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THE ADVANTAGE OF THE COLOR-CODE MODALITY VERSUS ALPHANUMERIC- A--ETC(U)

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THESIS

THE ADVANTAGE OF THE COLOR-CODE MODALITY
VERSUS ALPHANUMERIC- AND SYMBOL-CODE

by

Henning Hoops

March 1980

Thesis Advisor: D. Neil

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The stimuli used in the experiment were the letters: E, F, N, U, the colors: red, yellow, green, blue, and the symbols:

square, triangle, circle, and cross. They stood for enemy, friendly, neutral, and unknown forces, respectively.

The analysis of the data obtained from the experiment suggested that the color- and symbol-codes were significantly better than the alphanumeric-code with respect to the number of errors. The reaction time of the color-code was shortest, followed by the symbol-code with reaction time for the alphanumerics being longest.

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The Advantage of the Color-Code Modality versus Alphanumeric- and Symbol-Code

by

Henning Hoops
Kapitänleutnant, Federal German Navy

Submitted in partial fulfillment of the requirements for the degree of

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Author: Henning Hoops

Approved by: Douglas E. Neil, Thesis Advisor

William F. Moroney, Second Reader

Michael G. Sovereign, Chairman, Department of Operations Research

D. A. Schrady, Dean of Information and Policy Sciences

ABSTRACT

This study describes an experiment designed to investigate potential advantages and/or disadvantages of color-coding relative to symbol- or alphanumeric-codes. Performance was evaluated in terms of reaction time and the number and type of errors made.

The stimuli used in the experiment were the letters: E, F, N, U, the colors: red, yellow, green, blue, and the symbols: square, triangle, circle, and cross. They stood for enemy, friendly, neutral, and unknown forces, respectively.

The analysis of the data obtained from the experiment suggested that the color- and symbol-codes were significantly better than the alphanumeric-code with respect to the number of errors. The reaction time of the color-code was shortest, followed by the symbol-code with reaction time for the alphanumerics being longest.

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I would like to express my heartfelt thanks to Mr. Paul Sparks of the Human Factor Laboratory of the Naval Postgraduate School for his time and physical effort in designing and building an interface between the Tachistoscope and the computer. Without this device, no reasonable data could have been obtained.

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I. INTRODUCTION

There are many stimuli that people sense directly (e.g., color, sound). However, there are many situations and environments (e.g., stimuli below threshold values or stimuli to which people are not responsive as X-ray radiation) in which information that people need in performing some activity must be presented by the use of a display. A display, in general, is any device or medium that is used to convey information to an operator. Displays can be either dynamic or static.

Dynamic displays are those that change through time, e.g., speedometer, television, or radar displays, while static displays remain fixed over time such as charts. Another feature of a display is whether it is formatted, unformatted, or whether it has a variable format.

Formatted displays have a fixed format such as specified scales or intervals like a thermometer. On unformatted displays, random stimuli are presented. A display with variable format is a combination of the other two. An Air Control Radar display, for example, has a variable format with fixed stimuli for the contours of landmarks and runways and random stimuli for incoming aircraft.

A variety of information can be presented by displays. The information can be:

1. quantitative as temperature or speed,
2. qualitative by indicating a change of a variable or parameter,

3. status indication such as on-off,

4. signal indicating an unsafe condition,

5. presentational information such as blips on a cathode ray tube (CRT),

6. identification information used to identify a static condition, situation or object.

7. alphanumeric or symbolic information such as musical notes, computer printouts, or

8. time-phased information such as Morse code.

This study is concerned with dynamic, unformatted displays with symbolic information such as might be used on CRTs for military purposes. Since World War II, these display types (e.g., radar, sonar) have been widely used and, as the weapon systems are getting more sophisticated, more information has to be displayed. In connection with external sensors, the computer aided displays not only present the blip of a radar contact; they provide additional information mostly in the form of alphanumeric codes such as classification, track-number, speed, altitude, etc.

Performing an activity with these displays requires an experienced operator to read the complex displays and to distinguish between relevant and irrelevant information/noise. Simultaneous to this increased complexity has been an increase in the workload of the operator in modern military systems. For example, the pilot of a single-manned fighter airplane is not only the pilot of a high-speed aircraft in the conventional sense; he is also a navigator, a tactical coordinator, a communications officer, and a weapon officer with responsibility for his expensive system and control of his weapons (nuclear warheads).

To improve efficiency, various methods of coding the increasingly complex information have been attempted. For example, in manual and computer-driven plotting systems, colored symbols (e.g., blue for own forces and red for hostile forces) may be used to make it easier for the operator to interpret the situation, and to reduce the reaction time to displayed information.

Today's state-of-the-art in electronic engineering suggests the possibility of using color-codes on tactical displays as well as in manual plotting systems. However, this coding technique is far more expensive than the monochromatic ones, and it has to be examined to determine whether the color-code technique does really have an advantage over less expensive coding techniques such as alphanumeric- or symbol-code.

Therefore, the experiment as reported here will test the three coding modalities to find out whether the color-code is superior to the other codes with respect to reaction time and to the number of errors made.

II. LITERATURE REVIEW

A. COLOR CODE AND PERFORMANCE

Considerable research has been performed on the application of color as a coding modality. For example, studies by Hitt (1961), Christner and Ray (1961), Cook (1974), Christ (1975), Wagner (1977), Teichner et al. (1977) have all examined color-aided displays. However, no definite conclusion is available that suggests color has an advantage over other coding modalities.

Specially, the literature dealing with color coding and performance does not lead to a specific conclusion relating increment or decrement in performance as a result of using color coding. Burdick et al. (1965) reviewed both the literature on color coding and the state-of-the-art for CRTs and emphasized a cost-effectiveness approach. They concluded that color CRTs were probably worth the additional cost for some tasks, such as search tasks, at the time of their writing. Oda (1977) summarized an experiment of a color-coded, computer-aided multipurpose display (MPD) for the TACCO of an S-3A Viking and found that the color-coded MPD tended to improve the functional effectiveness of TACCOs with low experience levels. This, of course, does not answer the total question about benefits of colored CRTs.

On the other hand, Teichner et al. (1977) concluded that color-coding is of little benefit with regard to performance and Christ and Corso (1975) indicated, after performing a series of experiments with colors, letters, digits, and symbols, that performance with color was not superior to the other codes.

B. USE OF COLORS IN CERTAIN TASKS AND SITUATIONS

Smith (1978) summarized the existing literature and related the best coding methods to certain tasks. This summary is given in Table I.

Table I

Task and Recommended Coding Methods

Task	Function	1st Coding Method	2nd Coding Method
Search	Where is it?	Color	Number or Letter
Identify	What is it?	Number	Letter
Count	How many?	Number	Color
Compare	Yes/No	Number	Color
Verify	True/False	Number	Color

Krebs et al. (1978) have suggested that color may be of benefit in the following situations:

1. The display is unformatted.
2. The symbol density is high.
3. The operator must search for relevant information.

4. The color code is logically related to operator's task.

5. The symbol legibility is degraded.

In addition to these criteria, Smith (1978) suggested that color may be of benefit as a coding modality if the target position is unknown, but the color of the target is known. This restricts the use of colors to certain types of situations such as in search tasks.

C. LIMITATION OF THE NUMBER OF COLORS

A major shortcoming of color is the number of dimensions that can be coded when color is the selected coding modality. The number of dimensions that can be coded is limited to four. This is a common finding of color researchers. Hanes and Rhoades (1959), Ruch (1966), Krebs et al. (1978), and Wagner (1977) stated that up to about 50 colors may be identified with extensive training, but in the applied sense, they agreed that if identification is required, the number of colors should not exceed four.

Krebs et al. (1978) summarized the criteria for selecting a specific color set:

1. Maximize wavelength separation.
2. High color contrast.
3. High visibility in specific application.
4. Compatibility of the use with conventional meanings.
5. Legibility and ease of reading.
6. Highly saturated colors preferable.

