1984-09

Shape with and without redundant colour as coding mechanism for simulated radar displays in a time-extended simple vigilance task.

Hessling, Urs

Monterey, California. Naval Postgraduate School

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SHAPE WITH AND WITHOUT REDUNDANT COLOUR
AS CODING MECHANISM FOR SIMULATED
RADAR DISPLAYS IN A TIME-EXTENDED
SIMPLE VIGILANCE TASK

by

Urs Hessling

September 1984

Thesis Advisor: C. W. Hutchins

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Shape with and without Redundant Colour as Coding Mechanism for Simulated Radar Displays in a Time-extended Simple Vigilance Task		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis September 1984
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Urs Hessling		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93943		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, CA 93943		12. REPORT DATE September 1984
		13. NUMBER OF PAGES 62
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		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)

vigilance task, redundant colour, operator performance, underload, nighttime, codes, shape, achromatic

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

A simple monitoring task was extended to eight hours to achieve a higher realism in testing human vigilance. An extremely low stimulus frequency, the confinement of the subjects during the test run, and the scheduling of the experiment from 10:00PM to 6:00AM were further tools to create a more operational environment. Subjects were treated in one of two conditions, simulating a shipborne tactical radar display with precoded

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. (Continued)

information, to test a currently operational shape coding mechanism (control condition) for positive effects due to the addition of redundant colour codes (experimental condition).

The results did not support the hypothesis of positive effects in the experimental condition. In fact, the number of ommissions was significantly higher in that condition. Longer reaction times in both conditions were found to be correlated to higher signal and display densities.

The following recommendations were made for further research:

In the area of monochromatic displays, the effects of different, non-white colours and changes in light characteristics, e.g. luminance and saturation, should be compared against those of standard CRT colour and light parameters.

For multichromatic displays, experiments involving secondary tasks or artificial stimuli should be conducted to gain further evidence about the possiblity of operator's 'target fixation' during monitoring due to certain colours or colour combinations. The importance of further research in the area of 'underload'-situations is emphasized.

Shape with and without Redundant Colour as Coding Mechanism for Simulated Radar Displays in a Time-extended Simple Vigilance Task

by

Urs Hessling
Lieutenant Commander, Federal German Navy

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1984

ABSTRACT

A simple monitoring task was extended to eight hours to achieve a higher realism in testing human vigilance. An extremely low stimulus frequency, the confinement of the subjects during the test run, and the scheduling of the experiment from 10 p.m. to 6 a.m. were further tools to create a more operational environment. Subjects were treated in one of two conditions, simulating a shipborne tactical radar display with precoded information, to test a currently operational shape coding mechanism (control condition) for positive effects due to the addition of redundant colour codes (experimental condition).

The results did not support the hypothesis of positive effects in the experimental condition. In fact, the number of missed signals was significantly higher in that condition. Longer reaction times in both conditions were found to be correlated to higher signal and display densities.

The following recommendations were made for further research:

In the area of monochromatic displays, the effects of different, non-white colours and changes in light characteristics, e.g. luminance and saturation, should be compared against those of standard CRT colour and light parameters.

For multichromatic displays, experiments involving secondary tasks or artificial stimuli should be conducted to gain further evidence about the possibility of operator's 'target fixation' during monitoring due to certain colours or colour combinations. The importance of further research in the area of 'underload'-situations is emphasized.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

I would like to acknowledge the voluntary work of the persons participating in the experiment:

Bert R. Algood, LT, United States Navy
Portia A. Baird, LCDR, United States Navy
Wendy L. Bradfield-Smith, LCDR, United States Navy
Bjoern Brekke, LCDR, Royal Norwegian Navy
Rivet J. Daigre, LT, United States Navy
William F. Eckert, Jr., LCDR, United States Navy
William J. Esmann, MAJ, United States Marine Corps
Michael J. Filkins, LCDR, United States Navy
Reinhard Haeger, LCDR, Federal German Navy
Roger D. Harrelson, LT, United States Navy
Hasan Basri Mutlu, LT(j.g.), Turkish Navy
John J. Parus, LCDR, United States Navy
Robert R. Richbourg, CAPT, United States Army
Timothy W. Rolston, LT, United States Coast Guard
Patrick A. Sandoz, LCDR, United States Navy
Mucahit Sislioglu, LT(j.g.), Turkish Navy
Herschel Smith, CAPT, United States Air Force
George G. Sprung, LT, United States Navy
Robert E. Westbrook
Klaus-Harald Zang, LCDR, Federal German Navy

I am grateful to my wife Wiebke and my son Christoph Gordon for the patience they showed during the time of my work.

