30 to 2.29 in Experiment 3. Note that given three- and six- equally probable stimulus alternatives the maximum information that could be transmitted is equal to 1.58 and 2.58 bits, respectively. Hence, the subjects were performing almost as well as possible. The overall decrease in information transmitted from Experiment 1 to Experiment 3 was due to the larger error rate in Experiment 3. The effect of target code on information transmitted in Experiment 3, even though significant, was not very large and again merely reflects small but significant variations in error rate among code conditions in that experiment. Since error rates were so small, performance levels measures in information terms (i.e., bits) were clearly influenced by an absolute ceiling. No further analysis was attempted using this measure of performance.

Experiments 4 and 5

Method

The single stimulus matrix CRT task and the multiple stimulus matrix CRT task were run in Experiments 4 and 5. The major independent variables for these two tasks were target code, number of target alternatives, and practice. The total display density and target-nontarget code combination were independent variables in only the multiple stimulus matrix CRT task.

Target codes and the number of target alternatives were the same as in the previously described simple CRT studies. Display density was either four or twelve stimuli; one target stimuli and either three or eleven nontarget stimuli.

All three stimulus codes which were not used as a target code within any target code condition were used as nontarget codes for that target code condition. For example, if letters were designated the target code, on three different occasions the subject would have digits, shapes and colors as nontarget or background stimuli in the matrix. Consequently, there were twelve unique combinations of target code conditions and background code conditions. The subjects were encouraged to respond as rapidly as possible. As an incentive to this end, each subject was given an extra 50 cents if his overall mean CRT in any session was within 75 msec of his overall mean performance in Experiment 3.

Experiment 4. Each of the two sessions of Experiment 4 consisted of two target code conditions. There were two practice sequences of the single stimulus matrix CRT task followed by eight experimental sequences of the same task, all with one target code. These ten sequences were followed by two practice sequences and eight experimental sequences with another target code. Hence, over the two sessions of Experiment 4, all four target codes were used. The order of occurrence of target codes was counterbalanced over subjects. All practice sequences consisted of six-alternative trials but four of each block of eight experimental sequences used six-alternative trials and the other four used either the top or the bottom sets of three-alternative trials. Each block of eight experimental sequences was divided into two blocks of two six-alternative sequences and two three-alternative sequences each. There were 20 to 30 seconds between successive sequences within a target code condition and five minutes between code conditions within a session. The luminance of targets was approximately matched over codes, 6.39 foot-lamberts (21.9cd/m^2) for colors and 4.5 foot-lamberts (15.4 cd/m^2) for achromatic stimuli.

Experiment 5. Experiment 5 consisted of six experimental sessions each of which was further divided into two half-sessions. Within any given session, one stimulus dimension is defined as the target code during one half-session and a different stimulus dimension is defined as the target code during the other half-session. A different pair of stimulus dimensions was used in each of the six sessions.

Each half-session of Experiment 5 consisted of three single stimulus matrix CRT task sequences followed by seven multiple stimulus matrix CRT task sequences. The first sequence for each task was a practice sequence; the remaining two or six sequences were experimental sequences. The number of target alternatives (three or six) was counterbalanced over the two single stimulus sequences. The six multiple stimulus sequences were divided into two blocks of three sequences each. Two sequences within each block of multiple stimulus sequences had six-alternative trials and the other had three-alternative trials. One each of the two six-alternative sequences within each block had a density of four and the other had a density of twelve. Likewise, one of the two sequences with three-alternatives had a density of four and the other had a density of twelve. Consequently the effect of practice within matrix density conditions could be determined over the two blocks of three sequences, but only for the six-alternative target conditions.

Within any given session, the target code in one half-session was the non-target background code in the other half-session. The order of occurrence of target code-background code combinations, and the matrix density-number of alternative combinations were balanced both within individual subjects over sessions and between subjects within code conditions. All projection lamps were driven with the power supply set at 14 volts. Hence, the average brightness of the colored dots was only 1.78 foot-lamberts (6.1 cd/m^2) while the average brightness of the achromatic stimuli was 4.5 foot-lamberts (15.4 cd/m^2).

Results

Commission errors. The frequency of errors in the single stimulus matrix task was analyzed within 96-trial blocks in Experiment 4 and within 48-trial blocks in Experiment 5, in both cases as a function of target code, number of alternatives, and practice. Practice was within a half-session for Experiment 4 and over three half-sessions with the same target code for Experiment 5. The square root transformation of these data was used in an analysis of variance which showed no significant effects in either experiment. The overall error rate for the single stimulus matrix task was 5.2 percent in Experiment 4 and 4.8 percent in Experiment 5. An investigation of the distribution of errors over the 16 positions of the matrix showed that there was no systematic pattern of errors as a function of the location of the target in the matrix. Instead, the errors were essentially evenly distributed over all 16 matrix cells for all target codes.

A similar analysis of errors was made over the 12 target-nontarget combinations in the multiple stimulus matrix CRT task. This latter analysis also showed no significant effects of experimental conditions on commission errors. The overall error rate was 2.5 percent. The distribution of errors over the 16 matrix cells as a function of stimulus dimension combinations was carefully examined, but, again, the errors were uniformly distributed.

Choice reaction time. The mean reaction time for all correct responses in the single stimulus matrix CRT tasks was determined for each subject as a function of target code, number of alternatives, and practice. In Experiment 4 the only significant effects were due to target code, $F(3, 21) = 3.22$, $p < .05$, and to the number of alternatives, $F(1, 7) = 203.06$, $p < .01$. An analysis of variance of the single stimulus conditions in Experiment 5 showed that target code $F(3, 21) = 21.21$, number of alternatives, $F(1, 7) = 411.19$, and the Target Code x Number of Alternatatives interaction, $F(3, 21) = 6.26$, were all significant at the .01 level. The only other effect significant for those data was the main effect for practice, $F(2, 14) = 5.77$ $p < .05$.

Figure 8 shows the form of these significant effects. Also shown for comparison in Figure 8 is the effects of target code and number of alternatives from the Simple CRT task in Experiment 3. Figure 8 shows that the introduction of position uncertainty in Experiment 4 was associated with an increase in absolute reaction time compared to the results found in Experiment 3, but that the relative speed of responding to the different codes within the different conditions of target alternatives did not vary. Overall, subjects still responded most quickly to digits and there were no differences in their response times to letters, digits and shapes.

Figure 8 also shows that with increasing amounts of practice the overall reaction times in the single stimulus matrix CRT task decrease. The net effect of this practice phenomenon is that by the end of the last stage of practice in Experiment 5, there was only a small effect which could be attributed to position uncertainty in the single stimulus matrix task relative to the simple CRT task. The form of the code by alternatives interaction in Experiment 5 is also shown in Figure 8. Overall, reaction times to color targets were always longer in this experiment than reaction times to the other codes but the relative times to respond to these other codes varied with the number of target alternatives. Specifically, with three alternatives, reaction time was longer to shapes than to letters and to digits which did not differ from each other. With six

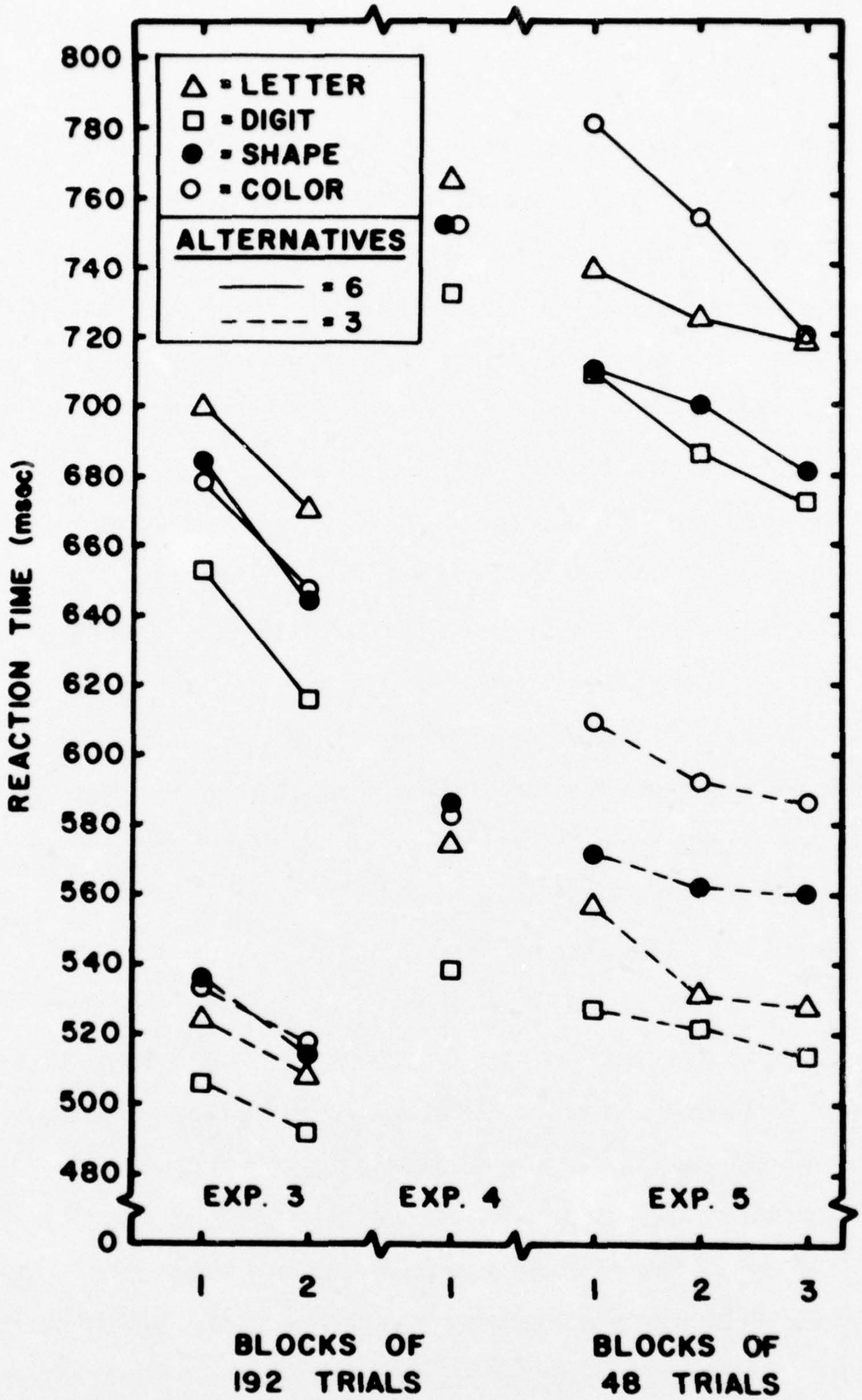

Figure 8. Reaction time as a function of practice, target code, and number of target alternatives in Experiments 3, 4, and 5. There was no target position uncertainty in Experiment 3 but the target could occur in any one of 16 alternative positions in Experiments 4 and 5.

alternatives, however, reaction time was longer to letters than to shapes or digits which did not differ from each other.

Reaction times in the multiple stimulus matrix task did not vary as a function of practice for the six-alternative conditions. Consequently, performance was pooled over practice for the four and twelve density six-alternative conditions. An analysis of variance was performed on the resulting data as a function of target-background combinations, density, and number of alternatives. This analysis showed that the main effects of code combinations, $F(11, 77) = 26.32$, density, $F(1, 7) = 100.81$, and number of alternatives, $F(1, 7) = 278.19$, were all significant at the .01 level. The only other significant effect was due to the Code Combination by Density interaction, $F(11, 77) = 19.860$, $p < .01$. The overall mean reaction time in the multiple stimulus task was shown to be longer when there were six alternatives (852 msec) than when there were three alternatives (722 msec). Both times were much longer than when only a single stimulus appeared in the matrix.

The form of the Code Combination x Density interaction is shown in Figure 9. This figure shows reaction time as a function of density and target codes, with background code as a parameter. It may be seen that an increase in the density of a matrix, i.e., an increase in background visual noise, had a rather large effect on the reaction time except when either the background code or the relevant target code was color. In either type of condition which involved color, there was no effect of display density on reaction time. Separate analyses performed within target code conditions showed that there was an effect due to background code, density and the Background Code by Density interaction when the target code was letters, digits, or shapes, but that none of these effects were significant when the target code was color.