D. COLORS AND THEIR CONVENTIONAL MEANING

Some colors have a conventional meaning. For example, red means danger or stop. Smith (1978) listed some colors in relation to their conventional meanings and to the operators' reactions. (See Table II.)

Table II

Colors and their Conventional Meanings

Color	Meaning	Operators' Reaction
Flash Red	Emergency	Immediate action required.
Red	Alert	Corrective action must be taken.
Yellow	Advice	Caution, recheck necessary.
Green	Proceed	Condition OK.
White	Transitory Function	No wrong or right indication.
Blue	Advisory	Should be avoided.

E. LUMINANCE, BRIGHTNESS, CONTRAST, SATURATION

Other factors that influence performance in using colored displays include:

1. Luminance

That is the amount of light emitted from a display surface (luminous intensity) as viewed by the observer. The subjective measure of luminance is brightness.

2. Brightness

Brightness refers to a subjective impression of relative luminance. That is, a symbol of fixed luminance will appear brighter on a dark background than on a light background. Thus, brightness judgments are at least in part influenced by contrast.

3. Contrast

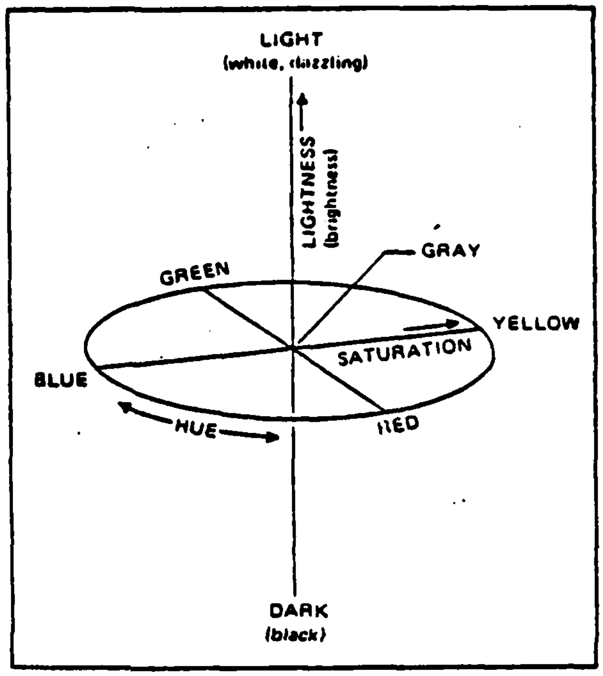
Contrast is a measure of the relationship between the luminance of a symbol and its background.

4. Saturation

The colors themselves are of different purity. For example, the two colors pink and red have nearly the same hue; that is the attribute of a color to which commonly used labels such as green are assigned, but red would be much more saturated than pink. Black, white, and gray have a saturation value of zero. Judd and Wyszecki (1952), cited in Haber and Herschenson (1973), utilized Figure 1 to explain color saturation. Saturation is the relative purity of a color defined in terms of its departure from a white or gray of the same lightness.

F. SYMBOL SIZE

For optimal perception of color, not only is color saturation of importance but also the size of the colored targets. Krebs et al. (1978) recommended sizes from 21 to 45 minutes of an arc (in terms of visual angle) depending on the number of colors used in the code (see Figure 2), and they stated



Note: The four hues shown are of the same saturation value.

Figure 1. Color Saturation

Figure 2. Symbol Size versus Number of Colors

that color perception may be adversely affected if the symbol size is below 21 minutes of an arc.

If luminance contrast, however, is low, or the display readability is degraded by noise and/or poor resolution, the symbol size should be increased beyond the minimum recommended levels.

All these factors -- number of colors, size, tasks, situations, conventional meaning, luminance, brightness, contrast, and saturation -- are important not only by themselves but also in all their possible combinations and interactions in discussing and evaluating performance with color-coded displays.

III. EXPERIMENT

The objective of this experiment was to test the Null hypothesis that there is no difference between the three coding modalities, colors, symbols, and alphanumerics, with respect to human performance measured as reaction time and the number of errors. The alternative was that one coding technique is superior to the other codes.

A. EXPERIMENTAL DESIGN

1. General Description

In most modern military systems, operators are expected to perform simultaneously multiple tasks such as flying an aircraft or navigating in addition to monitoring a tactical display and making decisions based on the information provided. Kopala (1979) performed a simulation experiment with pilots. Pilots simultaneously performed routine flying tasks, while monitoring the display, but she compared symbols with the redundant colored symbol code. The task selected for this experiment, however, involved only a search task and a choice reaction task (identification). As in case of a CRT for a pilot, we have an unformatted display with moderate to high contact density; further the pilot has to search the display for relevant information.

The experiment itself was divided into three sub-experiments. The subjects were shown decks of cards with either symbols, colors, and alphanumerics. Within each deck of cards were five "target cards." Target cards were those cards that presented a specific letter, symbol, or colored dot, which were known in advance by subjects. Targets in this context could mean anything to the subjects, e.g., an attacking missile, a hostile fighter, or something specified in their missions.

2. Stimuli Presented

Since the recommended number of colors is four, only four symbols, colors, and alphanumerics were used. This variable was held constant to obtain the same number of dimensions in the three sub-experiments.

The human eye is limited to a visible spectrum of electromagnetic radiation with wavelength from 380 nanometers (violet) to 750 nanometers (red). Out of this spectrum, the following four colors were chosen for the experiment: blue, green, yellow, red.

These colors were selected not only because of their high wavelength separation; they were also logically related to the task of the operator and are compatible to conventional meanings. Further, these colors are well saturated and no confusion has been reported by subjects. The diameter of the colored dots was 3.1 millimeters. This corresponds to about 35 minutes of an arc at a viewing distance of 30 centimeters, which is more than the minimum size of 31 minutes of an arc suggested by Krebs et al. (1978).

The colors, alphanumerics, and symbols selected for the experiment are shown in Table III together with their possible meaning.

Table III

Stimuli for the Experiment and their Meaning

Color	Symbol	Alphan	Possible Meaning
Red Dot	Δ	E	Enemy, Danger
Yellow Dot	□	U	Unknown, Unidentified, Attention
Green Dot	+	F	Friendly, No Danger
Blue Dot	○	N	Neutral, No Danger

The alphanumerics and the symbols were of the same size as the colored dots with a stroke thickness to height of about 1:6 and in case of the letters with a width-height ratio of 3:5 as recommended in McCormick (1976). The symbols are commonly known and easy to discriminate. Some of the symbols are used in existing codes, for example, on German Fast Patrol Boats.

The four letters were chosen because they are the first letters of the word and could serve as abbreviations:

F - Friendly

U - Unknown

E - Enemy

N - Neutral.

Target cards were those cards with a red dot, a triangle, or an E. There were 10 stimuli on each 12 x 8.5-centimeter card. A deck of cards consisted of 40 cards with either alphanumerics, colors, or symbols. The five target cards were randomly distributed within the decks using the Uniform Random Number generator of the hand-held calculator TI59 (Statistics Module, Program 02). The positions of the target cards within each deck were changed for each subject.

Superimposed on the 120 cards was a single card with colors, alphanumerics, and symbols not used on the other cards. This card represented noise or disturbances. It should make the task more realistic because noise is also found on radar scopes and other displays. A single noise card was used throughout the experiment to hold this variable constant and to prevent the possibility that several noise cards influenced performance differences. For the same reason, the number of stimuli presented per trial (density) was the same; there were 20 stimuli on the noise card in addition to the 10 stimuli per signal card.

No attempt was made to control the position of the stimuli on the card. All stimuli were put on the card in a random fashion; superposition was avoided.

3. Procedure and Outcomes Measured

A random number generated from the discrete Uniform Distribution between one and six (TI59 Statistics Module, PGM 02) determined in which sequence the three decks of cards (one deck for each code) were presented. The possible outcomes and the resulting sequences are listed in Table IV.