I. INTRODUCTION

A. OPERATIONAL SETTING

The employment of fast patrol boats (FPB's) of the Federal German Navy in operations in the Baltic creates a special vigilance problem. Due to limitations in accomodation space, the boats have a small complement of men, just sufficient in number to man battle stations, but excluding any watch shifts. A normal operation, preceded by replenishment of ammunitions, water, and fuel, maintenance work, and tactical briefings during daylight, commences after sunset and is completed or terminated before dawn. Even in the age of sophisticated weapon and surveillance systems, the dark still provides the best cover against the FPB's most feared predator, the aircraft. But it is just that time interval, which arouses major concern about the performance of radar operators. The introduction of an up-to-date combat information system has eased the operators' surveillance task, but there are still questions about intolerable decrements in operator vigilance, which is crucial through the whole length of a mission, especially under the expection of comparably low signal density for sea surveillance in the Baltic in time of tension or armed conflict.

B. TECHNICAL BACKGROUND

Since the FPB's combat information system is designed to allow the incorporation of user-originated software changes, attention has focused on improvements in that sector. Most likely, the eventual results will be, in human factors vocabulary, changes in signal display, more specificly, in information coding. Other environmental improvements to enhance operator performance are infeasible in view of the limited space and other restrictions typical for a naval vessel. Such a set of conditions requires further research to gain insight into the several possibilities of improvement which are available. The one chosen as a promising alternative was the addition of redundant colour to the shape coding mechanism already in use in the tactical display. It is the goal of this study to determine whether the expenditure of the considerable costs of implementing such a change can be justified.

The following review covers relevant findings in both vigilance and signal theory to establish a more thorough understanding for this combination.

II. REVIEW

A. VIGILANCE

1. Circadian Rhythm and Correlates

Vigilance has been a major concern of human factors studies in the past and present. For our special case, an eight hours sustained operation, it has been found that

> " ... with a few notable exceptions,... ,vigilance researchers simply have not attempted to measure whatever performance decrements may occur during such time frame." [Ref. 1: p. 49].

All those who make the attempt have to deal with the phenomenon of circadian or diurnal rhythm. Coates [Ref. 2] states that the extent of performance decrement in sustained operations depends on the simultaneous phase of circadian rhythm. More specifically, we derive from his results that a operational phase from dusk to dawn coincides with a worst case decrement in vigilance performance of nearly 35 %. The few existing investigations of real world performance in the same time frame are even more specific showing a performance 'low' in terms of number of errors at 3 a.m. [Ref. 3] and from midnight to 6 a.m. [Ref. 4], respectively. A field study on vigilance during prolonged night driving [Ref. 5] concurs with these results. Furthermore, the experimenters conclude that the decrement found in their case was not only caused by previous daily work, but by its combination with declining diurnal rhythm, monotonous task, and lack of sleep, all these contributing to a marked deterioration of performance even under confrontation with personal danger. We could hardly find a situation more apt to comparison with the present experiment. The experiments of O'Hanlon and Kelley [Ref. 6], Klein [Ref. 7], and Poulton [Ref. 8] confirm the concern about loss of vigilance in spite of grave personal consequences of inattention, even in recognized emergencies.

One must exercise caution, however, in assuming an external validity of these results for this test setting, because all of the studies mentioned above are field experiments and used a relatively more complex task , e.g. the driving of a motor vehicle, instead of monitoring.

The important aspect of visual fatigue can only be mentioned, emphasizing that there are no results showing a definite correlation between that phenomenon and degradation in performance [Ref. 9].

2. Signal Detection Theory (TSD)

A major question in vigilance research remains whether the theory of signal detection is generally applicable or not. It seems to be especially applicable to a monitoring task involving both decision and discrimination [Ref. 1]. Some more specific remarks are, however, necessary. An in-depth literature review by Swets [Ref. 10] points out that there is evidence that the normally observed increase in the observer's decision criterion did not occur in experiments in which signal occurrences were as probable as or more probable than background events. A contemporary experiment by Vickers [Ref. 11] shows that criterion to be dependent on the difference between a 'local' and a cumulative signal probability established by the observer. Teichner [Ref. 12], a major critic, states that the assumption of a subjects' change of the decision criterion based on an acquired knowledge of signal probability is unlikely to occur within an experiment. For the case of a very low rate, but high irregularity of signals, even with an underlying constant signal probability, those observed effects are likely to occur, but very difficult to observe.