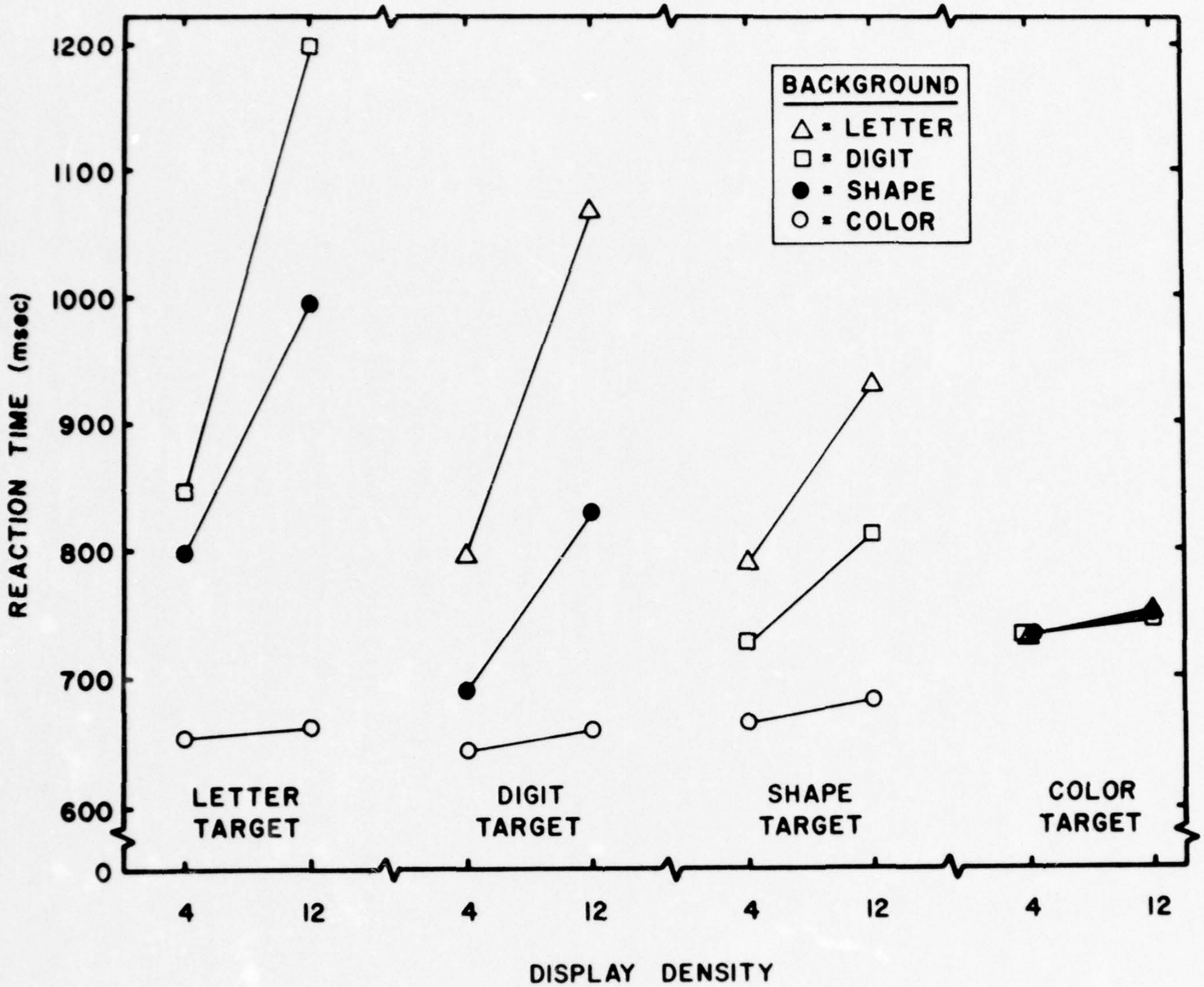

Figure 9. Reaction time in the multiple stimulus matrix CRT task as a function of target code, background code, and display density.

Relative Effectiveness of Color in Choice Reaction Tasks

Since the primary aim of the present series of experiments was to quantify the gains or losses associated with the use of color relative to achromatic codes, the correct CRT measures were used to calculate relative scores. Specifically, the difference between performance with color and with an achromatic stimulus as the target code was divided by the results obtained with achromatic code, i.e.,

$$\text{Percent Difference Score} = \frac{\text{Achromatic-Color}}{\text{Achromatic}} \times 100. \tag{1}$$

These calculations were based on data obtained from each individual long-term subject and were always made within a given experiment when all other task parameters were held constant. Positive scores indicate an advantage of a color, negative scores a disadvantage of a color, both relative to a particular achromatic target code.

Table 3 summarizes the percent difference scores for the three- and six-alternative conditions in both the simple CRT task and the single stimulus matrix CRT task. The former is presented as a function of practice, the latter is shown for only the last stage of practice. With respect to the simple CRT task it may be seen that color was less effective as a target code than letters, digits, and shapes but that the relative disadvantage of color decreased with practice. In terms of the percentage difference scores, the relative disadvantage of color decreased from -5.9 percent to -0.8 percent between the first stage of practice (Sessions 1-4 in Experiment 1) and the last stage of practice (Experiment 8). Analyses of variance of the data from the simple CRT task showed that the following results were significant: For Experiment 1, achromatic code, $\underline{F}(2, 14) = 8.90$; number of alternatives, $\underline{F}(1, 7) = 27.39$ and the Code x

TABLE 3

Percent Difference Scores[a] for Color Codes Relative to Achromatic Codes in Single Stimulus CRT Tasks

Achromatic Code	Simple CRT: Before Practice 3-Choice	Simple CRT: Before Practice 6-Choice	Simple CRT: After Practice 3-Choice	Simple CRT: After Practice 6-Choice	Single Stimulus Matrix CRT 3-Choice	Single Stimulus Matrix CRT 6-Choice
Letters	- 6.7	2.7	-1.1	3.8	-11.8	-1.3
Digits	-16.0	-6.0	-5.1	-3.1	-14.5	-8.3
Shapes	- 6.5	-2.6	0.5	0.3	- 5.3	-6.8

[a]Scores are derived from mean correct reaction times for each condition. Positive scores represent an advantage for color relative to the indicated achromatic code, negative scores represent a disadvantage.

Alternatives interaction, $\underline{F}(2, 14) = 12.64$, all at $\underline{p} < .01$; for Experiment 8, code $\underline{F}(2, 14) = 6.02$, alternatives, $\underline{F}(1, 7) = 9.71$ and Code x Alternatives, $\underline{F}(2, 14) = 4.04$, all at $\underline{p} < .05$. The loss associated with the use of color in the simple CRT task was greatest for the three-alternative digit comparison and the gain with color was greatest for six-alternative letter comparison, the remaining results were not different from one another.

The data shown in Table 3 for the single stimulus matrix CRT task indicate that conditions in that task increased the relative losses associated with color compared to the simple CRT task without substantially changing the order of effects for the different experimental conditions. The overall percent difference scores for the single stimulus matrix task in Experiment 4 was -1.8 percent. Those results were not much different from the results obtained in the simple CRT task and they indicate that position uncertainty per se did not seriously affect the relative effects of color. The data shown for the single stimulus matrix task in Table 3 indicate the effects of position uncertainty <u>and</u> the reduced discriminability of the color codes. The data shown are from the last replication of the single stimulus matrix task in Experiment 5. The rather substantial increase in the relative disadvantage for colors shown in that section of Table 3 seems to reflect the decreased discriminability of colors. However, while the overall disadvantage of color in Experiment 5 was -8.8 percent the relative effects due to comparison code and number of alternatives was not substantially altered. Hence, an analysis of variance of the single stimulus matrix CRTs for Experiment 5 showed that the only significant effects were due to the comparison achromatic code, $\underline{F}(2, 14) = 10.22$, and to the Achromatic Code x Number of Alternatives interaction, $\underline{F}(2, 14) = 15.84$, both effects significant at the .01 level. These effects show that in the single stimulus matrix CRT task, as in the simple CRT tasks, color is least effective relative to digits in the three-alternative condition and most effective relative to letters in the six-alternative condition.

Table 4 summarizes the percent difference scores which were computed from the correct CRTs obtained in the multiple stimulus matrix task. The results shown in Table 4 are divided into three parts, each concerned with a different type of comparison between multiple stimulus matrix display. Part I shows the percent difference scores obtained when comparisons were made between displays in which color was the target stimulus and displays where colors were the background stimuli, both displays employing the same second (achromatic) code. The CRTs obtained when color was the target were subtracted from the CRT when color was the background. An analysis of variance of these data showed that the only significant effect was due to the density of stimuli in the display, $\underline{F}(1, 7) = 8.33$, $\underline{p} < .05$. It may be seen from Part I of Table 4 that a letter, digit, or shape could be identified more rapidly in a background of colored dots than a colored dot could be identified in a background of letters, digits, or shapes, and that this effect was greater for Density 12 displays than for Density 4 displays (13.5% vs. 11.5%), respectively. Considered in a different light these results suggest that color is a better background stimulus for achromatic targets than it is a target stimulus in a background of achromatic stimuli.

Part II of Table 4 is concerned with color as a target code relative to each of the achromatic target codes when the background code was held constant. The difference between performance with color targets and achromatic targets was divided by performance with achromatic targets. An analysis of these data showed that comparison achromatic target code, $\underline{F}(5, 35) = 7.30$, and display density, $\underline{F}(1, 7) = 92.12$, were both significant at the .01 level. The only other effect was due to the Comparison Target Code x Density interaction,

TABLE 4

Percent Difference Scores Associated With Comparisons Made Between Multiple Stimulus Matrix Displays[a]

Target/Background Comparison	Density 4	Density 12
I. Color as target relative to color as background		
C/L vs. L/C	-10.5	-16.4
C/D vs. D/C	-13.6	-14.7
C/S vs. S/C	-10.4	- 9.6
II. Color relative to achromatic target with constant background		
C/L vs. D/L	7.9	29.2
C/L vs. S/L	6.5	16.4
C/D vs. L/D	12.4	36.5
C/D vs. S/D	- 1.0	8.0
C/S vs. L/S	7.7	23.2
C/S vs. D/S	- 3.6	9.6
III. Color relative to achromatic background for constant target		
L/C vs. L/D	22.0	43.9
L/C vs. L/S	17.4	32.4
D/C vs. D/L	19.0	38.0
D/C vs. D/S	6.5	20.5
S/C vs. S/L	15.4	23.5
S/C vs. S/D	8.7	16.0

[a] Difference scores are determined by subtracting the correct CRT obtained with the first target/background combination shown from that obtained with the second shown, and then dividing this difference by the correct CRT obtained with the second target/background condition shown. Abbreviations are as follows: C = color dot, S = geometric shape, D = digit, L = letter; the letter proceeding the slash represents the target code; the letter following the slash represents the nontarget gackground code.

$F(5, 35) = 3.77$, $p < .05$.

Overall, the results summarized in Part II of Table 4 show that for a constant background code, a color target was 12.7 percent better than an achromatic target in a choice reaction task. This advantage for color effect was greater for Density 12 displays than Density 4 displays (20.5% vs. 5.0%) and best relative to when letters were the comparison achromatic target code or when letters were the background stimuli. The gain for color was least, and in fact could be a slight loss, relative to shape targets or to letter and digit targets in a background of shape stimuli. These data seem to back up the value of color as a warning or alerting signal. That is, if one signal must be identified as quickly as possible, the specific hue of a color target can be identified in an array of letters, digits, and shapes better than any other differentiating target code.

A third type of comparison between multiple stimulus matrix displays is shown in Part III of Table 4. This comparison considered the effects of color as a background code relative to each of the achromatic stimuli as background codes when the target code was held constant. The issue involved in this comparison was which background stimuli would be least disruptive (or more facilitating) for the identification of a given achromatic target. An analysis of variance of those data showed that comparison achromatic code, $F(5, 35) = 8.75$, display density, $F(1, 7) = 108.24$, and the Comparison Code x Density interaction, $F(5, 35) = 5.90$, were the only significant effects, all at $p < .01$.

The data shown in Part III of Table 4 show that in general, color was a better background stimulus for an achromatic target than any of the other achromatic codes. The overall advantage of color was 21.9 percent. Color was more effective at the higher density (29.0% vs. 15.0%) and relative to letters as a background code or when a letter was the target stimulus. Color as a background stimulus was least effective relative to when the background consisted of shapes and when the target was a shape stimulus.

Another type of comparison concerning the potential interfering effects of different background stimuli considered the difference between performance with single stimulus displays and multiple stimulus displays. Specifically, the CRTs obtained with multiple stimulus displays were subtracted from the CRTs obtained on the single stimulus display condition which occurred during the same session in Experiment 5. This difference was divided by the mean CRTs obtained with single stimulus displays. An analysis of variance of those data showed that all main effects and all two-way interactions were significant at the .01 level; the three-way interaction was nonsignificant. The F-ratios were as follows: code comparison, $F(11, 77) = 33.72$; number of alternatives, $F(1, 7) = 173.37$; display density, $F(1, 7) = 150.93$; Code x Alternatives, $F(11, 77) = 2.86$; Code x Density, $F(11, 77) = 19.55$; and Alternatives x Density, $F(1, 7) = 12.33$.

These data are summarized in Table 5. As may be seen, the presence of any nontarget background stimuli always led to an increase in CRT. The extent of the loss decreased as the number of alternative targets increased but the relative loss in performance increased as the display density increased, the latter was more evident when there were three target alternatives than when there were six target alternatives. Generally there was very little loss in performance when an achromatic background was added to a color target or when a color background was added to an achromatic target. The relative amount of loss in performance was substantial when achromatic background stimuli was added to an achromatic target display; the extent of this relative loss increased in order from shape-digit to shape-letter to letter-digit combinations.

TABLE 5

Percent Difference Scores for Multiple Stimulus Displays Relative to Single Stimulus Displays[a]

Display Conditions	Density 4		Density 12	
	3-Choice	6-Choice	3-Choice	6-Choice
L/D vs. L	-44.2	-28.8	-112.1	-77.9
L/S vs. L	-31.2	-18.7	- 67.3	-47.1
L/C vs. L	-10.3	0.5	- 11.6	- 1.1
D/L vs. D	-43.6	-27.9	- 97.5	-66.0
D/S vs. D	-19.4	-11.1	- 48.2	-30.1
D/C vs. D	-12.3	1.7	- 10.8	- 4.4
S/L vs. S	-26.5	-23.6	- 54.4	-38.6
S/D vs. S	-20.0	-11.9	- 35.1	-25.1
S/C vs. S	- 5.8	- 6.2	- 12.8	- 5.9
C/L vs. C	-11.8	- 7.5	- 7.0	-19.2
C/D vs. C	-10.1	- 6.0	- 13.7	- 6.4
C/S vs. C	-11.6	- 8.0	- 16.2	- 8.8

[a]Difference scores are determined by subtracting the correct CRT obtained with multiple stimulus displays from the CRT obtained with single stimulus displays and then dividing this difference by the CRT obtained with single stimulus displays. Abbreviations are the same as those described in Table 4.