Within the three decks of cards, each card was presented to the subjects for 1.5 seconds. During this time, they had to search the card and determine whether or

Table IV

Sequence of Code Presentation

Random Number	Sequence
1	alphan. - colors - symbols
2	alphan. - symbols - colors
3	colors - alphan. - symbols
4	colors - symbols - alphan.
5	symbols - alphan. - colors
6	symbols - colors - alphan.

not it was a target card. Subjects were required to identify the red dot, the triangle, or the E, respectively, and to respond to the target cards by pressing a button. The outcomes measured were:

1. Reaction time. That is the time from first showing the target card until the subject responded. The reaction time included information processing (decision), a central response, and the movement time.

2. Number of errors of omission. These are those errors that occurred where the subject missed a target card or responded too late (after presentation of the card).

3. Number of errors of commission. These are the errors that occurred where the subject responded to a non-target card (False Alarm).

The subjects did not know how many target cards were within the decks of cards. They were informed that the probability of viewing a target card was much lower than 0.5. (See Instructions, attached as Appendix A.)

Prior to the experiments with the three decks of 40 cards, three "warm-up runs" had to be completed by the subjects. In these runs, 10 cards of each code were presented to the subjects. The probability of viewing a target card here was 0.5 (every other card). These trials familiarized the subjects with the stimuli equipment and ascertained that the instructions were understood.

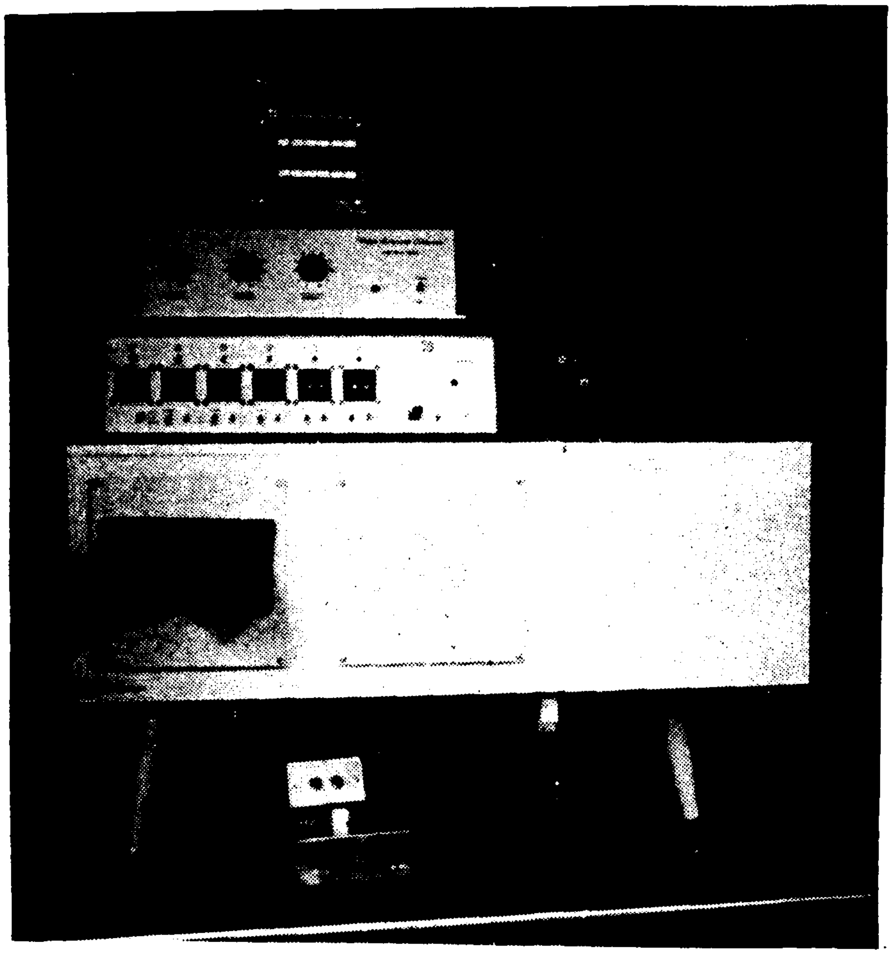
Between each sub-experiment, breaks of two minutes were given to the subjects to avoid possible fatigue effects and to set up the next sub-experiment. Smoking was not allowed while performing the experiment to avoid possible performance degradation due to reduced oxygen.

B. APPARATUS

The stimulus presentation apparatus used was a Tachistoscope G1130 Model T-3A manufactured by Ralph Gerbrands Company. It consisted of:

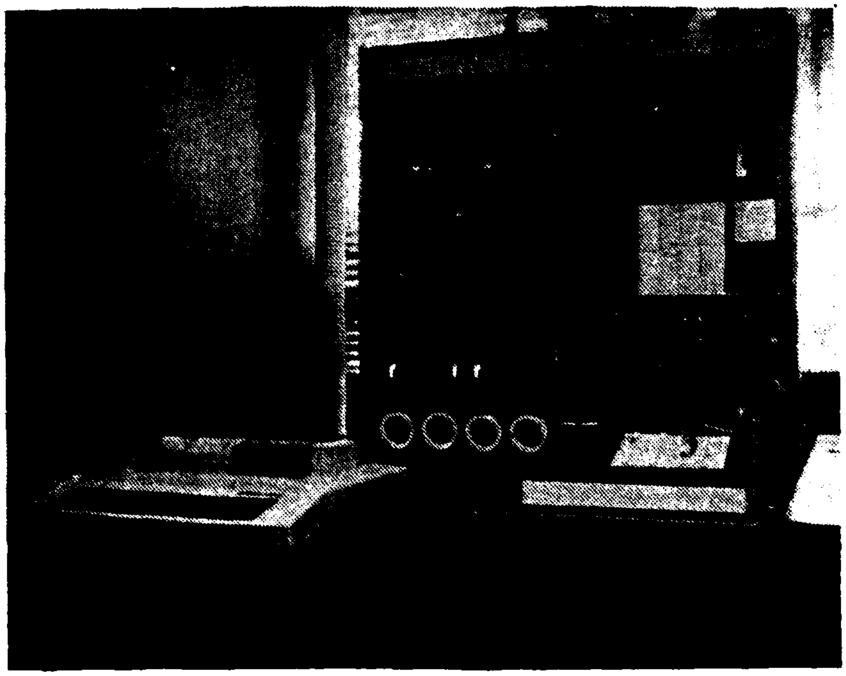
1) 3-Field Exposure Cabinet
2) 6-Channel Digital Timer
3) 3-Field Lamp Driver
4) Logic Interface (G1159) and
5) Automatic Card Changer (G1150).

The physical set-up of the equipment is shown in Figures 3 and 4. The tachistoscope is an instrument for providing very



From top to bottom:
Logic Interface
Lamp Driver
Automatic Card Changer
Timer
Exposure Cabinet with Viewing Field
Response Button

Figure 3. Tachistoscopic Equipment



Digital Lab 8/E Computer with Terminal and Logic Interface between Card Changer and Response Button and Computer.

Figure 4. Computer, Terminal, Interface

brief timed exposure of visual material as images, letters, or digits. It is a tool in learning, attention, and perception studies.

The exposure cabinet had three viewing fields into which visual material could be placed. These materials are shown to the subjects via a system of mirrors. Superposition is possible. Two of the viewing fields are semi-automatic; that is, the cards have to be placed in the field manually. The third field is connected to the Automatic Card Changer in which up to 100 cards can be preloaded.

The Digital Timer normally times the Automatic Card Changer and the Lamp Driver. The Lamp Driver supplies drive current to the lamps in the Exposure Cabinet. The Logic Interface is placed in series between the Timer and the Lamp Driver. By using controls, it is possible to operate any of the three viewing fields of the Tachistoscope with any of the six channels of the Timer.