3. Stimulus Characteristics

A low signal rate is notable in itself, because it leads us into the field of theory concerning arousal and vigilance as a function of stimuli. Miller and Mackie list

> "... three critically important characteristics of the stimuli used in experiments on vigilance that affect performance, namely the background event rate (BER), signal probability, and signal complexity." [Ref. 1: p. 59].

These topics will be dealt with in the following paragraphs.

a. Background Event Rate

The authors conclude that all reviewed experiments used high or extremely high BERs compared to operational settings, making generalization difficult. But, they state, vigilance theories concur in predicting that low background event and signal rates will lower the monitoring load, and hence the levels of arousal and expectancy, resulting in greater deterioration of performance.

b. Signal Probability

A well established result of vigilance testing is that signal probability, i.e. the ratio of signal rate to background event rate, is directly related to the probability of detection itself. Thus, a low signal probability will lead to a reduced detection probability. It is suggested that the signal probability in a vigilance experiment should be as low as in comparable operational settings if the experimenter wishes to be able to generalize his results to that environment. One question that has not been dealt with is whether an experiment in which signal cccurrences are nearly as probable as background events (i.e. a 'high' signal probability), but the background event <u>rate</u> is very low itself, can be classified under high signal probability and included in the mentioned doubts about its validity.

c. Signal Complexity

Signal complexity stands for the dimensionality, duration, pattern, and sequence of signals. Dimensionality, i.e. the difference in representation (code) and location of symbols on the display, is found to have a negative effect on performance if it increases [Ref. 1]. An extensive, or repetitive duration of the signal, like, e.g., in the operational environment of a radar monitoring task, apparently shifts the emphasis of the operator's perception of the task from detection of signals to reacton time [Ref. 13], [Ref. 14].

Signal pattern and sequence describe spatial and temporal relation of signals to background events. A signal that changes the display by being added to a previous symbol pattern of other signals and background events in a continuous presentation is defined as "simultaneous". Such a signal occurrence is considered to be comparable to those in operational settings, especially monitoring. The reaction to signals presented like that may develop into what Wiener [Ref. 15] calls "inferential monitoring", essentially a continuous 'no signal'-hypothesis testing by the individual operator [Ref. 1: p. 24].

d. Signal Regularity

In addition to the factors described above, temporal and spatial uncertainty, e.g. total randomization, of signal occurrences on the display are found to have a negative, possibly even additive influence on reaction times, the latter on reaction accuracy as well [Ref. 16].

e. Display Density

Display density is a synonym for the total number of symbols on display when a signal is presented. The term 'signal density' refers to the number of signals among them. Generally, increasing display density is expected to affect reaction times adversely [Ref. 17], with strong evidence that the use of colour codes reduces this effect considerably [Ref. 17], [Ref. 18]. It must be emphasized, however, that the experiments referred to did not use a simultaneous signal presentation.

B. SIGNAL DISPLAY

1. Coding Mechanisms and Different Tasks

Additional coding on radar displays was introduced to enable operators to cope with the increasing workload placed on them by modern information systems. The three major coding modalities are alphanumeric, shape, and colour. The goal of improving efficiency, measured in reaction time and number of errors, was tested in numerous experiments. However, they are far from unanimous in their findings about the superiority of a particular code.

The positive or negative effect of a coding mechanism is inseparably related to the task it is used in [Ref. 19]. For vigilance experiments using visual displays those tasks have been mostly search and identification. In a search task the subject knows the type of signal to expect and has to locate it on the screen. For identification the signal type is not known in advance and the task is to find a target and identify the category to which it belongs.

In 1975, Christ [Ref. 20] came to the following conclusions in his extensive literature research on colour coding :

1. Non-redundant colour in a search task is superior to all other codes by a wide margin, in an identification task to most others except alphanumeric coding.

2. The effects of redundant colours in an identification task are still undetermined, with one experiment in favour of colour coding [Ref. 21].