Summary of Color Effects in Choice Reaction Tasks

In summary, when a subject's task is to identify a single target as rapidly as possible, color is either the least or the most effective target code depending upon whether the single target stimulus is presented in an otherwise empty field or in a field which also contains stimuli from another nontarget stimulus code category. In the former case, the sex of the subject may be an additional factor; females generally respond more quickly to color targets than males. The relative effectiveness of colors in the case of multiple stimulus displays may be due to the fact that color is an essentially nonspatial stimulus feature while each of the achromatic stimulus codes examined were spatial (i.e., shape) codes. In a heterogeneous stimulus field, a colored target may be located and subsequently identified without much interference from the shape encoded achromatic background stimuli. Conversely, the subject may be able to locate and identify a particular achromatic target in a visual field of nontarget colored dots with less interference from the color dots than from other spatially encoded but irrelevant achromatic stimuli.

It is important to note that the loss associated with colored targets in the single stimulus conditions and the relative gain associated with colors in the multiple stimulus display conditions were never very large. The maximum loss in the former case was -16 percent, the maximum gain in the latter case was +36.5 percent. It should also be noted that color had the least gain or loss relative to familiar geometric shapes and the most gain or loss relative to letters and digits. These comparative values suggest that letters and digits are processed differently than colors and that familiar shapes may be processed in a manner similar to that used for colors.

SEARCH AND LOCATE TASKS

Method

As shown in Table 2 there were two experiments which required the long-term subjects to search for and then to indicate the location of a single specified target. The stimulus which was to serve as the target for any given trial was first presented in the display panel labeled LOCATE in Figure 2. The large matrix display consisted of one occurrence of the target and either three or eleven nontarget background stimuli. The matrix display was presented 200 msec after the target was specified in the locate panel. Both displays remained illuminated for four seconds or until the subject specified the location of the target by pressing one of the four quadrant buttons with the index finger of his left hand.

There were always 48 trials within a sequence of trials and 100 msec between successive trials in a sequence. The total number of stimuli in the matrix display (Density 4 or Density 12) was constant over a 48-trial sequence but varied over successive sequences. The stimulus code which could serve as a target code was constant over successive sequences within each half of an experimental session, but varied over successive half-sessions. The voltage used to activate lamps was always set at 18 volts; the average brightness of colors was 3.19 foot-lamberts (10.9 cd/m^2) and of achromatic codes was 8.0 foot-lamberts (27.4 cd/m^2).

<u>Experiment 6</u>. Experiment 6 used only unidimensional stimulus displays. The specific stimuli used in the displays with Density 4 were always one of the 15 possible combinations of four different stimuli drawn without replacement from the six stimuli within a given stimulus code. The stimuli used in the

displays with Density 12 were one of the 90 possible combinations of six different stimuli drawn with the restriction that two stimuli would occur once each, two would occur twice each, and two would occur three times each. The spatial arrangement of stimuli over the 16 cells of the matrix was such that one stimulus (when the density was 4) or one blank cell (when the density was 12) occurred once in every row and once in every column. The stimuli designated as the target always occurred once and only once in the matrix. The target could be any one of the six possible stimuli within a stimulus code or any one of the three possible stimuli within the sets of three alternative targets described earlier in connection with the choice reaction tasks. The different stimulus combinations, the spatial arrangement of stimuli, the stimulus designated as the target, and the quadrant within which the target was located was balanced within and between 48-trial sequences. Figures 4B and 4D show two examples of the unidimensional location displays. Familiar geometric shapes were used as stimuli in the Density 4 display shown in Figure 4B; the target was the triangle located in Quadrant 4. Letters were used as stimuli in the Density 12 display shown in Figure 4D; the target was the letter K shown in the third quadrant.

Each subject was run in two experimental sessions in Experiment 6. Each session consisted of two practice and eight experimental sequences using one unidimensional stimulus code, followed by two practice and eight experimental sequences using another unidimensional code. All four stimulus codes were used once each over Sessions 1 and 2. The order of codes over half-sessions and sessions was balanced over subjects. The two practice sequences both used Density 12 displays and both used six-target alternatives. The eight experimental sequences within a half-session were arranged so that each combination of the two levels of display density and the two levels of the number of target alternatives would occur once in the first four and once in the second four sequences. There was about 30 seconds between successive sequences within a half-session. A five minute rest interval separated the two halves of each session.

Experiment 7. Experiment 7 used the unidimensional displays already described and bidimensional displays which were constructed from those unidimensional displays. One-half of the stimuli used in each of the unidimensional displays were changed so they would be from a second stimulus code. Rather than using only the top or the bottom half of each IEE film, the bidimensional displays had one-half of the stimuli drawn from each half of a given film. A table of random numbers was used to select two stimuli to be changed in each unidimensional Density 4 display. Similarly, for each unidimensional Density 12 display, two stimuli were changed in each of two rows selected at random and one stimulus was changed in each of the remaining two rows; the particular stimuli changed in each row was randomly determined.

As a result of the changes made, each bidimensional display contained two or six stimuli from one stimulus dimension, called the target code, and another two or six additional stimuli from a second nontarget background code. In the former case, one stimulus was designated the target and the remaining stimuli would represent nontarget stimuli in the target dimension. When the display had a density of 12, the five nontarget stimuli in the same dimension as the target could consist of from two to five of the nontarget stimuli in the target dimension. The nontarget background stimuli could also consist of from two to five of the six alternatives in the set of background stimuli.

Each subject was run through six daily sessions in Experiment 7. Each session was divided into two half-sessions so that the stimulus dimension which served as target code in one half-session served as the background code in the other half-session, and vice versa. All six stimulus alternatives within a stimulus dimension could be specified as the target in Experiment 7. Each half-session of Experiment 7 consisted of one practice and two experimental sequences of unidimensional trials followed by one practice and six experimental sequences of bidimensional trials. The practice sequences always consisted of Density 12 matrices. The experimental sequences consisted of an equal number of Density 4 and Density 12 sequences. In the six experimental sequences of bidimensional displays the two levels of density were run in random order within three successive blocks of two sequences each. As in Experiment 6, there was about 30 seconds between successive sequences in each half-session of Experiment 7 and there was a five-minute break between the two halves of each session.

To encourage maximum levels of performance in Experiment 7, each subject was given a bonus for every session in which his overall mean search time for that session exceeded his overall mean search time from the two sessions of Experiment 6.

Results

Commission errors. The frequencies of error responses for the unidimensional display conditions of Experiments 6 and 7 were analyzed as a function of target code, display density, number of target alternatives (for Experiment 6 only), and practice. Practice was based on the two 48-trial sequences per combination of code, density, and the number of alternative conditions in Experiment 6 and on the three replications of each unidimensional code by density combination over sessions in Experiment 7. The square root transformation of these error data was used in analyses of variance. The analysis of data from

Experiment 6 showed that the number of target alternatives was the only significant source of variation, $F(1, 7) = 9.62$, $p < .05$. There were, on the average, 6.7 percent errors when there were three-target alternatives and 7.9 percent errors when there were six-target alternatives. No significant sources of variation were found for commission errors in the unidimensional display condition of Experiment 7. The overall mean error rate for that experiment was 7.9 percent.

An analysis of the frequency of commission errors was also done for the bidimensional display conditions of Experiment 7. The square root transformation of those data were analyzed as a function of the 12 target code-background code combinations and the two levels of density. This analysis of variance showed that there were no significant sources of variation. The range of errors rates went from a low of 6.6 percent for the letter target-color background condition to a high of 8.1 percent for the color target-digit background condition.

An analysis of errors in terms of the correct quadrant position of the target was done for both unidimensional and bidimensional display conditions. In no case was there any evidence for a systematic relationship between error response and the target location in the matrix display.

Search/Locate time. The mean time required for all correct location responses in the unidimensional display conditions of Experiments 6 and 7 were analyzed as a function of target code, display density, number of target alternatives (for Experiment 6 only), and practice. The only significant effects in Experiment 6 were due to the main effects of display density $F(1, 7) = 251.97$, the interaction between display density and target code, $F(3, 21) = 11.14$, and the interaction between display density and the number of target alternatives, $F(1, 7) = 10.31$, all at $p < .01$.

The interaction between density and alternatives was shown to be due to the absence of an effect for the number of alternatives with Density 4 displays (mean search time was 879 msec) while search time was greater for three than six alternatives (1167 vs. 1132 msec) with Density 12 displays. The density main effect was due to a substantial increase in search time as density increased from four to twelve (879 vs. 1149 msec). The Density x Code interaction was due to a change in the ordering of code conditions at the two levels of density. From shortest to longest search times, the order of codes at Density 4 was Digits, Letters, Shapes, and Colors; the only pairwise difference which was significant was the digit-color difference. The corresponding ordering of codes at Density 12 was Shapes, Colors, Digits and Letters; there was no difference between adjacent pairs in this ordering but all non-adjacent conditions in the ordering were significantly different.

The analysis of search time in the unidimensional conditions of Experiment 7 showed that all main effects were significant at the .01 level: For practice, $\underline{F}(2, 14) = 11.77$, for density, $\underline{F}(1, 7) = 187.03$, and for target codes, $\underline{F}(3, 21) = 6.20$. The only other significant effect found was for the interaction between density and code, $\underline{F}(3, 21) = 17.25$, $\underline{p} < .01$. The form of these effects are shown in Figure 10. This figure shows search time as a function of practice and density for the unidimensional code conditions in both Experiments 6 and 7. Only the data for the six-alternative conditions of Experiment 6 are shown in the figure. It may be seen that overall level of performance improves considerably between Experiment 6 and Experiment 7 and then continues to improve over the three successive replications of the unidimensional code conditions in Experiment 7. As may be seen in Figure 10, there was no difference between code conditions in Experiment 7 when only four items appeared in the matrix. However, when there were twelve items in the matrix the search time for letters and digits was significantly longer than for shapes and colors.

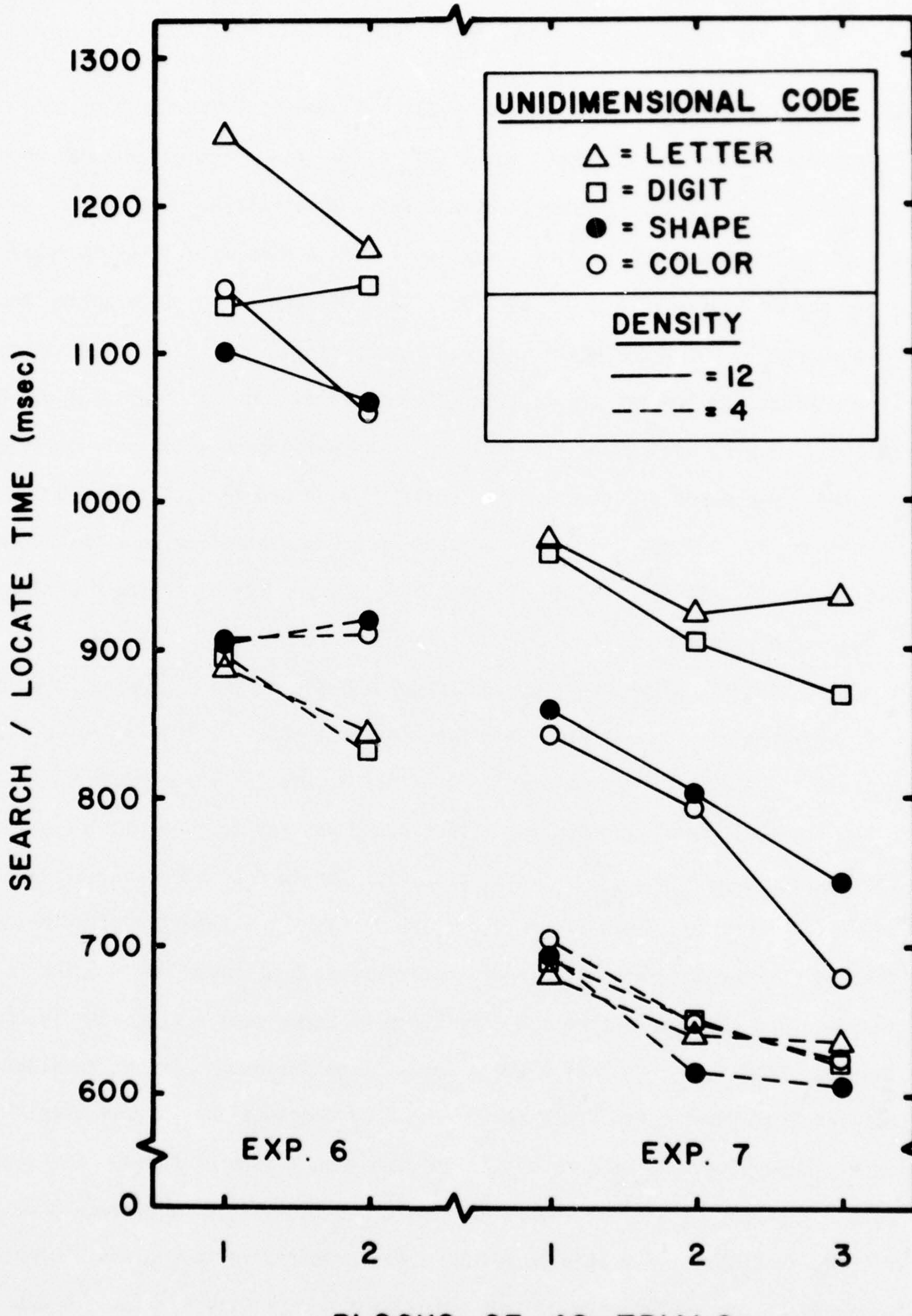

Figure 10. Search and location time in the unidimensional search task as a function of practice, target code, and display density.