For this experiment, a Digital Equipment Corporation Lab 8/E computer was used to record the responses. The computer was connected to the Card Changer and the response button (Figures 3 and 4). The response button was placed under the viewing hood in front of the subject.

A Basic (computer language) Program, provided by the Human Factors Laboratory of the Naval Postgraduate School, was used to time the Automatic Card Changer, to count the errors of commission and omission, and to measure the reaction time to the one-hundredth of a second. The Basic Program is attached as Appendix B.

The noise card was placed in one of the semi-automatic viewing fields and superimposed on the decks of 10 cards of the "warm-up runs," and the decks of 40 cards of the "hot runs," respectively.

Except for the computer, the terminal, and the Interface, the equipment was placed in an "Industrial Acoustic Co., Inc. Control Acoustic Environmental Chamber" to minimize distraction of subjects while performing the experiment and to have the same environmental conditions for all subjects.

C. SUBJECTS

Twenty-three students and one member of the faculty of the Naval Postgraduate School volunteered as subjects for this experiment. All 24 subjects were military officers. They were from six different countries, USA (11), Germany (9), Canada (1), India (1), Israel (1), and Korea (1). Twenty subjects were from the Operations Research Department, four from other departments of the Naval Postgraduate School. All were of age between 27 and 39. Subjects were asked before performing the experiment about color defects; none were reported. As the subjects were officers, they had been military screened and corrected to 20/20 vision.

IV. ANALYSIS AND RESULTS

A. ERRORS

The percentage of errors made by the 24 subjects under the three codes are given in Tables VI and VII of Appendix C.

Table VI shows the percentage of errors due to errors of omission, Table VII the percentage of errors due to errors of commission.

The nonparametric test "Friedman Two-Way Analysis of Variance by Ranks" (Siegel, 1956, p. 166) was conducted to test the Null hypothesis,

H_0 : the three coding techniques have no differential effects on the number of errors of omission/commission,

against the alternative,

H_1 : the three coding techniques have differential effects on the number of errors of omission/commission.

The teststatistic for this test is computed by the formula

$$X_r^2 = \frac{12}{Nk(k+1)} \sum_{j=1}^{k} (R_j)^2 - 3N(k+1) ,$$

where N is the number of subjects,

k the number of codes, and

R_j the ranksum of code j (column ranksum).

For large N ($\geq$ 10) the test statistic is approximately CHI SQUARE distributed with k-1 degrees of freedom (df).

An α-level of 0.05 was used throughout all Hypothesis tests.

1. Errors of Omission

In case of the errors of omission, the following data were used to calculate the test statistics:

$\alpha = 0.05$, $k = 3$, R_1 (alphan.) = 62.5,
$N = 24$, $df = 3$, R_2 (colors) = 39.5, and
R_3 (symbols) = 42.5 .

This resulted in a value for the chi square test statistic of $X_r^2 = 13.27$. The corresponding probability obtained from a chi square table (Siegel, 1956) is approximately 0.001. As $p \sim 0.001$ is less than $\alpha = 0.05$, H_0 is rejected.

Although there is no range test available to indicate where the differences are, it seems to be obvious that the alphanumeric code differs from the other two codes because R_1 was much larger than R_2 and R_3, while R_2 and R_3 were quite similar.

2. Errors of Commission

For evaluation of the errors of commission, the following data were computed to calculate the test statistic:

$\alpha = 0.05$, $k = 3$, R_1 (alphan.) = 59,
$N = 24$, $df = 2$, R_2 (colors) = 43.5, and
R_3 (symbols) = 41.5 .

Here the test statistic was $X_r^2 = 7.65$ with an associated probability of $p \sim 0.02$, and as p was less than α, the Null hypothesis was rejected. For the same reason as above, a difference of the alphanumeric code versus the other two codes is concluded.

B. REACTION TIME

The observed reaction times are listed in Appendix E, Table IX. First, the mean reaction times of the subjects under the three coding techniques were analyzed by the "Friedman Two-Way Analysis of Variance by Ranks" to test the Null hypothesis,

H_0 : the three coding techniques have no effect on the mean reaction time of the subjects,

against the alternative,

H_1 : the three coding techniques have differential effects on the mean reaction time.

The mean reaction times in seconds are given in Appendix D, Table VIII.

The following data were used to calculate the chi square test statistic:

$N = 24$, $k = 3$, R_1 (alphan.) = 68,

$\alpha = 0.05$, df = 2 , R_2 (colors) = 24, and

R_3 (symbols) = 52 .

This resulted in a value of $X_r^2 = 41.34$ with an associated probability of less than 0.001 which is less than the selected α-level. Therefore, H_0 is rejected and differences between the three coding modalities with respect to reaction times are concluded. Regarding the ranksums of 24, 52, and 68, the only actual conclusion that can be drawn is that the reaction time of the color code technique is significantly faster than the reaction time of the alphanumeric code. Therefore, the parametric test "Analysis of Variance" (ANOVA) (Hicks, 1973) was applied to the data. A comparison of the Boxplots (McNeil, 1977) shown in Appendix F, Figure 5, however, indicated the non-homogeneity of the variances and positive skewness of the data.

In order to obtain homogeneity, McNeil (1977) suggested a series of transformations that can be applied to the raw data. Within the root transformation, the fifth root turned out to be best. The resulting Boxplots in Figure 6 of Appendix F show that the Midspreads, that is, the spread from the 25th to the 75th quantile, are nearly the same, and that most of the positive skewness disappeared. The transformed data are attached in Appendix E, Table X. A summary table of the original and the transformed data is given in Table XI of Appendix E.

To test the Null hypothesis,

H_0 : the variances are the same, against the alternative

H_1 : the variances are not homogeneous,

Bartlett's Test (Brownlee, 1960) was conducted.

The test statistic, $TS = \dfrac{-\sum_{i=1}^{k} f_i \ln \dfrac{s_i^2}{s^2}}{1 + \dfrac{1}{3(k-1)} \sum_{i=1}^{k} \dfrac{1}{f_i} - \dfrac{1}{f}}$, is

chi square distributed with k - 1 degrees of freedom.

f is the number of data minus the number of columns,

f_i is the number of data in column i minus one,

s_i^2 is the variance of column i,

k is the number of columns, and

s^2 is calculated by the formula

$$s^2 = \frac{1}{\sum_{i=1}^{k} f_i} \sum_{i=1}^{k} f_i \, s_i^2 .$$

To calculate the test statistic, the following data were used:

$S_1^2 = 0.0035$ $f_1 = 87$ $f = 319$

$S_2^2 = 0.0024$ $f_2 = 117$ $s^2 = 0.0031$

$s_3^2 = 0.0035$ $f_3 = 115$ $df = 2$.

This resulted in a test statistic of $X^2_{(2)} = 4.38$. The corresponding probability of about 0.12 is more than the α-level of 0.05. H_0 is accepted; homogeneity of the three variances is concluded.

Inspection of the Stemleaf plots (McNeill, 1977, p. 2), given in Appendix G, indicated that the data of the three columns were normally distributed.

The summary of the two-way ANOVA is given in Table V.

Table V

ANOVA Summary

Source	df	SS	mS	F
Code	2	0.78	0.390	130**
Subjects	23	0.11	0.005	1.67*
Codes X Subjects	46	0.22	0.005	1.67*
Error	250	0.65	0.003	
Total	321	1.76		

* $P < .05$

** $P < .01$

The results of the ANOVA confirmed that there are differences in reaction time between the three coding modalities. As the critical value for 2 and 250 degrees of freedom is approximately 3 (Hicks, 1973, tables), the obtained F-ratio of 130 indicates high significance. The F-ratios for the subjects and for the interaction of subjects with codes are also significant at the 0.05 level, but much less than the ratio for the codes alone.