The more recent publications of Wagner [Ref. 22] and Christ [Ref. 17] are much more cautious in establishing an order and do not suggest a superiority for any particular code. During the same time, Oda [Ref. 23], Carter [Ref. 18], Kopala [Ref. 24], Noble and Sanders [Ref. 25], and Luder and Barber [Ref. 26] all reported significant improvements in performance of a search task using redundant colour coding. It must be emphasized, however, that those last experiments included multiple tasks and, in most cases, extremely high workloads. A widely used, more technically oriented reference [Ref. 27] states that

> " ... color coding will be helpful, if
> - The display is unformatted,
> - Symbol density is high,
> - Operator must search for relevant information,
> - Symbol legibility is degraded, and
> - Color code is logically related to operator's task." [Ref. 27: p. 44]

but admits that colour coding may have a negative effect on the symbol identification time. In the case of redundant codes, the same authors suggest to

> " ... use fully redundant coding to improve symbol detectability and to aid in discriminating among symbols ..." [Ref. 27: p. 79],

and they report the combination colour/shape to be the most efficient.

2. Technical Use of Chromatic Coding

a. Dimensionality

An accepted result of colour research is the limitation in the number of different colours for identification tasks. The established maximum in operational applications is four, although more colours may be used in other tasks after extensive previous training without negative effects on performance [Ref. 22], [Ref. 27].

b. Light Characteristics

Luminance, brightness, contrast, saturation, and wavelength separation are all found to be factors in the effects of colour coding. Although low differences, i.e. weak signals, may be used for subliminal perception or TSD experiments [Ref. 12], high contrast, saturation, and wavelength separation are recommended to enhance search performance in monitoring tasks [Ref. 24], [Ref. 27].

c. Size

In addition to the factors mentioned, symbol size is considered to be a determinant in identification tasks using colour. Krebs [Ref. 27] suggests a minimal symbol width of 20 to 45 minutes of arc as necessary for unimpaired visual identification, the size increasing linearly with the number of colours in use.

C. EXPERIMENTAL HYPOTHESES

From the previously presented research results we conclude the following :

1. Human performance is liable to show severe decrements between 10 p.m. and 6 a.m. due to a low in diurnal rhythm. Those decrements will occur in addition to and later than

the decrements that have been observed in most vigilance experiments during the first 30 minutes of time on task. There is some evidence that this decrement may not be found in a pure monitoring task [Ref. 12].

2. There seems to be a strong case for the beneficial effects of redundant colour coding in complex tasks and under high workloads. However, there is no evidence to suggest similar effects in a simple monitoring task of extended length.

3. A very low signal probability, combined with temporal and spatial uncertainty of signal occurrences, is expected to have negative influence on both reaction time and accuracy. It should be recalled that there is neither a theory nor data concerning the combination of a 'high' signal probability with a low background event rate, and its possible classification.

Proceeding from those conclusions, we expect the following results from the present experiment:

- Operator performance will show further decrements through session duration after the first 30 minutes, documented by an increase in detection latency (= reaction time) and a decrease in reaction accuracy (= increase in number of errors).

- Operator performance will be enhanced by the use of redundant colour coding, both in reaction time and accuracy.

- There will be an interaction between treatments (mono- vs. multichromatic) and session duration. The application of the redundant colour coding mechanism is anticipated to result in increasingly beneficial effects.

III. METHOD

A. OBJECTIVE

The objective of this experiment was twofold, first, to collect data on operator performance in a simple monitoring task during an 8-hour night time interval, and second ,to search for possible positive effects by the addition of redundant colour codes to a currently operational set of shape codes.

B. SUBJECTS

20 subjects participated in the experiment, nineteen were military, one a civilian. 18 subjects were male, two female. Subjects belonged to four different nations, namely Germany(2), Norway(1), Turkey(2), and United States(15). Pair matching was used for the 3 smaller groups of different gender and nationality. The age of the youngest subject was 26 years, that of the oldest 42 years. The average age was 32.35 years. The chosen subjects had previous experience in working with displays containing coded information. A learning effect during the experiment was assumed to be negligible.

No cases of deficiencies in colour vision were reported among subjects, and sight anomalies were ruled out as non-existing or corrected. None of the subjects reported medical treatment with drugs that might have impaired their abilities. All subjects volunteered and most of them expressed genuine interest in the experiment. They could be described as highly motivated towards their task.

C. APPARATUS

1. Equipment

The test device was located inside a sound-attenuating and lightproof experimental booth with the dimensions L = 6'2", W = 6'0", H = 6'5". A Hewlett-Packard HP 9845 C desk-top computer placed on a 30" high table was used for the simulation display and the response input. The response keys were located on the keyboard as shown in figure 3.1.