Search times for the bidimensional display condition in Experiment 7 were analyzed as a function of the twelve levels of target code-background code combinations, the two levels of density , and the three levels of practice within each half-session. This analysis showed that the only significant effects were due to code, $F(11, 77) = 8.30$, density, $F(1, 7) = 201.75$, and the Code by Density interaction, $F(11, 77) = 19.24$, all at $p < .01$. The form of these effects is shown as solid lines in Figure 11. It may be seen that density had a greater effect when the displays contained letters and digits than when they contained either shapes or colors or both, as either the target code or the background code. It may also be seen that search times were generally longer when the target code and background code consisted of combinations of letters and digits and that search times were generally shorter when either the target code or the nontarget background code was color.

In an attempt to simplify the analysis of search time performance in the search and locate task, all of the data in Experiment 7 were pooled over practice. There were no interactions involving practice for the unidimensional display conditions and no effects involving pracitce for the bidimensional display conditions. Using the data from both the unidimensional and the bidimensional display conditions it was possible to generate an orthogonal design consisting of four levels of target code, four levels of background code and two levels of density. An analysis of variance of those data showed that all effects were significant at the .01 level: $F(1, 7) = 209.36$ for density; $F(3, 21) = 8.20$, 36.44, 31.85, and 19.55 for target code, nontarget code, Target Code x Density, and Nontarget Code x Density, respectively; and $F(9, 63) = 6.55$ and 6.50 for Target Code x Nontarget Code and Target Code x Nontarget Code x Density.

These significant effects are shown in Figure 11, which shows search/locate

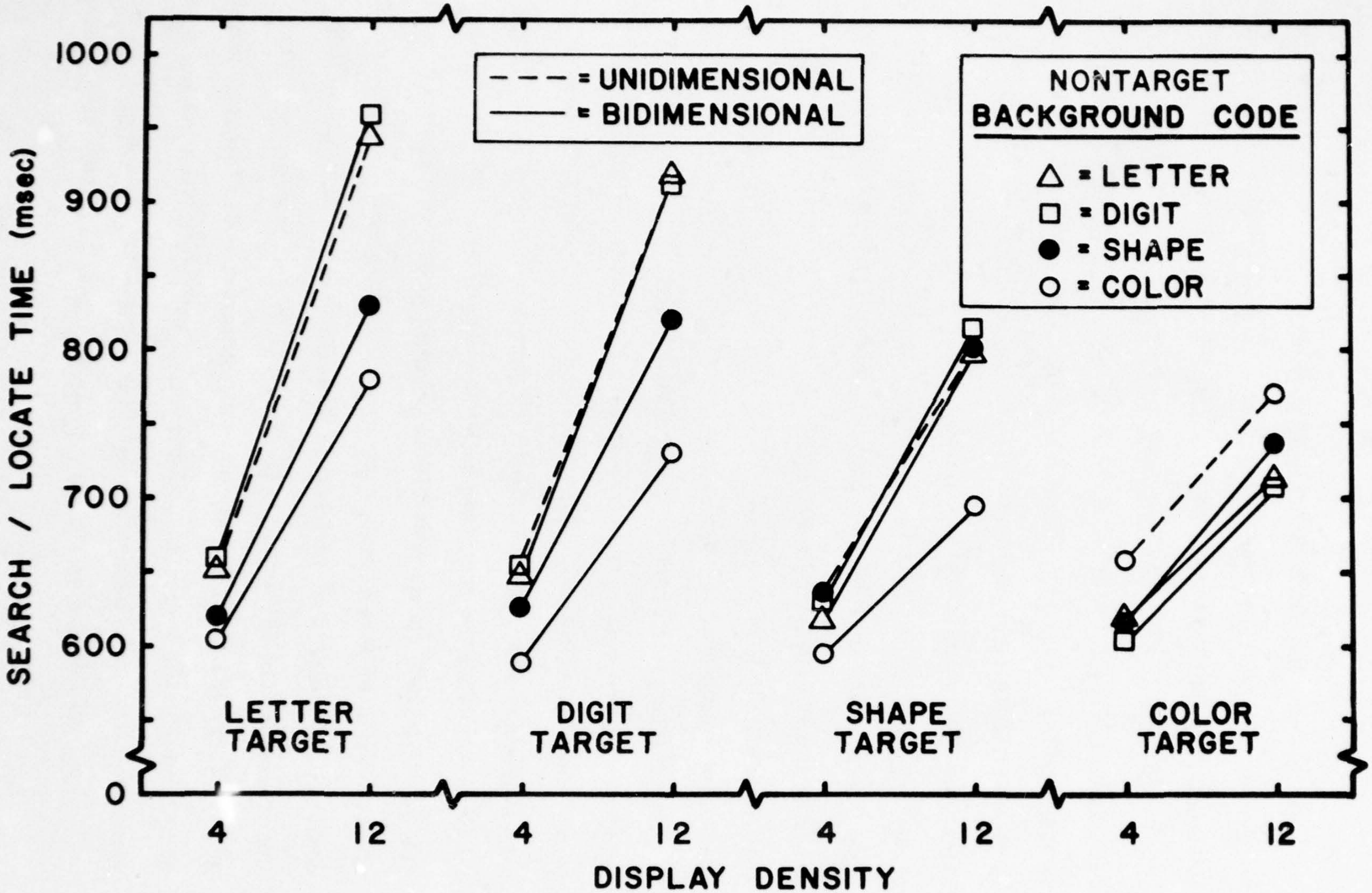

Figure 11. Search and location time in the unidimensional and the bidimensional search tasks as a function of target code, nontarget code, and display density.

time as a function of density and background codes separately for each target condition. Pairwise comparisons showed that the effect of density was significant for all 16 target code-background code combinations. When the display consisted of only four items there were only very small differences among code conditions. With letter or digit targets, color in the background leads to shorter times than letter or digit backgrounds, but color is no better than shape as a background, and letter and digit backgrounds do not differ from shape background. Within shape or color target conditions only the two extreme conditions differ. When comparisons are made across target codes but within background codes the differences are also very small. With letter or shapes as background codes there are no pairwise differences among target code conditions. With digits as background codes, the color target code led to shorter locate times than digit or letter target codes but there was no difference between colors and shapes as target codes and shape targets did not differ from digit or letter targets. When color was the background code there were no differences between digits, shapes, or letters as target codes and all three bidimensional conditions led to shorter locate times than the unidimensional color display.

The differences within target code conditions were much larger when the density of the displays was increased to twelve items. With letter and digit targets, colors in the background led to shorter locate times than when shapes were in the background, and both color and shapes in the background led to shorter locate times than when letters or digits were in the background. When shapes were targets, colors in the background led to shorter locate times than letters, shapes or digits, and the latter three did not differ. When a color was the target, the three bidimensional displays led to the same overall levels of locate time and all three were better than the unidimensional color display.

The four target conditions were all different from one another when comparisons were made within the nontarget letter or the nontarget digit background code. When shapes were the nontarget background code color targets led to shorter locate times than shape, digit, or letter targets and the latter three did not differ from one another. When colors were the nontarget background code shapes were better targets than digits and both shapes and digits were better than color or letter targets; the latter two did not differ.

Relative Effectiveness of Color in Search/Locate Tasks

The relative effects of color in the search tasks of Experiments 6 and 7 were computed for each subject in a manner similar to that used for the choice reaction tasks. Each subject's mean search time with color was subtracted from his mean search time with an achromatic comparison code and the difference was divided by the search time for the achromatic code. An analysis of variance of the data from the unidimensional display condition of Experiment 6 showed that the only significant effect was due to the Comparison Code x Density interaction, $F(2, 14) = 6.95$, $p < .01$. A similar analysis of the data derived from the unidimensional display condition of Experiment 7 showed that the only significant effects were due to the main effects of codes, $F(2, 14) = 10.35$, and density, $F(1, 7) = 24.37$, and to the Code x Density interaction, $F(2, 14) = 12.33$, all effects significant at the .01 level.

Table 6 summarizes the gain or loss scores associated with the six-alternative color conditions relative to the six-alternative letter, digit and shape conditions for the unidimensional displays. The data shown in the table are broken down by stage of practice: Experiment 6 versus the last replication of each unidimensional code condition in Experiment 7. It may be seen that before

TABLE 6

Percent Difference Scores[a] for Color Codes Relative to Achromatic Codes in Unidimensional Search/Locate Displays

Comparison Achromatic Code	Before Practice Density 4	Before Practice Density 12	After Practice Density 4	After Practice Density 12
Letters	-7.76	8.96	1.61	27.33
Digits	-6.68	3.39	-0.15	21.48
Shapes	0.60	-0.37	-2.83	8.19

[a] See footnote for Table 3.

subjects had received practice, there was a relative loss associated with color codes in the Density 4 locate displays and a relative gain associated with color codes in the Density 12 displays. However, these effects varied with the comparison achromatic code; there were no differences between the two levels of density when the effectiveness of color was considered relative to shapes but density had a significant effect when color was compared to letters and digits.

After the subjects had received practice in the unidimensional locate task the relative effectiveness of color increased (or, the relative loss decreased). It may be seen that color was more effective in the higher density displays; the increase between four- and twelve-density displays after practice was significant for all comparisons. There were no differences between comparison codes for the Density 4 displays, but for Density 12 displays the effectiveness of color relative to letters and digits was much greater than the effectiveness of color relative to shapes. It should be noted that the relative effects of color were never large for the Density 4 displays and also that the effects of color relative to shapes were not very large for either level of density.

The relative effectiveness of color in the bidimensional search/locate displays was examined in three different types of comparisons. The first comparison was done within comparable display conditions; mean search time when color was the target code was subtracted from mean search time when color was only a background code, and this difference was then divided by search times obtained when color was only a background code. Note, the number of color stimuli in a given display which contained color stimuli was the same whether or not the target was a color. These data were used in an analysis of variance which showed that the comparison achromatic code main effect, $\underline{F}(2, 14) = 6.04$, was significant at the .05 level, and that display density, $\underline{F}(1, 7) = 12.98$, and the Code x Density interaction, $F(2, 14) = 3.29$ were significant at the .01 level.

Part I of Table 7 summarizes the percent difference scores obtained in the within-display comparison. It may be seen that while the overall effects were not large (-.42%) there was an advantage for color as a target relative to letters as a target in the Density 12 color-letter displays. The three effects shown for the Density 12 displays all differed from one another, but there were no differences among the Density 4 displays. There was an increase in the effectiveness of colors relative to letters between the Density 4 and Density 12 displays but density had no effect on the other two sets of difference scores.

Comparisons between bidimensional displays were made with either the nontarget background code or the target code held constant. In both cases, mean search time with color in the display was subtracted from mean search time without color in the display and the difference was divided by search time without color in the display. In both analyses, color in a display led to a general decrease in search time relative to when only achromatic codes were used. Hence, there was an overall advantage for color targets (+9.32%) relative to achromatic targets when background codes were achromatic and there was an overall advantage for achromatic targets when colors were in the background (+9.62%) relative to when only other achromatic stimuli were in the background.

Analyses of variance showed that these effects were not uniform over levels of the independent variables. The analysis of the relative effectiveness of color target data (Part II of Table 7) showed that density, $F(1, 7) = 68.16$, was significant at the .01 level and that the Code x Density interaction, $F(5, 35) = 3.03$, was significant at the .05 level. The main effect of code was nonsignificant. The analysis of the relative effects of color background stimuli relative to only achromatic background stimuli showed again that the only significant

TABLE 7

Percent Difference Scores Associated with Comparisons Within and Between Bidimensional Search/Locate Displays[a]

Target/Background	Density 4	Density 12
Within Bidimensional Displays		
I. Color as a target relative to color as a background only		
C/L vs. L/C	-2.13	8.35
C/D vs. D/C	-2.49	3.44
C/S vs. S/C	-3.59	-6.08
Between Bidimensional Displays		
II. Color relative to achromatic target with constant background		
C/L vs. D/L	4.34	21.87
C/L vs. S/L	-0.88	10.59
C/D vs. L/D	8.74	26.20
C/D vs. S/D	4.24	12.91
C/S vs. L/S	0.43	11.66
C/S vs. D/S	0.94	10.04
III. Color relative to achromatic background with constant target		
L/C vs. L/D	8.29	18.43
L/C vs. L/S	2.17	6.09
D/C vs. D/L	9.19	20.20
D/C vs. D/S	5.64	10.57
S/C vs. S/L	3.58	12.67
S/C vs. S/D	4.74	13.88

[a] See footnote for Table 4.

effects were the main effect of density, $\underline{F}(1, 7) = 39.90$, and the interaction between code and density, $\underline{F}(5, 35) = 2.86$, $\underline{p} < .01$ and .05 respectively.