For the codes, the Newman-Keuls range test (Hicks, 1973, p. 35) was conducted to analyze between code differences. The standard error of the mean for each code was 0.005 for colors and symbols and 0.006 for alphanumerics. This resulred in values for least significant ranges of 0.0139 and 0.0166 for differences between adjacent (ordered) mean values and 0.0166 and 0.0199 for every other mean value. As all three differences between the means of the codes:

colors versus symbols 0.069

colors versus alphanumerics 0.123

symbols versus alphanumerics 0.054

exceeded the least significant ranges, differences in reaction time between all three codes are concluded. That is, the reaction time of the color code is shortest, followed by the symbol code, and the reaction time for the alphanumeric code is longest.

V. DISCUSSION AND CONCLUSION

The data obtained from the experiment therefore suggested that the color- and symbol-codes are superior to the alphanumeric code with respect to the minimum number of errors made, and that with regard to the reaction time the color code is superior to the other codes, followed by the symbol code.

Although the ANOVA gives strong evidence that there are differences between the three coding modalities, the result was to be treated with caution. As the exposure time of the cards was exactly 1.5 seconds, all reaction times exceeding this value were lost. In case of the colors, two reaction times were truncated for the symbols four, and in case of alphanumeric code 32 data were truncated. The truncation of the reaction time data, mainly for the alphanumeric code, led to an underestimation of the mean values. As, however, with the underestimated mean value for the reaction time of the alphanumeric code, ANOVA suggests significant differences; it would give an even more significant difference if all reaction time data for the alphanumeric code were included. For this reason, the conclusions drawn from the ANOVA test are justified.

Nevertheless the general statement that the color code is superior to the other coding techniques under all conditions cannot be made because of the following limitations imposed on the experiment:

1. Artificial Environment

The experiment was carried out in a controlled artificial environment that eliminated most sources of environmental load imposed on the subject as noise, different light conditions and temperature. Further, because of the short duration of the experiment, no significant additional load because of fatigue effects could arise. And more important, during the experiment the subjects had only a single task (scan the cards, search for a target, identify it, and respond) while under operational conditions, an operator has multiple, complex tasks to perform which may impose a large workload. Under these conditions, different results for the three codes may be obtained.

2. Selection of Subjects

The selection of subjects was not random. All subjects were from the Naval Postgraduate School population. This sample represents neither the whole population nor the population of pilots. Therefore, the conclusions are only valid for individuals with backgrounds similar to those of Naval Postgraduate School military officers.

3. Selection of Stimuli

The selection of stimuli imposes another limitation on the results because the results can only be regarded with respect to the three sets of stimuli used in the experiment. Different sets of symbols and/or alphanumerics may lead to different reaction times and different percentages of errors. The color code in general seems to have an advantage because some colors have a conventional meaning while symbols and alphanumerics do not. In addition, the two alphanumerics E and F, used in the experiment, might have increased the load on the subject because of their similarity. To discriminate between these letters probably two fixations were necessary which might have caused longer reaction times and more errors. Also, the letter F could have been erroneously interpreted as foe. Further, the experiment emphasized the search task because the finding of the target included probably at least for the color code the identification of the target. Therefore, the results concerning the reaction time were not surprising as it is known that the color code has the shortest search time.

Even if repeated experiments with different sets of stimuli and different subjects under more load confirm the results obtained from this experiment, there are some factors that have to be regarded before colored CRTs can be utilized in the cockpit of aircraft:

a. Training.

The advantage of colors versus symbols in reaction time might be overcome by training. Research should be done in this area and the cost of additional training compared with the cost of a color display.

b. Number of Dimensions that Can Be Coded with Color

As the number of colors was limited to four, only four dimensions could be coded with colors. Coding of more dimensions with colors will lead to performance degradation. Another coding modality (e.g., colored symbols) should be used for this case, thus utilizing the principle of redundant coding.

3. Ambient Illumination

Brightness and contrast of displayed information in relation to ambient illumination is an important factor for display systems. With conventional color CRT displays, the brightness of the spectral colors is lower than can be obtained with a black and white CRT. Therefore, the colored system must normally be operated in lower ambient illumination. Infalling sunlight in the cockpit during daytime is, however, very high ambient illumination and can cause colors to wash out and to reduce saturation.

4. Peripheral Color Vision

Color cannot be sensed in the peripheral area of the retina and vision becomes dichromatic at approximately 60 degrees from the fovea (Krebs, 1978). This zone varies from individual to individual. The lack of color vision in the periphery sets constraints on the location of the colored display.

5. Color Vision Defects

There are several types of color vision defects, but these defects should not influence the decision whether to use a color display because only eight percent of the healthy male population (female 0.4%) have some kind of color defects.

These individuals are excluded from most military jobs by screening. However, before extending the use of colored displays for other types of jobs, these personnel have to be screened, and the number of operators will be restricted. Perhaps some operators that perform well on monochromatic systems will be eliminated from their jobs.

6. Cost, Reliability, Readiness

Not only the procurement cost for a colored CRT is higher than for a black and white CRT (about 20%); also the maintenance cost will be increased due to more sophisticated maintenance equipment and better trained maintenance personnel. Further, a shorter lifetime and shorter maintenance intervals can be expected in combination with longer maintenance time. This leads consequently to a reduction in the availability of the aircraft and therefore to a decrease in their readiness.

Although most people like colored displays, the above factors have to be considered before selecting a colored display. A cost-benefit analysis should be performed.

APPENDIX A

INSTRUCTIONS FOR CODING EXPERIMENT

I. Objectives of the Experiment

The objective of this experiment is to find out whether there are differences between several coding modalities with respect to reaction time and the number of errors made.

An application might be the coding of a tactical display on board airplanes.

The coding modalities used in the experiment are:

- alphanumerics,
- colors, and
- symbols.

Today's state-of-the-art in electronic engineering allows all three coding modalities at different costs.

II. General Instructions

Each subject is shown three sets of cards with either alphanumerics, colors, or symbols by means of a Tachistoscope with automatic, computerized cardchanger.

The following table shows the codes used together with their possible meaning:

Color	Symbol	Alphanum.	Possible Meaning
Red Dot	Δ	E	Enemy, Danger
Yellow Dot	□	U	Unknown, Unidentified
Green Dot	+	F	Friendly Forces
Blue Dot	○	N	Neutral Forces/contacts

Subjects have to search the cards and determine whether or not they show a red dot, a triangle, or an E, respectively, and respond to those, and only to those, cards by pressing a button placed under the Tachistoscope as fast as possible. Superimposed on the cards is a "noise" card to complicate the task. The number of errors will be counted, and the reaction time will be measured.

The next figures represent samples of the three sets of cards. Note that they show an E, a red dot, or a triangle. Subjects have to respond to those cards while they are presented; a later response will be counted as an error. Upon a correct response a new card will be presented immediately. Otherwise the card stays in the viewing field for 1.5 seconds.

III. Procedure

A. Determination of the Sequence

The Random Number Generator of the hand-held calculator TI 59 (PGM 2 of applied statistics module) will be used to generate random numbers drawn from the uniform distribution between 1 and 6. These random numbers determine the sequence in which the codes will be presented.