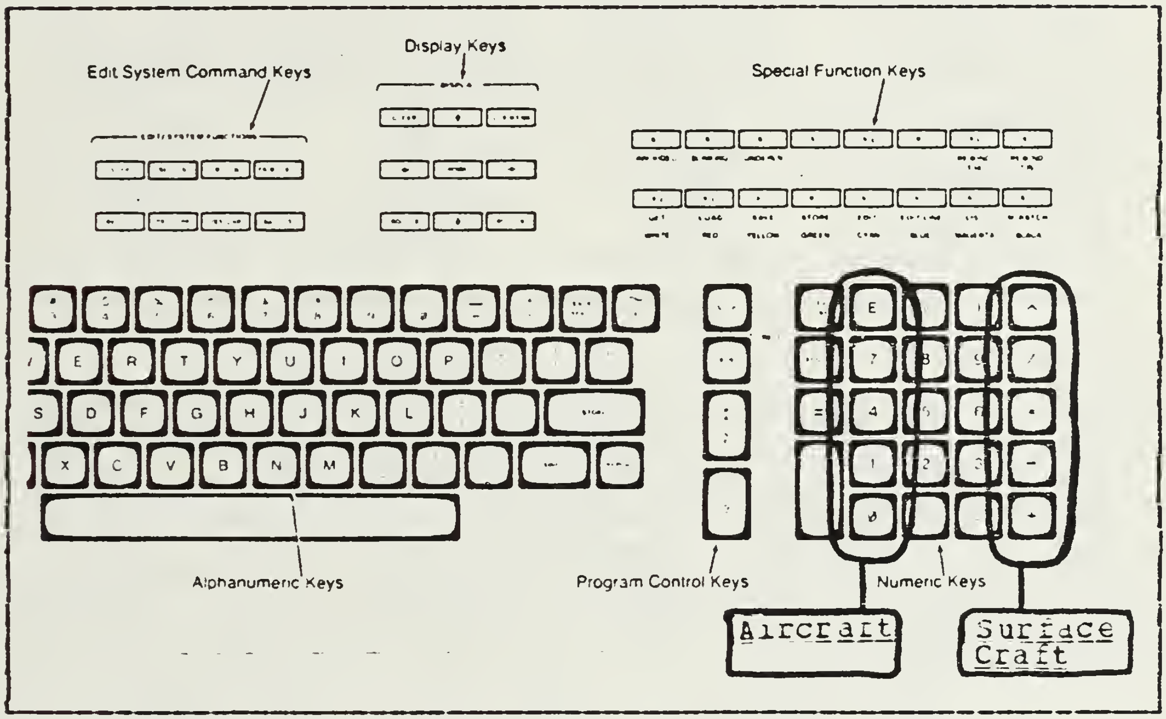


Figure 3.1 Response Keys on the Keyboard.

The subjects were seated on an office chair with height 20", the back resting against one wall of the booth. The peripheral test devices (clock and printer) were located outside of the booth.

2. Symbols

The presented symbols were either monochromatic with white cclour, or multichromatic with colours red, green, and blue as redundant codes, both against a black background. The presentation of the symbols used in this experiment was as given in table 1.

TABLE 1

Shape and Redundant Colour Codes for Symbols

Symbol	Aircraft	Surface Craft	Colour
Enemy			Red
Neutral			Green
Friendly			Blue

The symbols had a width of 0.65 cm and a height of 0.40 (aircraft) or 0.65 cm (surface craft). Assuming an average distance of 75 cm between the observer's eye and the screen, the signals subtended a width of 25 minutes of arc, satisfying the technical requirements for a three-colour display [Ref. 27].

The three-colcur combination of red, green, and blue was chosen as preferable to the normally used red-yellow-green for the following reasons :

1. The code red = enemy, green = neutral, blue = friendly is commonly used on coloured plots in the military services of NATO countries, and thus a 'population stereotype' for the participating subjects. The logic relation to the task was assumed to be strongest for that combination.

2. As the identificaton task requested reaction to enemy, i.e. red, signals only, a higher wavelength separation of that colour to the nearest one also in use (in this case, green instead of yellow) was considered favourable [Ref. 27] and less likely to induce errors of commission.

D. PROCEDURE

1. Design

There were two possible treatments in the experiment, both using the same shape coding mechanism against a black background, with an equal number of subjects in each treatment group. The 'operational' treatment, henceforth referred to as the control condition, used white symbols, the experimental treatment, henceforth referred to as the experimental condition, used coloured symbols with the colours red, green, and blue as redundant codes.