Pairwise comparisons of the data shown in Part II of Table 7 showed that the relative effectiveness of color was always greater with the Density 12 than the Density 4 displays. Within the Density 4 displays the effectiveness of color relative to letters with digit background stimuli was greater than any other comparison except color relative to digit targets with letters in the background. Within the Density 12 displays the effectiveness of color targets relative to digits or letters with letters and digits as background stimuli was greater than any other comparison.

Pairwise comparisons of the data shown in Part III of Table 7 showed that there was an increase in the relative effectiveness of performance with color as a background code as density increased, except for the comparisons involving displays with shape as a background and with letter or digit targets. Within either level of density color was a more effective, less interfering, background in comparison to letter or digit background or target condition. Color was least effective as a background relative to conditions which involved shapes, either as the comparison background or as the common target.

When search times for a target in a bidimensional display were evaluated relative to search times for the same target in a unidimensional display the search times in bidimensional displays were generally superior; overall, the relative advantage of bidimensional displays was 5.54 percent. Table 8 shows the mean percent difference scores obtained when performance with bidimensional displays was subtracted from performance with unidimensional displays and these differences were divided by performance with unidimensional displays. An analysis of variance of those data showed that only the effects of code comparisons,

TABLE 8

Percent Difference Scores Comparing Unidimensional and Bidimensional Search/Locate Displays[a]

Comparison Displays	Density 4	Density 12
L/D vs. L	-1.61	- 3.60
L/S vs. L	3.41	9.91
L/C vs. L	8.30	19.24
D/L vs. D	-0.52	- 0.31
D/S vs. D	5.53	10.52
D/C vs. D	0.09	18.84
S/L vs. S	-0.42	0.54
S/D vs. S	4.50	0.24
S/C vs. S	6.28	10.61
C/L vs. C	6.63	10.20
C/D vs. C	6.16	9.17
C/S vs. C	6.70	- 6.57

[a] See footnote for Table 5.

$\underline{F}(11, 77) = 6.11$, and the Code Comparison by Density interaction, $\underline{F}(11, 77) = 3.16$, were significant, both at the .01 level.

For the Density 12 displays with letter targets the improvement in performance with color in the background was significantly different from the decrease in performance with digits in the background. None of the other changes in performance caused by adding a second, irrelevant code to the letter target displays were different from one another. Similar results were obtained when a second stimulus code was added to the displays with a digit target. Specifically, the Density 12 displays with a digit target and with colors as a background stimuli led to an improvement in performance relative to unidimensional digit displays which was different only from the change in performance caused by adding irrelevant letters to the display. No other pairwise difference among digit target displays was significant. There were no differences among the six-percent difference scores concerned with shape targets. Finally, the relative loss in performance caused when shapes were introduced as irrelevant stimuli in a Density 12 display with color targets was different from any of the other difference scores and none of the latter differed from each other.

Summary of Color Effects in Search/Locate Tasks

In summary, it may be concluded that the use of color in search/locate tasks generally leads to a relative decrease in search time. The relative increase in performance is true for both unidimensional displays and for bidimensional displays. In either case, the gain in performance may be as great as 27 percent but there may also be a loss in performance as great as -8 percent. The greater gains are more likely to occur for the more dense displays and when colors are the target code in bidimensional displays involving irrelevant letters or digits. The relative advantage of color is least (or the relative disadvantage is greatest) in Density 4 displays or when the comparison display codes included familiar geometric shapes.

The relative advantage of color in a search/locate display, either as a target code or as an irrelevant background stimulus may be due to the fact that the nonspatial color stimuli are easily segregated from the spatially encoded letters, digits or familiar geometric shapes. If this is so, the effective density of the search display is reduced since the subject may disregard all color stimuli if they are irrelevant or attend to only the color stimuli if a specific color happens to be the target. If this explanation of the relative effectiveness of color is correct, it is interesting to speculate how effective colors would be if the target were not designated until after the display had been terminated and if the target code could vary from one display (i.e., one trial) to the next. Would the subject inadvertently disregard the color stimuli when they were targets or overly attend to them if they were irrelevant?

The apparent similarity between colors and shapes, both as target stimuli and as irrelevant background stimuli, raises again the possibility that these two stimulus codes are processed in the same manner and that both are processed differently from letters or digits. As was indicated in the discussion concerning color effects in choice reaction tasks, the possibility of colors and shapes being processed in a similar manner, as well as the distinction between color as a nonspatial stimulus feature relative to shape features, needs further evaluation by future studies.

IDENTIFICATION TASKS

Method

The task of the long-term subjects in Experiment 9 was to identify all of the stimuli they could remember from multiple target displays. The multiple target displays consisted of four or eight stimuli. Figure 4C shows one of the target displays used in the identification experiment. The display shown in this figure is a bidimensional letter-color display with a density of eight targets, four letters and four color dots.

The stimuli in each display were distributed over the four by four matrix so that there were an equal number of stimuli per row and column. The specific stimuli used in each unidimensional identification display were selected so that one-half of the targets were sampled from the first three stimuli in a given target code and the other half were sampled from the second three stimuli in that code. An additional constraint was that no stimulus could occur more than twice in any given display. This procedure for sampling stimuli yielded 36 possible combinations of stimuli for the Density 4 displays and another 36 for the Density 8 displays. Two different variations of bidimensional displays could be constructed from any given unidimensional display. Specifically, the stimuli used from the first half of one target code were combined with the stimuli from the second half of another target code or vice versa. All two-way combinations of the four codes were available in the six films used in the IEE display units.

Each trial in Experiment 9 began with the presentation of the message "FULL" in the small display panel labeled IDENTIFY in Figure 2. This stimulus was designed to serve as a warning signal; it preceded the multiple target display by 200 msec. The warning signal and the multiple target display were jointly presented to the subject for a maximum duration equal to 400 or 800 msec (for the Density 4 and 8 displays, respectively) or until the subject began his series of identification responses, whichever interval was shorter. The average brightness of color targets was 3.19 foot-lamberts (10.9 cd/m^2) and the average brightness of achromatic targets was 8.0 foot-lamberts (27.4 cd/m^2). The subject was allowed 1000 msec per displayed target to make his identification responses, but once he had reported all he could remember he could end the response interval and hence the trial by pressing a button called the terminate button. As a result of these procedures, the subject could control both the exposure duration of the multiple target display and the duration of the response interval.

The subject identified all targets he remembered from each display by pressing the buttons which corresponded to those targets. The buttons used and the mapping of targets onto buttons were the same as those used in the choice reaction experiments. In the unidimensional display condition the top three buttons corresponded to the first three stimuli in the target code and the bottom three buttons corresponded to the second set of three stimuli in that target code. In the bidimensional display conditions the top three buttons corresponded to the first three stimuli in one code and the bottom three buttons corresponded to the last three stimuli in the second target code. Each subject was encouraged to respond as quickly and as accurately as possible, and in addition, a monetary incentive was designed to encourage maximum accuracy. Specifically each subject was told he would earn a bonus of 50¢ in all sessions where his overall accuracy was 85 percent or more.

There were a total of twenty trials per sequence and 100 msec between successive trials within a sequence. Each sequence of trials consisted of ten trials with display density of four targets and ten trials with a display density of eight targets. The display density was constant over blocks of five successive trials and was alternated over successive blocks of five trials. One-half of the sequences began with Density 4 and the other half began with Density 8.

A typical session consisted of a practice sequence and five experimental sequences with unidimensional displays followed by a practice sequence and five experimental sequences with bidimensional displays. All subjects experienced each of the six possible bidimensional conditions over six successive sessions. For four subjects the first three targets in one code (e.g., letters C, H, K,) were associated with the last three targets in the second code (e.g., digits 5, 6, 7). The other four subjects had the last three targets of one code (e.g., letters N, P, S) and the first three targets of the second code (e.g., digits 2, 3, 4). All subjects experienced a different unidimensional target condition on each of the first four experimental sessions and then had two of these unidimensional target conditions replicated in experimental sessions 5 and 6. The order of unidimensional and bidimensional display conditions within sessions and the order of target code conditions over sessions was counterbalanced over subjects. Before beginning the first experimental session each subject was run through a practice session which was identical in all respects to an experimental session except for maximum stimulus duration which was 300 msec per stimulus (1200 and 2400 msec for the Density 4 and 8 displays, respectively). There were about 30 seconds between sequences and five minutes between unidimensional and bidimensional halves of each session.

Results

Since each of the four unidimensional target code conditions occurred once each during the first four experimental sessions, and then each of two occurred a second time during the last two experimental sessions, the bulk of the results reported for the unidimensional condition are derived from only the first four sessions. The results reported for the bidimensional conditions are derived from all six experimental sessions.

Subject terminated stimulus and response intervals. The first response made on each trial was assigned to one of two categories as a function of whether it terminated the stimulus exposure or occurred after the maximum stimulus duration. These data showed that the subjects rarely voluntarily terminated the stimulus. Furthermore, there were no systematic relationships between the frequency of subject-terminated stimulus exposures and the independent variables of the experiment. Hence, on the average, a subject terminated only 1.0 and 0.8 out of every 50 trials in the unidimensional and bidimensional display conditions, respectively. Several subjects went through an entire session without ever terminating a stimulus and the maximum number of terminations for any subject was only 4 out of the 100 trials in a half-session.

Most subjects did frequently use the terminate button to end the response interval. The frequency of trials which were terminated by the subjects was determined separately for the unidimensional and bidimensional trials, as a function of target code condition and density in each case. The square root transformation of those data was used in analyses of variance which showed that there were no significant experimental effects in the bidimensional condition and that only density was significant in the unidimensional condition, $F(1, 7) = 7.13$, $p < .05$. On the average, subjects terminated 64.7 percent of the trials in the bidimensional condition and 50.0 and 57.0 percent of the trials in the unidimensional Density 4 and 8 conditions, respectively.

A separate analysis was performed on the mean time which elapsed between the onset of the multiple target display and the subject's termination of the trial. To take into account the absence of subject-terminated trials in some sessions, these latency data were weighted by the frequency of times the subject used the terminate button. Only seven subjects were used to analyze these data since one subject never used the terminate button. These data were analyzed separately for the unidimensional and bidimensional conditions, in each case as a function of target code and density. The analyses showed that target code, $\underline{F}(8, 18) = 4.13$, $\underline{p} < .05$, density, $\underline{F}(1, 6) = 67.31$, $\underline{p} < .01$, were the only significant effects for the unidimensional condition; only density, $\underline{F}(1, 6) = 62.48$, $\underline{p} < .01$, was significant for the bidimensional condition. In the unidimensional condition subjects terminated shape trials more quickly than letter trials (4010 vs. 4959 msec) but the latency of termination of shape trials and letter trials did not differ from the termination latency of digit and color trials (4786 msec), nor did the latter two conditions differ from each other. The trial termination latencies in the unidimensional condition were 3486 msec and 5496 msec for Density 4 and 8, respectively; corresponding times were 3104 msec and 5226 msec in the bidimensional condition.

Commission errors. The number of incorrect (commission error) responses per trial was determined separately for the unidimensional and the bidimensional display conditions, as a function of target code (or code combination) and density in each case. An analysis of those data for the unidimensional displays showed that target code, $\underline{F}(3, 21) = 10.11$, density, $\underline{F}(1, 7) = 18.21$, and Target Code x Density, $\underline{F}(3, 21) = 5.35$, were significant at the .01 level. It was determined that subjects made more commission errors for Density 8 displays than for Density 4 displays (1.14 vs. 0.48 per trial). It was also shown that errors increased over code conditions (0.61, 0.76, 0.88, and 1.00 per trial for digit, letter, shape, and color targets, respectively). All nonadjacent scores in the rank ordering were significantly different from one another. The magnitude of the code effect was also shown to be greater for the Density 4 displays than for the Density 8 displays.

An analysis of the commission error data from the bidimensional condition showed that target code combination, $F(5, 35) = 4.70$, density, $F(1, 7) = 28.27$, and the within-target code combination effect, $F(1, 7) = 12.35$, were all significant at the .01 level. The only other effect significant for these data was an interaction between code combination and the within-target code combination effect, $F(5, 35) = 3.12$, $p < .05$. It was shown that more commission errors were made for Density 8 than Density 4 displays (.49 vs. .17 per trial, respectively). It was also shown that the number of commission errors was the same for the shape-color (.42) and the letter-digit (.40) combinations but that the shape-color combination had more errors than all other combinations. The letter-digit combination had no more commission errors than the letter-color (.31) combination but was different from the letter-shape (.29), digit-color (.28), and the digit-shape (.28) combinations. These differences seem too small for practical significance.

To clarify the nature of the code combination by within-code combination interaction, the number of commission errors in the unidimensional display conditions were halved to yield scores which should have been roughly comparable to the number of commission errors obtained for each code within the bidimensional code combinations. Then, the unidimensional and bidimensional data were combined to generate a 4x4x2 factorial design in which each of the four levels of target code could be examined over displays in which each of four codes appeared as the background for each of the two levels of density. An analysis of that data matrix showed that target code, $F(3, 21) = 8.28$, Target Code x Background Code, $F(9, 63) = 5.26$, density, $F(1, 7) = 25.86$, and Background Code x

Density, $F(3, 21) = 6.70$, were the only significant factors, all at $p < .01$. The density factor and the Background Code x Density interaction were due to the fact subjects made more commission errors with the more dense displays, and to the fact that background effects were much greater with the more dense displays. The Target code effect was shown to be due to the higher overall frequency of commission errors for color targets (.44 per trial) than for letters (.32), digits (.29), or shapes (.35), the latter three not differing from each other. The Target Code x Background Code effect was due principally to more commission errors for letter and digit targets in a background of letters and/or digits than in a background of shapes and/or colors. On the other hand, when shapes were targets, commission errors were greater for unidimensional shape displays (i.e., displays containing only shapes) than for any of the bidimensional displays. There were no differences among the four types of displays in which color could be considered a target.