1 means alphanumerics - colors - symbols

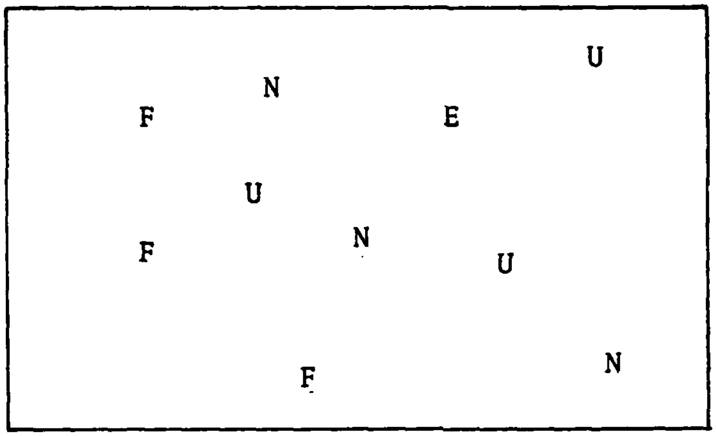
2 means alphanumerics - symbols - colors

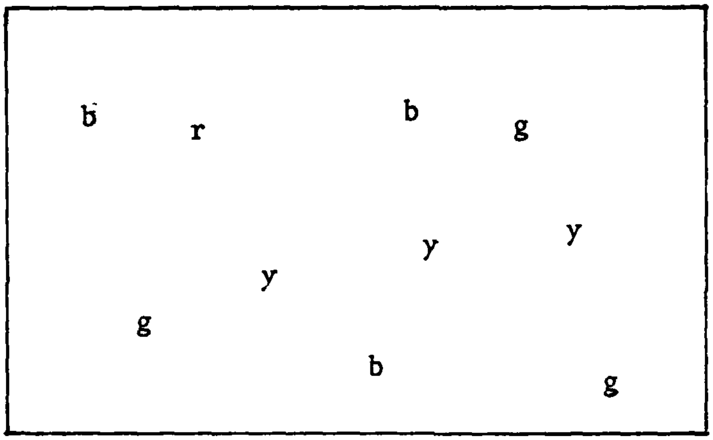
3 means colors - alphanumerics - symbols

4 means colors - symbols - alphanumerics

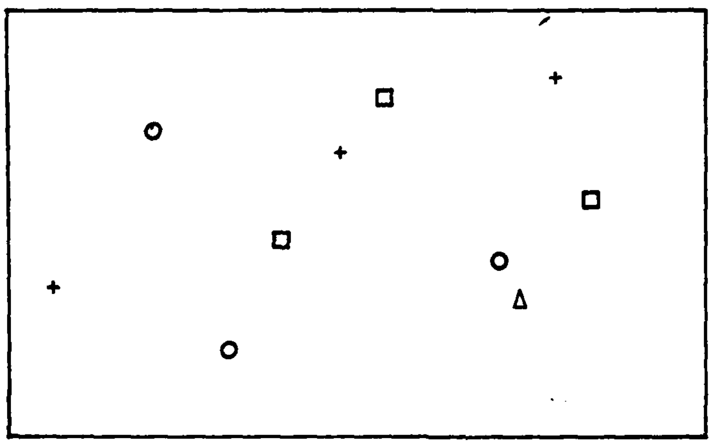
5 means symbols - alphanumerics - colors

6 means symbols - colors - alphanumerics.





y = yellow dot
g = green dot
b = blue dot
r = red dot



B. Warm-up Phase

After the subjects are seated in the booth, and the deck of cards is placed in the card changer by the experimenter, the door will be closed and after 10 seconds the first 10 cards will be shown to the subjects in the viewing field of the Tachistoscope at a rate of one card per 1.5 seconds. On identification of an E, a red dot, or a triangle, the button under the Tachistoscope has to be pressed.

This will be repeated for the remaining two sets of cards. The probability of getting a card that requires a response is 0.5.

C. Hot Runs

After completion of the warm-up phase, sets of 40 cards will be placed in the card changer. The procedure, the sequence of the codes and the presentation rate will be the same. The probability of getting a card that requires a response, however, will be much lower. These cards are randomly distributed within the deck of cards.

IV. Please do not smoke while performing the experiment.

V. Thank you for participating in the experiment.

APPENDIX B

BASIC PROGRAM

```
10  REM -  THIS PREAMBLE MUST PRECEDE ALL PROGRAMS
20  REM -  USING THE LAB8/E 'SPECIAL FUNCTIONS'.
30  UDEF INI(N),PLY(Y),DLY(N),DIS(S,E,N,X)
40  UDEF SAM(C,N,P,T),CLK(R,O,S),CLW(N),ADC(N)
50  UDEF GET(M,L),PUT(M,L),DRI(N),DRO(M,N)
90  DIM A(100)
91  PRINT"NUMBER OF CARDS"
92  INPUT N1
93  PRINT "ENTER VIEWING TIME IN 1/100 OF A SECOND"
94  INPUT N2
95  E0=0\E1=0\E2=0
100 REM **********INITIALIZE FOR SET OF 50 CARDS  ************
105 PRINT "ENTER SUBJECT'S NUMBER"
106 INPUT S1
120 FOR I=1 TO N1
122 A(I)=0
123 NEXT I
125 PRINT "ENTER TARGET CARDS EACH # FOLLOWED BY <RET>"
126 FOR I=1 TO 5
127 INPUT N
128 A(N)=1
135 NEXT I
140 E0=0 \ E1=0 \ E2=0
200 REM ************   RELEASE CARDS   **********************
202 Z=CLK(2,500,0)
204 Z=CLW(0)
210 FOR I=1 TO N1
220 Z=DRI(0)\J=0
230 Z=DRO(1,0)
231 Z=CLK(2,23,0) \ Z=CLW(0)
232 Z=DRO(0,0) \ Z=CLK(2,100,0) \ Z=CLW(0)
```

```
235 Z=CLK(2,1,0)
240 Z=CLW(0)
245 Z=DRI(0)
250 J=J+1
255 IF Z<>0 GO TO 300
260 REM  *********NO RESPONSE YET  ****************
265 IF J<N2 GO TO 235
270 REM  ********  NO RESPONSE AFTER N2 CARDS  ************
275 IF A(I)=0 GO TO 399 \ REM  CORRECT RESPONSE
280 IF A(I)=1 GO TO 399 \ REM  OMISSION ERROR
300 IF A(I)=0 GO TO 370 \ REM COMMISSION ERROR
305 IF A(I)=1 GO TO 320 \ REM TARGET DETECTED
320 REM ***************  COLLECT RESULT  ***************
325 A(I)=J
330 GO TO 399
370 A(I)=2
380 R1=N2-J \ Z=CLK(2,R1,0) \ Z=CLW(0)
399 NEXT I
420 FOR I=1 TO N1
425 IF A(I)>0 GO TO 430\E0=E0+1\GO TO 499
430 IF A(I)>1 GO TO 440\E1=E1+1\GO TO 499
440 IF A(I)>2 GO TO 450\E2=E2+1\GO TO 499
450 E0=E0+1
499 NEXT I
510 PRINT "RESULTS - SUBJECT NUMBER";S1
512 PRINT "-----------------------------------------"
513 PRINT
514 PRINT "NUMBER OF CARDS = ";N1
516 PRINT "CORRECT RESPONSES =";E0
518 PRINT "COMMISSION ERRORS =";E2
520 PRINT "OMISSION ERRORS =";E1
530 PRINT
540 PRINT "RESPONSE TIMES FOR DETECTED TARGETS"
545 PRINT "-----------------------------------"
555 FOR I=1 TO N1
560 IF A(I)<3 GO TO 570
```

```
565 PRINT TAB(20);A(I)
570 NEXT I
580 PRINT "IF ANOTHER RUN FOR THIS SUBJECT TYPE 1 ELSE TYPE 2"
590 INPUT K
600 IF K=1 GO TO 91
670 PRINT "IF ANOTHER SUBJECT IS WAITING TYPE 1 ELSE TYPE 2"
675 INPUT K
680 IF K=1 GO TO 91
690 PRINT
700 PRINT "END"
998 STOP
999 END

READY
```

APPENDIX C
PERCENTAGE OF ERRORS

Table VI

Percentage of Errors Due to Errors of Omission

	Codes		
Subjects	Alphan.	Colors	Symbols
1	5	0	0
2	5	0	0
3	10	0	0
4	0	0	2.5
5	0	0	0
6	2.5	0	0
7	0	0	0
8	10	0	0
9	7.5	0	0
10	2.5	0	0
11	2.5	2.5	0
12	0	0	0
13	2.5	0	0
14	0	0	0
15	10	0	0
16	2.5	2.5	2.5
17	2.5	0	0
18	0	0	0
19	2.5	0	0
20	5	0	0
21	2.5	0	0
22	0	0	0
23	2.5	0	2.5
24	5	0	2.5
$\bar{X}$	3.33	0.21	0.42
σ	3.27	0.71	0.95