In each condition, six different symbols could be presented, of which two ('enemy') were defined as signals, four ('neutral' and 'friendly') as background events. Appearance of a signal required detection and discrimination between the two possible signals ('aircraft' or 'surface craft'), i.e. a combined search- and identification task, and the appropriate manual reaction, which will be explained in detail below.

The treatment that a subject received remained unchanged for the entire length of the experiment. Although the sequence and the inter-arrival time of the stimuli were randomized, the experiment was the same for each subject, except for the condition differences, this being ensured by the use of the same randomization procedures. The experiment was divided by breaks into four time segments of equal length and approximately equal workload, as defined by the number of signal occurrences in a segment.

The independent variables were the condition and the time segment, during which a particular signal occurred, resulting in the experimental design given in table 2.

TABLE 2
Experimental Design

Segment Conditions	1	2	3	4
Control Condition	Subject S1-S10	Subject S1-S10	Subject S1-S10	Subject S1-S10
Experimental Condition	Subject S11-S20	Subject S11-S20	Subject S11-S20	Subject S11-S20

Reaction time and accuracy, i.e. number of errors, were the dependent variables.

2. Preparation

The first part of the subjects' preparation was a briefing which took place at least 6 hours before the experiment. It covered the motives for and the goal of the experiment, information about the shape codes, explanation of the display and simulation of the symbols, and instructions about the task, as given in the relevant sections within this chapter, without mentioning the different experimental conditions.

The second part was a short demonstration, taking place 5 to 10 minutes before the start of the experiment. It consisted of a self-paced display of the symbols in the coding condition the subject was to receive, and a test run of 60 seconds' length, including 2 signal occurrences.

3. Time Schedule and Questionnaires

Subjects entered the experimental laboratory at 9:45 p.m. to go through the preparatory demonstration. The experiment proper began at 10 p.m. and ended at 6 a.m. of the following day. Except for breaks, the subjects remained in the experimental booth. A break was scheduled every two hours for 15 minutes. Non-alcoholic beverages and snacks were offered, and the subjects had time to visit the bathroom. Before and after the test and in every break the subjects had to fill out a questionnaire referring to their self-estimated state and performance. The questionnaires are given in appendices A1 - A3.

4. Experiment

a. Display

The computer's CRT represented a tactical radar screen of dimensions 60 x 50 nm with precoded information only. A simulated situation could contain simultaneously up to four signals and seven symbols (signals + background events). A situation was displayed on the screen without change or interruption for an interval of 6 seconds. After that, symbol positions were updated according to their previously determined movements (that could mean disappearance of the signal/symbol, if the new position was outside the screen boundaries), a new signal/symbol could be added (see below), and the new situation was displayed again. An 'own-ship' symbol remained in the center of the screen throughout the test. Three typical situations at signal entry are given in appendices B1 - B3.

b. Simulation

Symbol characteristics were created randomly with five different random draws :

1. Symbol identity (enemy, neutral, or friendly), using a uniform distribution with the probabilities p(enemy) = 0.4, p(neutral) = 0.3, and p(friendly) = 0.3

2. Symbol type (aircraft or surface craft), using the conditional probabilities p(aircraft I enemy) = 0.625, p(aircraft I neutral) = 0.667, and p (aircraft I friendly) = 0.667.

3. Speed, based on type, could vary uniformly between 400 and 600 knots for aircraft and 12 and 36 knots for surface craft.

4. Entry Point. First occurrence on the screen was possible only on its boundaries with equal probability for all points.

5. Course. Dependent on the side of the screen on which the entry occurred, a stimulus' course could vary uniformly through the semicircle extending towards the center of the screen, e.g. for an entry from the 'bottom' from 'left' (= 270 degrees) over 'up' (= 360 degrees) to 'right' (= 90 degrees).

Speed, entry point, and course were the factors deciding how long, i.e. in how many 6-seconds-iterations, a symbol was displayed on the screen. For aircraft, that time varied between one and three minutes, for surface craft, between 5 and 63 minutes.

A sixth random draw at the beginning of each 6-seconds display interval determined whether the entry of a new stimulus took place or not. The probability of a new entry was

0.02, setting the expected time interval between entries at 5 minutes. An experiment included presentation of 33 signals, distributed with 8, 9, 7, and 9 occurrences in the four time intervals, and 59 background events, distributed with 25, 10, 8, and 16 occurrences, 92 stimuli in all.

c. Task

Subjects were required to respond to the appearance of a signal on the CRT by pressing one button in one of two specified columns on the keyboard, discriminating between the two possible signals by chosing the respective column associated with that signal. They received no feedback as to the accuracy of their discrimination or response. The program used in the experiment was designed to record only the first reaction on a new target and to disregard further corrective or inadvertent input.