Accuracy of responses. The number of correct responses on each identification trial was determined separately for the unidimensional and bidimensional tasks. In the unidimensional condition target code, $F(3, 21) = 3.78$, was significant at the .05 level and density, $F(1, 7) = 86.17$, and Target Code x Density, $F(3, 21) = 5.90$, were significant at the .01 level. The subject reported more items correctly for the Dinsity 8 displays (6.1) than for the Density 4 displays (3.5). The variation in accuracy due to target code was due entirely to variations which occurred with Density 8 displays; there was no code effect with Density 4 displays. The overall code effect was due to more accurate responses for digits (5.0) than for the other three codes (4.8) on the average) which did not differ from one another.

In the bidimensional condition there were effects for each of the following at the .01 level: Density, $F(1, 7) = 117.83$, code combinations, $F(5, 35) = 6.93$, and Code Combination x Density, $F(5, 35) = 5.80$. The within-code combination main effect, $F(1, 7) = 11.30$, and the two-way interactions of the within-code combination effect with density, $F(1, 7) = 5.76$, and with code combination, $F(5, 35) = 2.75$, were all significant at the .05 level. The density main effect was due to a higher frequency of correct responses for Density 8 displays (6.4) than for Density 4 displays (3.6). The variation in accuracy due to code combinations was much greater for the more dense display. Overall, accuracy was highest for the Digit-Color combination (5.28) and then it decreased going from Letter-Shape (5.16), to Letter-Color (5.10), to Digit-Shape (5.08), to the Letter-Digit and the Shape-Color combinations (4.84 each).

To clarify the within-code combination effects, the mean accuracy obtained for each unidimensional code was halved and combined with the accuracy of each code condition within the bidimensional displays. An analysis of variance was used on the data in the resulting 4x4x2 orthogonal design. That analysis showed that target code, $F(3, 21) = 4.53$, and background code, $F(3, 21) = 4.41$, were both significant at the .05 level. Furthermore, the interaction between target code and background code, $F(9, 63) = 6.92$, was significant at the .01 level. The form of the within-code combination effect is shown by the open bars in Figure 10. Pairwise comparisons showed that there was no effect of background codes when the subjects were reporting shapes or colors. On the other hand, letters were reported more accurately against a background of shapes and colors than when digits or only other letters were in the background. Digits were more accurately reported in a field of color dots than when shapes, letters, or only other digits were in the background. Overall, colors were reported with less accuracy than any of the other targets but all achromatic targets were reported more accurately when colors were the background code. There was no overall difference in the accuracy of reporting letters, digits, or shapes. Similarly,

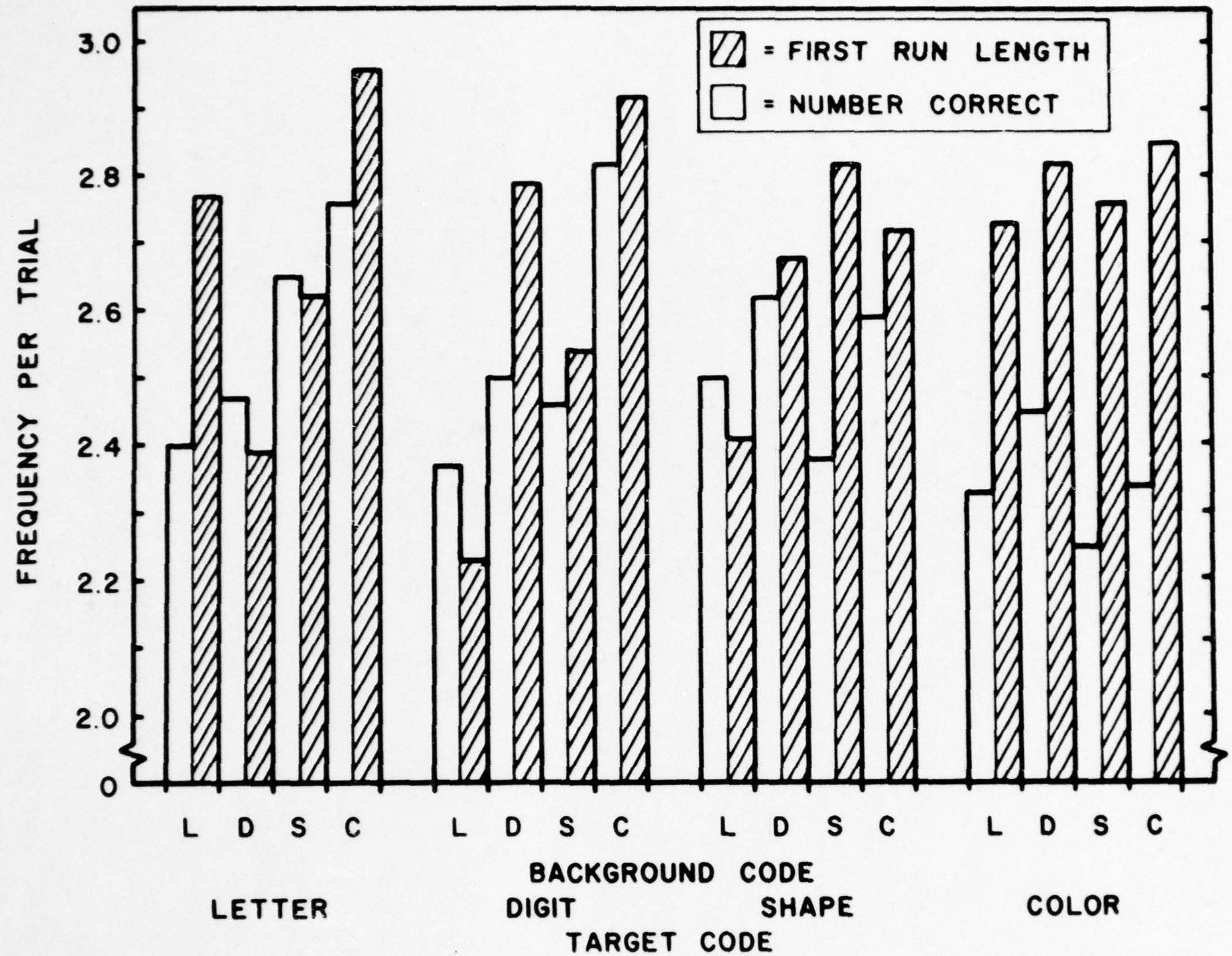

Figure 12. Mean length of the first run of responses and the mean number of correct responses per trial in the identification tasks as a function of target code and background code.

there was no overall fference in the effects of letter, digit, or shape background codes.

Order and organization of responses. The series of identification responses made by each subject in the bidimensional conditions were examined in an attempt to discover what, if any, differential organizational tendencies there might be for the target code combinations. Since the subject could report either one of the two types of targets first, one measure of response organization was the frequency of times the subject's first response was for a target from one or the other target code condition. Those data were analyzed as a function of the six levels of target code combinations and two levels of display density. That analysis showed that the only significant source of variability was due to target code combinations, $F(5, 35) = 2.59$, $p < .05$. It was shown that when given a free choice, subjects tended to report first the achromatic targets from a bidimensional display which combines letters, digits, or shapes with color dots. The percentage of trials on which letters, digits, and shapes are reported first, relative to color dots, was 67.2, 57.0 and 56.2. It was also shown that letters are likely to be reported first in letter-digit (59.5%) and in letter-shape (57.6%) displays, and that shapes are likely to be reported first in digit-shape displays (62.7%).

Another measure of response organization in the bidimensional condition was the number of responses made in the target code reported first before the subject shifted his responses to the second target code, i.e., the length of the initial run of responses. These data were weighted by the proportion of times each target code was reported first. The weighted first run lengths were analyzed as a function of target code combinations and density. It was shown that code combinations, $F(5, 35) = 4.15$, density, $F(1, 7) = 109.41$, and Code Combination x

Density, $F(5, 35) = 4.03$, were the only significant effects, all at $p < .01$. The mean first run length was 1.96 responses when the display density was four stimuli and this value did not vary over the six bidimensional code combinations. When the total display density was eight stimuli, four stimuli in each of two target codes, the mean length of the initial run of responses within a target code category was 3.33 responses, but this value varied over code combinations.

To further clarify the first run length data, the total number of responses made in the unidimensional code condition was determined for each level of code and density. Those data were then halved to yield values which should be comparable to the initial run length derived in the bidimensional conditions. Combining the data from the unidimensional and bidimensional conditions it was possible to generate a 4x4x2 factorial design in which there were four levels of targets corresponding to the code reported first in a series of responses, four levels of background code corresponding to the code not reported first, and two levels of density. An analysis of variance of those data showed the following significant effects: background code, $F(3, 21) = 6.87$, $p < .01$, density, $F(1, 7) = 143.31$, $p < .01$, Target Code x Background Code, $F(9, 63) = 2.10$, $p < .05$, Background Code x Density, $F(3, 21) = 5.98$, $p < .01$ and Target Code x Background Code x Density, $F(9, 63) = 2.18$, $p < .01$.

The density effects were due to a longer run length with Density 8 displays (3.42 responses) than with Density 4 displays (1.96 responses). All of the significant effects involving an interaction with the density factor were shown to be due to the absence of any variation in run length when density was four and to the presence of systematic variations in run length when density was eight. The overall form of the code combination effect is shown by the shaded bars in Figure 12. The height of those shaded bars represents the mean first run length for each code condition in the bidimensional conditions and the roughly comparable data derived from the unidimensional condition. While there was no overall difference between target (first reported) code conditions there was shown to be an effect for background code conditions when the target code was letters and digits. In both of the latter cases pairwise comparisons showed that backgrounds of color dots led to longer initial runs of letters and digits than backgrounds of digits and letters, respectively. No other pairwise comparisons were significant for letter and digit target codes. There was no effect for background code when targets were shapes or colors. It should also be noted that the mean number of responses in the first run of responses exceeded the mean number of correct responses for 12 of the 16 code combinations shown in Figure 12. Hence, commission errors tend to be made even during the first run of responses.

Response time. Figure 13 shows the distribution of response times for each unidimensional code condition and for each code combination within the bidimensional displays. Three different time measures are shown in the figure: the mean latency of the first response in a series of identification responses, the mean latency for all correct responses, and the mean latency for all responses regardless of their accuracy. Response times in the latter two cases were determined by averaging over the time for the first identification response and all relevant interresponse times in the subsequent series of responses. It may be observed that the time required for making the first response was considerably longer than the mean correct response times or the mean of all response times. When the time between the onset of the display and the first response was analyzed, the main effects of density and the main effects of code (or code combinations) were the only significant effects found for the unidimensional

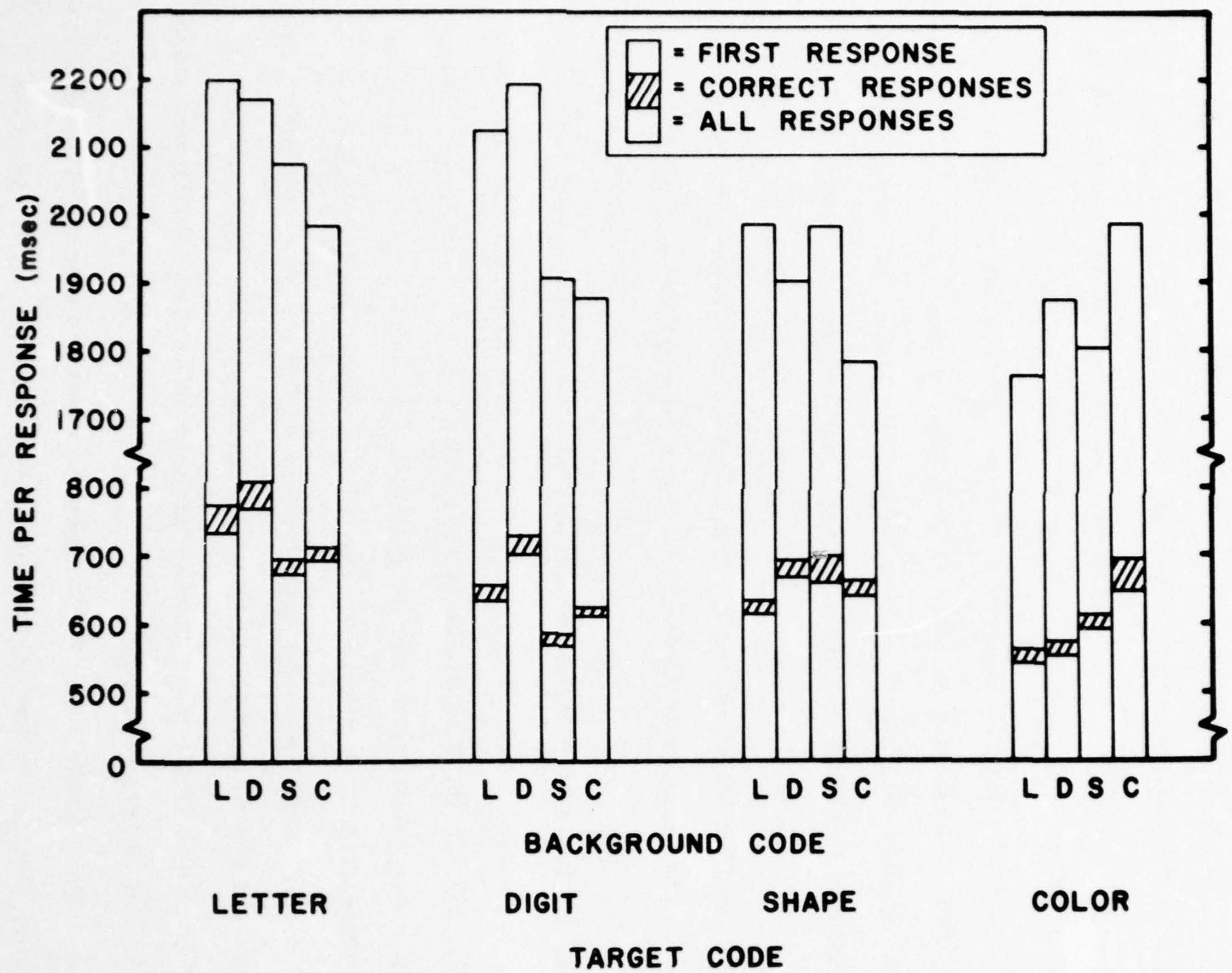

Figure 13. Mean response time for the first response, for all correct responses, and for all responses regardless of accuracy in the identify task as a function of target code and background code.