Table VII

Percentage of Errors Due to Errors of Commission

Subjects	Alphan.	Codes Colors	Symbols
1	0	0	0
2	0	0	0
3	2.5	0	0
4	2.5	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	2.5	0	0
9	7.5	0	0
10	2.5	0	0
11	0	2.5	0
12	0	0	0
13	0	0	0
14	0	0	0
15	7.5	0	0
16	2.5	2.5	0
17	2.5	0	0
18	0	0	0
19	2.5	0	0
20	2.5	0	0
21	0	0	0
22	0	0	0
23	5	0	2.5
24	2.5	0	0
$\bar{X}$	1.77	0.21	0.10
σ	2.27	0.71	0.51

APPENDIX D

Table VIII

Mean Reaction Time (in Seconds)

	Codes		
Subjects	Alphan.	Colors	Symbols
1	0.86	0.64	0.76
2	0.98	0.47	0.69
3	1.39	0.45	0.67
4	1.08	0.38	0.52
5	0.65	0.33	0.91
6	1.07	0.42	0.72
7	0.89	0.40	0.84
8	0.82	0.57	0.65
9	0.55	0.34	0.72
10	1.10	0.63	0.67
11	0.81	0.46	0.63
12	0.91	0.44	0.76
13	0.92	0.34	0.62
14	1.07	0.49	0.70
15	0.60	0.57	0.75
16	0.72	0.40	0.82
17	0.72	0.47	0.57
18	0.75	0.47	0.54
19	0.82	0.37	0.52
20	1.02	0.37	0.47
21	0.74	0.49	0.57
22	0.91	0.31	0.51
23	0.72	0.38	0.57
24	1.03	0.43	0.73
$\overline{X}$	0.88	0.44	0.66
σ	0.19	0.09	0.11

APPENDIX E

Table IX

Reaction Time Data of Subjects (in Seconds)

Subject	Codes: Alphanumerics			Codes: Colors			Codes: Symbols		
1		0.92	1.04	0.55	0.58	0.75	0.41	0.89	1.28
		0.61		0.84	0.49		0.51	0.69	
2		0.53	1.28	0.65	0.54	0.33	0.69	0.83	0.57
		1.14		0.25	0.58		0.50	0.87	
3		1.39		0.65	0.45	0.41	0.91	0.61	0.67
				0.34	0.39		0.54	0.63	
4	0.87	1.36	1.43	0.36	0.36	0.52	0.52	0.46	0.48
	0.77	0.98		0.27	0.38		0.62		
5	0.48	0.65	0.68	0.26	0.35	0.31	1.17	1.37	0.77
	0.51	0.95		0.33	0.40		0.49	0.77	
6	1.07	1.37	1.11	0.44	0.34	0.47	0.91	0.74	0.72
	0.71			0.43	0.42		0.55	0.68	
7	0.49	1.13	1.12	0.37	0.48	0.41	0.60	0.75	1.19
	0.65	1.04		0.36	0.38		0.50	1.15	

Subject	Codes		
	Alphanumerics	Colors	Symbols
8	0.82	1.00 0.54 0.45 0.52 0.36	0.63 0.50 0.62 0.51 0.99
9	0.43 0.66	0.44 0.34 0.33 0.29 0.29	0.89 0.64 0.92 0.66 0.47
10	1.48 0.77 1.15 1.01	0.89 0.49 0.48 0.56 0.74	0.54 0.44 0.36 0.55 1.44
11	1.07 0.75 0.71 0.70	0.72 0.41 0.35 0.37	0.48 0.50 0.50 0.46 1.21
12	1.02 0.95 0.88 0.91 0.78	0.51 0.41 0.39 0.42 0.46	0.61 0.71 0.62 0.87 0.98
13	1.15 0.84 0.70 0.99	0.29 0.37 0.34 0.36 0.32	0.47 0.56 0.57 0.58 0.94
14	1.36 0.69 1.38 0.65 1.28	0.49 0.42 0.44 0.51 0.57	0.58 0.74 0.43 0.43 1.34
15	0.6	0.45 0.53 0.76 0.51 0.58	0.56 0.89 0.82 0.93 0.57
16	0.61 0.57 1.17 0.51	0.37 0.41 0.41 0.39	0.83 0.84 0.91 0.70

Subject	Codes								
	Alphanumerics			Colors			Symbols		
17	0.70 0.67	0.62	0.87	0.51 0.44	0.68 0.36	0.38	0.55 0.51	0.76 0.60	0.41
18	0.86 1.14	0.63 0.55	0.56	0.78 0.42	0.49 0.31	0.34	0.46 0.41	0.77 0.59	0.47
19	0.84 0.72	1.01	0.72	0.29 0.57	0.30 0.33	0.37	0.51 0.49	0.62 0.45	0.55
20	0.99	1.28	0.78	0.47 0.37	0.40 0.30	0.32	0.49 0.50	0.49 0.43	0.43
21	0.71 1.07	0.66	0.51	0.65 0.58	0.40 0.33	0.48	0.44 0.80	0.60 0.49	0.54
22	0.68 0.91	0.95 0.70	1.29	0.29 0.39	0.24 0.32	0.29	0.40 0.62	0.52 0.30	0.72
23	0.61 0.71	0.80	0.75	0.35 0.43	0.41 0.27	0.46	0.54 0.57	0.40	0.76
24	0.60	1.16	1.34	0.37 (.62	0.43 0.32	0.39	1.01 0.45	0.52	0.95

APPENDIX E

Table X

Transformed Reaction Time Data

Subject	Codes		
	Alphanumerics	Colors	Symbols
1	0.98 1.01 0.91	0.89 0.90 0.94 0.97 0.87	0.84 0.98 0.87 1.05 0.93
2	0.88 1.03 1.08	0.92 0.88 0.80 0.76 0.90	0.93 0.96 0.89 0.87 0.97
3	1.07	0.92 0.85 0.84 0.81 0.83	0.98 0.91 0.92 0.88 0.91
4	0.97 1.06 1.07 0.95 1.00	0.82 0.82 0.88 0.77 0.82	0.88 0.86 0.86 0.91
5	0.86 0.92 0.93 0.87 0.99	0.76 0.81 0.79 0.80 0.83	1.03 1.06 0.95 0.87 0.95
6	1.01 1.06 1.02 0.93	0.85 0.81 0.86 0.85 0.84	0.98 0.94 0.94 0.89 0.93
7	0.87 1.02 1.02 0.92 1.01	0.82 0.86 0.84 0.82 0.82	0.90 0.94 1.04 0.87 1.03
8	0.96	1.00 0.88 0.85 0.88 0.82	0.91 0.87 0.91 0.87 1.00

Subjects	Codes		
	Alphanumerics	Colors	Symbols
9	0.85 0.92	0.85 0.81 0.80 0.78 0.78	0.98 0.92 0.98 0.92 0.86
10	1.08 0.95 1.03 1.00	0.98 0.87 0.86 0.89 0.94	0.88 0.85 0.82 0.89 1.08
11	1.01 0.94 0.93 0.93	0.94 0.84 0.81 0.82	0.86 0.87 0.87 0.86 1.04
12	1.00 0.99 0.98 0.98 0.95	0.87 0.84 0.83 0.84 0.86	0.91 0.93 0.91 0.97 1.00
13	1.03 0.97 0.93 1.00	0.78 0.82 0.81 0.82 0.80	0.86 0.89 0.89 0.90 0.99
14	1.06 0.93 1.07 0.92 1.05	0.87 0.84 0.85 0.87 0.89	0.90 0.94 0.85 0.85 1.06
15	0.90	0.85 0.88 0.95 0.87 0.90	0.89 0.98 0.96 0.99 0.89
16	0.91 0.89 1.03 0.87	0.82 0.84 0.84 0.83	0.96 0.97 0.98 0.93
17	0.93 0.91 0.97 0.92	0.87 0.93 0.82 0.85 0.82	0.89 0.95 0.84 0.87 0.90
18	0.97 0.91 0.89 1.03 0.89	0.95 0.87 0.81 0.84 0.79	0.86 0.95 0.86 0.84 0.90