The use of a position indicator, e.g. a light pen or a marker on the CRT, to associate a reaction with a particular signal that had occurred, was considered to be a confounding factor with respect to reaction time in a vigilance task, and was therefore excluded from the experiment. Without such an indicator, the recorded reactions could only be attributed to the symbol which had appeared most recently on the screen.

5. <u>Supervision</u>

The program caused the printer to print a warning message in the situation that a subject missed a signal in the first interval of appearance, i.e. for 6 seconds. This was interpreted as a possible indication that the subject had fallen asleep. The experimenter remained in the test room, but outside the booth, for the full length of the experiment. He entered the booth only, if alarmed by the printed warning message, 30 seconds after the warning.

6. Recording

Reaction time and accuracy were recorded automatically by the program. At the end of the experiment the records were transferred to a magnetic tape data file for further use and printed in hard copy for an immediate check.

a. Reaction Time

Reaction time was recorded with an accuracy of 1/10 of a second.

b. Errors

The following errors were recorded :

- Error of Omission. The subject did not react to a signal until the next stimulus appeared. This caused a check of the subject in the booth by the experimenter.

- Error of Discrimination. The subject reacted to the appearance of a signal, but identified it incorrectly.

- Error of Commission. The subject reacted to a non-signal stimulus by pressing a response button ('False Alarm').

c. Recording Device

As the response buttons were sensitive to the lightest touch, there were frequent recordings of inadvertent input after appearance of a non-signal stimulus. Those were easily recognized by their excessive reaction times of, e.g., 77 seconds. There was no ambiguous case, which might have been interpretable as an error of commission.

IV. RESULTS

A. ERRORS

The main characteristic of the error data was the performance of a few 'bad watchkeepers' and the high number of misses in the experimental condition. Errors are listed per subject in appendices C1 and C2. Summed up, the distribution of errors was as given in table 3.

TABLE 3
Distribution of Errors over Conditions

Error :	Ommission	Discrimination	Commission
Control	1	3	5
Experiment	11	2	5

In view of the many ties in the data a nonparametric rank test seemed the best choice to test the null hypothesis that

- both conditions will have the same effects on the number of errors.

The null hypothesis was tested separately for each of the three possible types of error. The Mann-Whitney-test [Ref. 28: p. 216 ff.] was selected as the most appropriate. In the following description of test results, X is used as index for data of the control condition, Y as index for the experimental condition. The test results for the different types of errors were as follows :

- Errors of Ommission. The ranksums were R(X) = 83.5 and R(Y) = 126.5, hence R(Y) was selected for the test. The null hypothesis was rejected, with a T1-value of 2.008, significant at the 0.02-level.

  Errors in the experimental condition were distributed with 1, 4, 3, and 3 occurrences over the four time intervals. Analysis by situations, i.e. by format and density of the display at the time of signal appearance and by the preceding interarrival time, did not indicate influences by spatial signal uncertainty, degrees of display density, or different preceding interarrival times of signals or background events.

- Errors of Discrimination. The ranksums were R(X) = 109.5, R(Y) = 100.5, R(X) was selected. The null hypothesis was accepted at the 0.25-level with a T1-value of 0.548.

- Errors of Commission. The ranksums were R(X) = 92.5, and R(Y) = 117.5, respectively; R(Y) was selected for the test. The null hypothesis was accepted at the 0.1-level with a T1-value of 1.131.

Errors in the experimental condition occurred in the first time interval only, in the control condition they were distributed with 2, 0, 2, and 1 over the time intervals.

B. REACTION TIME

1. General

The recorded reaction times are shown in figure 4.1 and figure 4.2 on the next page.