and the bidimensional display conditions: for density, $F(1, 7) = 90.39$ and 49.42, $p < .01$ respectively; for unidimensional codes, $F(3, 21) = 4.09$, $p < .05$, and for bidimensional codes, $F(5, 35) = 4.18$, $p < .01$. In general, first response time was longer for unidimensional displays than for bidimensional displays (2096 vs. 1939 msec) and, for both display conditions the first response time was longer for the Density 8 condition than for the Density 4 condition (1800 vs. 2392 msec and 1618 vs 2260 msec, respectively). In the unidimensional display condition the first response to letters was slower than the first response to shapes or colors but the first response to digits was not different from any of the other code conditions. In the bidimensional condition the first response to the letter-digit combination was longer than the first response to the shape-color combination but no other differences were significant.

When the two target display conditions were combined to allow an analysis of within-code combination effects, significant effects were found for target code, $F(3, 21) = 6.56$, $p < .01$, background code, $F(3, 21) = 3.67$, $p < .05$, and the Target Code x Background Code interaction, $F(9, 63) = 3.61$, $p < .01$. The form of these effects on first response times is illustrated in Figure 13. Pairwise comparisons showed that background codes had a significant effect only for letter and digit targets. In both of those target code conditions the latency of the first response was shorter when the background stimuli were shapes or colors than letters or digits.

Comparisons between mean correct response times and mean overall response times showed that the latter was only slightly shorter than the former and that the relationship between those measures and code conditions was essentially identical. Hence, only the correct reaction time data will be discussed in detail.

Overall, mean correct reaction time was longer for unidimensional displays than for bidimensional displays (726 vs. 653 msec). The only significant effect on correct reaction time in the unidimensional display condition was the main effect for target code, $\underline{F}(3, 21) = 4.09$, $\underline{p} < .05$. Target code combinations were significant in the bidimensional display condition, $\underline{F}(5, 35) = 5.70$, $\underline{p} < .01$. When data from the two types of display conditions were combined to produce a factorial design for target code, background code, and density, the only significant effects were due to the main effects of target code, $\underline{F}(3, 21) = 10.96$, and to the Target Code x Background Code interaction, $\underline{F}(9, 63) = 3.26$, both at the .01 level. The trends for the target code or code combinations were consistent over all three sets of data. Reaction times in the unidimensional displays were longer for letters than for shapes and colors; reaction times in the digit condition did not differ from reaction times in any of the other unidimensional code conditions. Across bidimensional displays the letter-digit combination led to longer latencies than any of the other five code combinations which did not differ from one another. The target code by background code interaction may be seen in Figure 13; subjects reported letter and digit targets faster when the display contained shapes or colors than only letters or digits. These background effects were reversed when the targets were colors. There was no effect of background code when targets were shapes.

Rate of correct responding. In an attempt to combine the accuracy and response time measures, each subject's mean frequency of correct responding was divided by his mean correct response time. This calculation was made for both display conditions as a function of target codes and density. The accuracy scores from the unidimensional display condition were halved before the calculation was made to facilitate a more complete analysis of the data. An analysis of variance of the rate of correct responding data as a function of target code, background code, and density showed that the only significant effects were the main effects of target code, $F(3, 21) = 3.47$, $p < .05$, and density, $F(1, 7) = 39.15$, $p < .01$, and the interaction of target code and background code, $F(9, 63) = 5.45$, $p < .01$.

The density effect was shown to be due to an overall higher rate of correct responding with Density 8 displays than with Density 4 displays (5.11 vs. 2.76 responses per second). The nature of the overall target code effect and the Target Code x Background Code effect may be seen in Figure 14. Pairwise comparisons showed that response rate was lower for letter targets (3.59 responses per second) than for the other three target code conditions which did not differ from one another (mean of the latter was 4.05 responses per second). There were no differences among the unidimensional display conditions and unidimensional displays always had a lower rate of correct responding than comparable bidimensional display conditions. It may also be seen in Figure 14 that the effects of background codes were very pronounced and very systematic for letter and digit targets. Hence, the rate of correct responding is much higher when letter or digit targets are seen in a field containing shapes or color targets than when the field contains either letters or digits. There is some suggestion that correct reports of color targets are faster in fields of letters and digits than in fields of colors or shapes but the effects of background codes on the correct shape report rate were not large.

Practice effects. The data obtained on the first and second occurrences of unidimensional displays were examined to see if there were any practice effects. Since a different subset of four subjects was used for the second

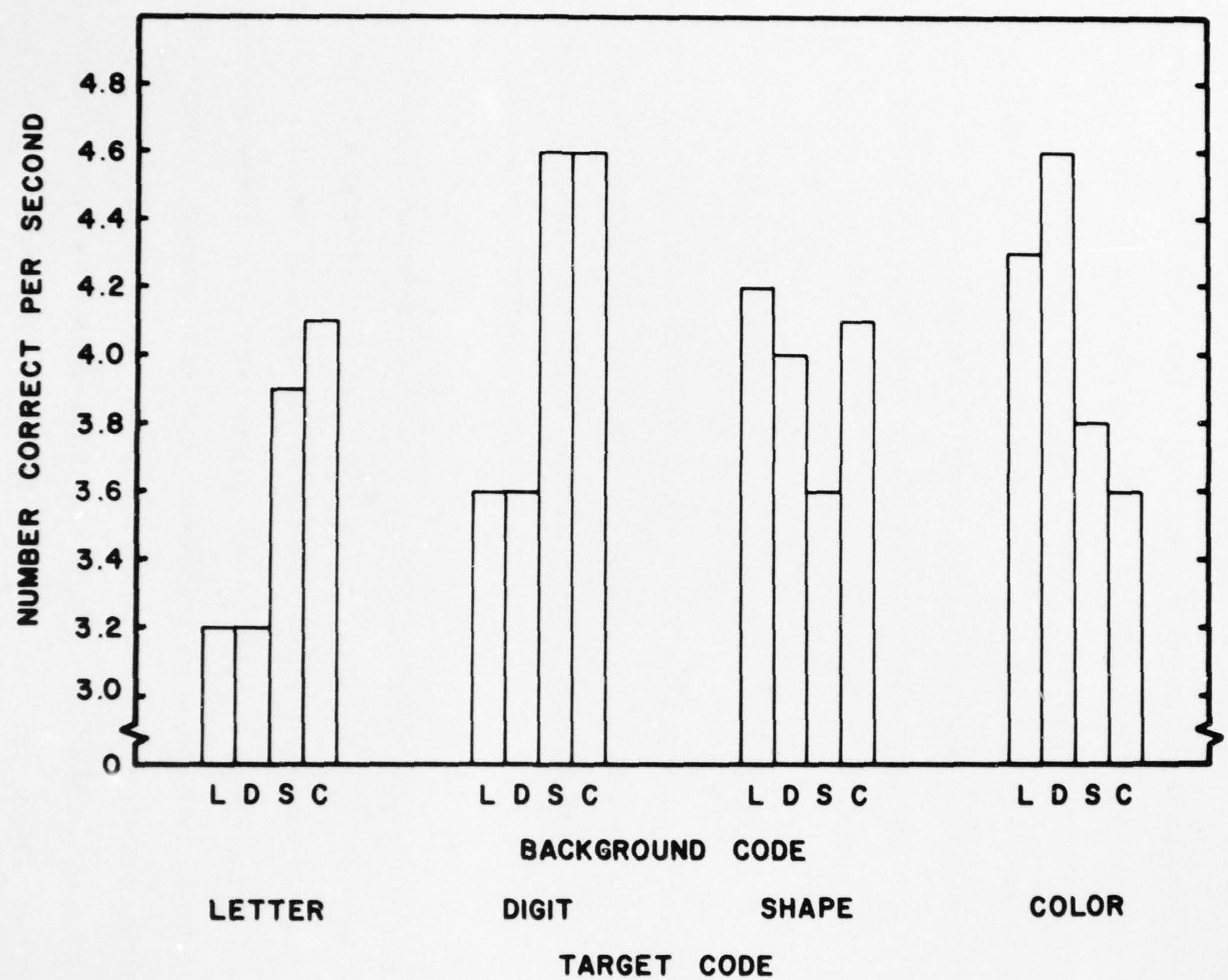

Figure 14. Mean correct response rate in the identify task as a function of target code and background code.

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occurrence of each unidimensional target code the effects of practice could be examined only within target code conditions. A comparison was made between performance on the first and second occurrence of each target code for each of several different dependent measures: number and time of trial termination, number of correct and commission responses, mean first response time and the mean rate of correct and total responses. The overall trends in these data were mixed or simply nonexistent. Consequently, the best conclusion might be that identification performance does not improve over the two short, 100-trial blocks, that were used in this study.

Relative Effectiveness of Colors in Identification Tasks

In order to evaluate the relative effectiveness of color as a target code in an identification task each subject's mean level of performance with color was subtracted from his mean level of performance with each achromatic coding condition and that difference was divided by performance with the achromatic code. As was the case in the choice reaction task and the search/locate task, several types of comparisons were possible: the relative effectiveness of color in unidimensional displays, the relative effectiveness of color as a target in a background of achromatic stimuli relative to those same achromatic stimuli as targets in a background of colors, color targets relative to achromatic targets with a constant background, and color codes relative to achromatic codes as background stimuli for constant target conditions. Furthermore, as for the previous tasks, a comparison was made of performance with each target code in a bidimensional display relative to that same code in a unidimensional display. These five types of comparisons were made separately for each of three dependent measures: mean number of correct responses per trial, mean correct response latencies, and mean rates of correct responding. The results of these comparisons are summarized in Tables 9, 10, and 11.

Table 9 shows the relative effectiveness of color as a coding variable in unidimensional identification displays. It may be seen that, in general, color was relatively ineffective with respect to accuracy (-4.4% overall) but relatively effective with respect to correct response time (4.7% overall). The net effect was that the rate of correct responding with color targets was equally good as with achromatic targets (0.2% on the average). Density was shown to be a significant factor only for the relative number correct and for the relative rate of correct responding measures, $F(1, 7) = 11.95$ and 6.64, respectively, $p < .05$ in both cases. The main effect of code and the Code x Density interaction was significant for all three measures: for relative number correct $F(2. 14) = 16.47$ and 7.04 respectively, $p < .01$ in both cases, for relative correct response time $F(2, 14) = 5.22$ and 4.50 respectively, $p < .05$ in both cases; for the relative rate of correct responding $F(2, 14) = 6.36$, $p < .05$, and 6.92, $p < .01$, respectively.

Pairwise comparisons were made among the six scores in each set of dependent measures. For the relative number of correct responses color was most ineffective as a unidimensional code when there were only four items in the display and then color was most ineffective relative to digits, next most ineffective relative to letters, and least ineffective relative to shapes. The relative ineffectiveness of color decreased when the display density was increased to eight items and in that more dense display condition color was equally effective (or ineffective) relative to all three achromatic comparison conditions.

The correct response time measure showed that there was an advantage for color coding relative to letters but no advantage (or disadvantage) for color

TABLE 9

Percent Difference Scores for Color Codes Relative to Achromatic Codes in Unidimensional Identification Displays

Comparison Achromatic Code	Number Correct		Correct Response Time		Rate of Correct Responding	
	Density 4	Density 8	Density 4	Density 8	Density 4	Density 8
Letters	-10.2	2.9	11.2	8.4	3.7	15.1
Digits	-15.0	-1.0	1.5	6.3	-12.0	7.7
Shapes	- 4.4	1.1	0.7	-0.1	- 3.2	2.2

[a] See footnote for Table 3.

coding relative to shapes. The relative scores for letters and shapes were different at each level of density. The effects of color relative to digits varied as a function of display density. At Density 4 there was no difference in performance relative to digits and shapes but at Density 8 there was no difference in performance relative to digits and letters.

The relative rate of correct responding increased as a function of density for only the comparisons with letters and digits. At Density 4 the rate of responding to colors relative to digits was less than that found relative to letters or shapes. At Density 8 the rate of responding to colors relative to letters was greater than that found relative to digits or shapes.