Subjects	Codés		
	Alphanumerics	Colors	Symbols
19	0.97 1.00 0.94 0.94	0.78 0.79 0.82 0.89 0.80	0.87 0.91 0.89 0.87 0.85
20	1.00 1.05 0.95	0.86 0.83 0.80 0.82 0.79	0.87 0.87 0.85 0.87 0.85
21	0.93 0.92 0.87 1.01	0.92 0.83 0.86 0.90 0.80	0.85 0.90 0.88 0.96 0.87
22	0.93 0.99 1.05 0.98 0.93	0.78 0.75 0.78 0.83 0.80	0.83 0.88 0.94 0.91 0.79
23	0.91 0.96 0.94 0.93	0.81 0.84 0.86 0.85 0.77	0.88 0.83 0.95 0.89
24	0.90 1.03 1.06	0.82 0.85 0.83 0.91 0.80	0.88 1.00 0.99 0.85

APPENDIX E

Table XI

Data Summary

	Original Data			Transformed Data		
	Alphan.	Colors	Symbols	Alphan.	Colors	Symbols
Mean	0.878	0.442	0.663	0.9670	0.8440	0.9130
Variance	0.072	0.019	0.054	0.0035	0.0024	0.0035
Std. Dev.	0.269	0.139	0.233	0.0590	0.0489	0.0059
Range	1.050	0.760	1.140	0.2370	0.2480	0.2900
Interquartile Range	0.405	0.160	0.270	0.0920	0.0634	0.0785
Coeff. of Skewness	0.465	1.420	1.260	0.1090	0.7550	0.689

APPENDIX F

Figure 5

Boxplots of Reaction Time Data

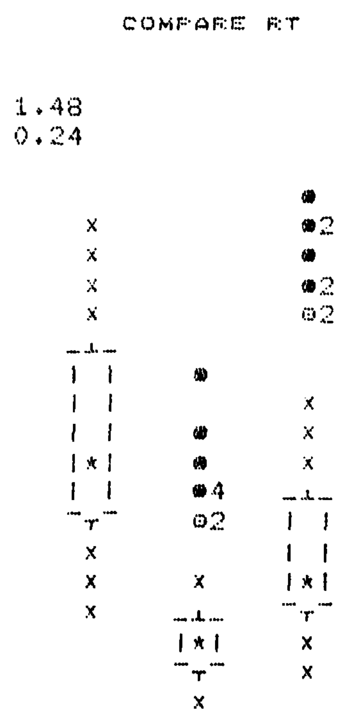
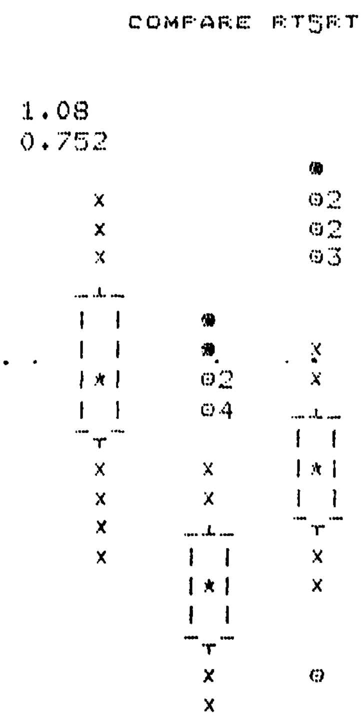


Figure 6

Boxplots of Transformed Reaction Time Data



APPENDIX G

```
STEMLEAF 88↑RT5RT[;1]

84|5
86|37EEE
88|17BE
90|336669CHHH
92|003668BBBBEEEEGG
94|4499CCG
96|166ADDF
98|113AAAGII
00|22488EEE
02|1357788AC
04|BBBC
06|033578E
08|2
```

Figure 7

Stemleaf Plot of Trans-Formed Reaction Time Data of Alphanumeric Code

```
STEMLEAF 118↑RT5RT[;2]

75|28
76|4
77|00
78|1111166
79|116666
80|1111166666
81|111555555
82|00000004448888
83|333777777
84|1111555999
85|22266
86|003337777
87|444477
88|1447
89|1447777
90|9
91|777
92|6
93|6
94|247
95|2
96|6
97|7
98|
99|
00|0
```

Figure 8

Steamleaf Plot of Trans-formed Reaction Time Data of Color Code

APPENDIX G

Figure 9

Stemleaf Plot of Transformed Reaction Time Data of Symbol Code

```
STEMLEAF 116↑RT5RT[⍋3]

78|6
79|
80|
81|5
82|
83|33777
84|555599
85|22666
86|0003377777
87|1111114444777
88|44447777
89|11144477
90|03336699999
91|225
92|03688
93|1466
94|22477999
95|6
96|1336
97|33777
98|111368
99|068
00|2
01|
02|8
03|259
04|
05|1
06|05
07|6
```

APPENDIX H

APL - Functions for Boxplots and Stemleafs

```
        ∇COMPARE[⎕]∇

     ∇ Z←COMPARE X;U;L;Y;M;C;J;F
[1]    X←(÷1E¯20+U−⎕←L)×((⎕←U←⌈/Y)−DEPTH×L←⌊/Y←(MISS≠,X)/,X)+X×DEPTH−1
[2]    M←(÷1E¯20+U−L)×(U−DEPTH×L)+MISS×DEPTH−1
[3]    Z←(DEPTH,6×C←ρX[1;])ρ' '
[4]    J←0
[5]    J←J+1
[6]    F←DEPTH FILL F[⍋F←(F≠M)/F←X[;J]]
[7]    Z[;¯2+6×J]←' |¯⊥_⊤|                         '[1+F]
[8]    Z[;¯1+6×J]←' ⋆⊤=⊥= |X  ○○○○○○○○○ ●●●●●●●●●'[1+≥
F]
[9]    Z[;6×J]←' |¯⊥_⊤|      23456789  23456789'[1+F]
[10]   →5×⍳J<C
[11]   Z←⊖Z
     ∇


        ∇STEMLEAF[⎕]∇

     ∇ Z←STEMLEAF X;C;R;S;SI;I;J;F;A;W;L;WW;AA;XW
[1]    C←10⋆1−⌊10⍟R←1E¯20+(X[ρX]−(X←X[⍋X←,X])[1])÷SCALE
[2]    SI←(1+3×+/(R×C)> 25 50)++/(ρX)> 25 100
[3]    X←⌊0.5+X×C×10⋆+/SI= 2 3 6
[4]    F←+/(SI=⍳9)/ 0.5 2 1 1 0.5 2 2 1 0.5
[5]    A←20ρ'0123456789ABCDEFGHIJ',Z←''
[6]    I←F×⌊X[1]÷10×F
[7]    XW←8+WW←WIDTH−4
[8]    S←'− '[1+J←X[1]≥0]
[9]    L←1+(|W←(X≤(10×I)+J×¯1+10×F)/X)−10×L|I
[10]   AA←A[1+(10 10)⊤|L|I]
[11]   →((ρA[L])≤WW)/L1
[12]   Z←Z,XWρS,AA,'|',(WW↑A[L]),'+',(LIT(ρA[L])−WW),2ρ' '
[13]   →L2
[14] L1:Z←Z,XWρS,AA,'|',A[L],XWρ' '
[15] L2:I←I+F×1−(I=0)×X[1]<0
[16]   →8×⍳0<ρX←(ρW)↓X
[17]   Z←((⌊(ρZ)÷XW),XW)ρZ
     ∇
```

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