Table 10 shows the relative effectiveness of color as a coding variable in bidimensional displays. Part I shows the percent difference scores obtained when color was considered a target relative to when each of the three types of achromatic stimuli were targets, all comparisons made within a constant bidimensional display condition. It may be seen that, in general, color was ineffective relative to each of the achromatic codes with respect to the number of correct responses (-12.3% overall), but that color was relatively more effective with respect to the correct response time and the rate of correct responding measures (+8.5% and +4.6%, respectively). The data obtained for each dependent measure were used in three separate analyses of variance which showed that none of the independent variables were significant sources of variation for any of the measures used. Hence, the relative effectiveness of within bidimensional display conditions was constant regardless of density or comparison achromatic stimuli.

Part II of Table 10 shows the effectiveness of color ar a target relative to each of the achromatic stimuli when the background code was held constant.

TABLE 10

Percent Difference Scores Associated with Comparisons Within and Between Bidimensional Identification Displays[a]

Target/Background Comparison	Number Correct		Correct Response Time		Rate of Correct Responding	
	Density 4	Density 8	Density 4	Density 8	Density 4	Density 8
Within Bidimensional Displays						
I. Color as a target relative to color as a background						
C/L vs. L/C	- 6.3	-19.6	11.3	21.3	20.1	5.6
C/D vs. D/C	- 7.1	-16.1	- 0.2	9.8	7.9	2.1
C/S vs. S/C	-11.1	-13.2	5.5	3.5	- 0.8	- 7.3
Between Bidimensional Displays						
II. Color relative to Achromatic Targets with Constant Background						
C/L vs. D/L	- 4.6	0.2	8.9	17.3	9.0	25.9
C/L vs. S/L	- 4.9	- 9.2	8.3	8.8	8.0	1.7
C/D vs. L/D	- 1.9	0.0	25.4	27.4	51.4	48.5
C/D vs. S/D	- 7.0	- 5.1	12.4	15.7	20.7	21.2
C/S vs. L/S	-15.0	-17.0	5.8	13.7	- 3.6	- 3.5
C/S vs. D/S	-13.1	- 7.5	- 9.7	- 8.7	-19.7	-12.2
III. Color relative to Achromatic Background for Constant Target						
L/C vs. L/D	4.2	17.4	11.1	5.8	28.0	37.6
L/C vs. L/S	- 0.7	9.6	- 7.1	0.3	- 0.8	13.3
D/C vs. D/L	4.1	33.9	4.2	5.1	9.8	43.5
D/C vs. D/S	3.2	36.4	-13.7	-12.4	- 3.3	34.8
S/C vs. S/L	- 1.6	10.6	- 6.1	- 8.4	- 3.9	11.7
S/C vs. S/D	- 4.9	1.2	0.2	0.4	1.5	9.1

[a] See footnote for Table 4.

Overall, color was relatively ineffective as a target if the number of correct responses is considered (-7.1% overall) but relatively effective as a target if correct response time or the rate of correct responding is of concern (+10.4% and +12.3% overall, respectively). Separate analyses of variance for the data in each set of measurements showed that in each case the only significant effect was for the target code-background code combination: for the relative number correct data $F(5, 35) = 1.53$, $p < .01$; for the relative correct response time data $F(5, 35) = 5.73$, $p < .05$; for the rate of correct responding data $F(5, 35) = 5.73$, $p < .01$.

Pairwise comparisons among the six target code-background code combinations for the number correct data showed that the relative ineffectiveness of color was greatest relative to letters with a constant shape background and was least relative to letters with a constant digit background. The effectiveness of color targets relative to letter targets with shapes in the background differed from all other difference scores except for the effectiveness of color targets relative to digit targets with shapes in the background. The latter did not differ from any other difference score except the color and letter comparison in a background of digits. The effectiveness of color relative to shapes or digits with letter backgrounds and relative to shapes or letters with digit backgrounds did not differ from one another.

Pairwise comparisons among the six target code-background code combinations for the correct response time data showed that the percent difference scores for colors and letters with a constant digit background were different from all other percent difference scores and that there were no other pairwise differences among the scores. Comparisons among the target-background conditions for the rate of correct responding data showed that there were no differences in the effect of color relative to digits or letters in a shape background, shapes or digits in a letter background, or shapes in a digit background. Similarly, there were no differences in the effects of color relative to letters or shapes in a digit background or to digits in a letter background.

The relative effects of color as a background code on the identification of achromatic targets are shown in Part III of Table 10. It may be seen that, in general, subjects correctly identify more achromatic targets when color is in the display than when any other achromatic stimulus code is in the display (+9.5%). The relative effects of color in a display on the time needed to identify achromatic targets correctly was quite mixed and overall was very small (-1.7%), but the relative effects of color in the background on the rate of correct identification of achromatic targets was more consistent and positive (+15.1% overall). Separate analyses of each set of dependent measures showed that there were no significant sources of variation attributable to the independent variables for either temporal measure and that only the target-background comparisons were significant for the number of correct responses data, $\underline{F}(5, 35) = 3.62$, $\underline{p} < .01$. Pairwise comparisons of the number of correct response data showed that the percent difference scores associated with digits in a color background relative to digits in a letter or shape background were greater than any other percent difference scores. These two conditions involving digits as targets did not differ from one another nor did any of the remaining conditions differ from one another.

Table 11 summarizes the percent difference scores obtained when performance with each target code in a bidimensional display is considered relative to that same target code in a unidimensional display. These data are given separately for three different measures of performance. Positive scores indicate an

TABLE 11

Percent Difference Scores Comparing Unidimensional and Bidimensional Identification Displays[a]

Comparison	Number Correct		Correct Response Time		Rate of Correct Responding	
Displays	Density 4	Density 8	Density 4	Density 8	Density 4	Density 8
L/D vs. L	1.2	5.1	- 1.7	- 6.6	0.7	- 0.2
L/S vs. L	5.9	13.7	16.4	3.3	27.9	18.1
L/C vs. L	5.2	24.2	12.4	3.4	25.0	33.9
D/L vs. D	- 2.9	- 7.7	10.9	5.4	9.8	0.5
D/S vs. D	- 2.0	- 2.4	21.1	18.2	30.3	24.2
D/C vs. D	1.1	21.4	14.9	12.1	20.3	44.3
S/L vs. S	9.8	3.3	9.8	8.7	24.6	14.7
S/D vs. S	13.3	11.8	1.1	- 2.9	19.0	16.5
S/C vs. S	7.7	-38.9	5.8	- 2.4	17.2	-37.2
C/L vs. C	9.8	- 7.1	18.0	17.8	37.1	15.6
C/D vs. C	11.2	1.0	16.7	17.2	41.9	28.9
C/S vs. C	0.8	- 8.6	12.9	8.3	19.1	0.5

[a] See footnote for Table 5.

advantage, negative scores a disadvantage for the bidimensional displays relative to the unidimensional display.

It may be seen that in general bidimensional displays were slightly superior to unidimensional display in terms of the relative number of targets correctly identified (+3.2%), the relative correct response times (+9.2%), and the relative rate of correct responding (+18.0%). It may also be seen that the relative advantage of bidimensional displays may vary considerably as a function of density and target code-background code combinations. Analyses of variance showed that the code combination main effect and the Code Combination x Density interaction was significant for only the number correct data $\underline{F}(11, 77) = 7.22$ and 7.21, respectively, and for the rate of correct responding data, $\underline{F}(11, 77) = 3.30$ and 2.60, respectively, $\underline{p} < .01$ in all cases. Density was significant for the correct response time data, $\underline{F}(1, 7) = 5.70$, $\underline{p} < .05$. No other effects were significant.

Pairwise comparisons among the scores shown for the number correct data showed that none of the effects shown for letter targets and none of the effects shown for color targets were significant. There were no effects of density for any comparison involving digit targets and no effect for different comparisons involving digits when display density was four. However, at Density 8 the relative gain associated with the bidimensional digit/color display was different from both the digit/letter and the digit/shape displays, the latter two did not differ. When shape targets were considered there was an effect for density only when color background stimuli were used in the bidimensional display. There were no effects for different background codes for the Density 4 shape-target displays but the shape-color combination was significantly different from the shape-letter and shape-digit displays when the display density was eight items.

A separate analysis of variance of the relative number correct data when target code was used as a factor showed that there was a Target Code x Background Code interaction, $F(6, 42) = 14.18$, $p < .01$, and a Target Code x Density interaction, $F(3, 21) = 5.94$, $p < .01$. While the different background codes are not orthogonal with the target code factor, the interaction of these two factors may be interpreted as showing that color background aids in the identification of letters and digits and that color background interferes with the identification of shapes. The Target Code x Density interaction reflects the fact that the relative effectiveness of bidimensional displays decreases with increases in density when targets are shapes or colors.

Overall, the only significant effect on relative correct response time was the density effect. It may be seen that relative gain associated with bidimensional displays decreased when density increased. When the data were reanalyzed using the four levels of target code as a separate factor target code was shown to be a significant main effect, $F(3, 21) = 3.41$, $p < .05$. It may be seen in Table 10 that a larger relative gain is associated with bidimensional displays when the targets are digits and colors than when the targets are letters or shapes.

Pairwise comparisons among the scores shown for the rate of correct responding data showed that there were no significant effects for letter-target conditions or color-target conditions. There were also no effects when density was four for the digit or shape target conditions. When density was eight, the digit-color combined display was different from the digit-letter display but neither of those displays were different from the digit-shape display. When density was eight for the shape targets, the shape-color display was different from the shape-letter and shape-digit displays.

A separate analysis of variance of the rate of correct responding data when the four levels of target code were used as a factor showed that there was a Target Code x Background Code interaction, $F(6, 42) = 3.03$, $p < .05$. The data given for this measure in Table 11 show that this interaction is due to the small and negligible gain associated with letter or digit target displays when digits or letters are added to the backgrounds while these same background stimuli produce relatively large gains when the targets are shapes or colors.

Summary of Color Effects in Identification Tasks

In summary, when a subject is required to identify multiple targets from a briefly exposed display, color is less effective as a target code relative to letters, digits, or shapes if the primary objective is to maximize the number of items correctly reported and minimize the number of items incorrectly reported. However, if the latency of correct responses or the overall rate of correct responding is of primary importnace, color coding will lead to superior performance relative to letters, digits, or shapes. The effects in either case are never very large. The greatest relative loss associated with color for the number of correct response data was only 17 percent, and the greatest relative gain in the rate of responding associated with color was about 50 percent. These larger relative scores were obtained with bidimensional displays; the effects were much smaller with unidimensional displays.

In general, the larger relative losses (or the smaller relative gains) with color targets in bidimensional displays were obtained when color was combined in some manner or other with familiar geometric shape codes. The larger relative gains (or the smaller relative losses) associated with color targets were obtained when color was combined with alphanumeric codes. These general results lend further support to the results obtained with the choice reaction task and with the search and locate task. Specifically, the overall results suggest that the colors and shapes are processed in a similar manner and that both are processed differently than alphanumerics. The facts that speed of responding to color stimuli and the rate of recalling color stimuli are so much faster than the speed of reporting shapes, letters, and digits while, at the same time, the accuracy of reports of color is less than that obtained for the other spatial target codes, also suggest that colors are processed earlier and more peripherally in the central nervous system (or, if preferred, the central processing system.)

GENERAL CONCLUSIONS
CONCERNING THE EFFECTIVENESS OF COLOR CODING
IN RELATIVELY SIMPLE TASKS

There is a rather large degree of consistency in the results obtained over the ten single tasks studies just reported. Three conclusions seem to be most salient. First, while color coding is often associated with statistically significant improvements in performance, colors are not necessarily better target codes than achromatic stimuli, either for the purpose of identification or for location. Color coding seems to be least advantageous when the display contains only one target or when multiple targets are all in the same coding dimension. Related to this conclusion is the fact that colors are often better background codes than they are target codes.

Second, colors in a display are most likely to aid performance if the subject must deal with more complex, multiple stimulus formats and when there is a need to distinguish one class of stimuli (e.g., targets) from another class of stimuli (e.g., noise). The need to organize or reorganize inputs from the display may be the issue which decides whether or not color leads to a gain in performance relative to other achromatic conditions. There is ample support in the experimental literature for the subject's "automatic" tendency to impose "subjective" organization onto a set of relatively homogeneous inputs and for the subject to utilize more objective differences in a heterogeneous input for the same end. There is also substantial evidence in the literature that performance improves as a result of this organization.

Third, if color is advantageous for the reasons just given, it is not at all clear from the single task studies reported that color is the only coding variable or that it is the best coding variable available for those purposes.

Indeed, the present studies clearly show that familiar geometric shapes are nearly as effective as colors for most of the tasks considered. There is also an obvious need to examine the effectiveness of color coding relative to other nonspatial coding variables.

Finally, while the present series of studies have considered the effectiveness of color in bidimensional displays which contain two distinct classes of stimuli, there remains the need to systematically study the effects of color in displays containing multidimensional stimulus codes.

REFERENCES

Christ, R. E. Review and analysis of color coding research for visual displays. Human Factors, 1975, 17(6), 542-570. (Also published as a Final Report; NMSU-JANAIR-FR-73-1, JANAIR Report 730703, July 1973, NTIS No. AD-767066.)

Christ, R. E., Stevens, A. L., & Stevens, D. Color research for visual displays (NMSU-JANAIR-FR-74-1, JANAIR Report 741103). Las Cruces, New Mexico: New Mexico State University, Department of Psychology, July 1974.

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