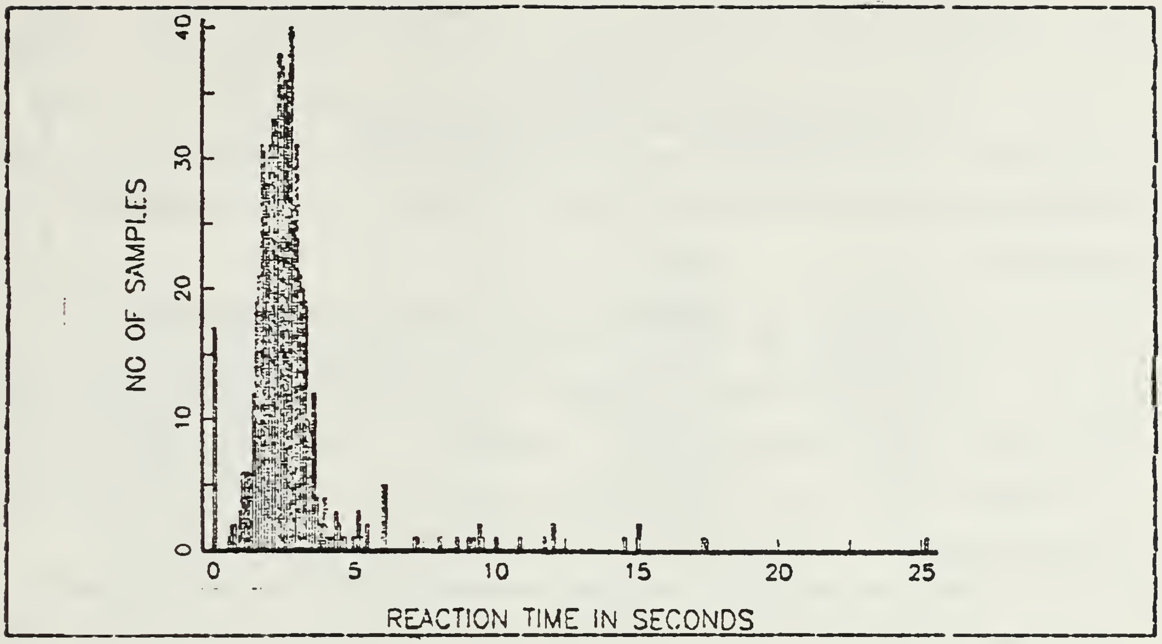


Figure 4.1 Histogram of Reaction Times.

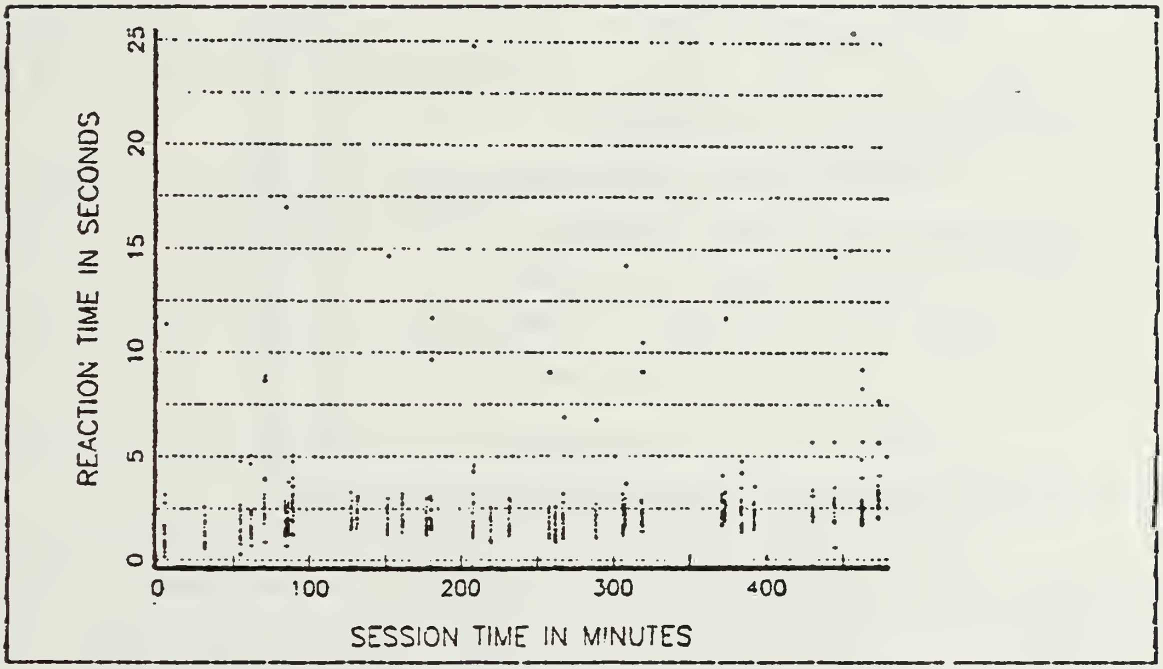


Figure 4.2 Distribution of Reaction Times over Duration.

An inspection of the data gave reason to perform an outlier test. This led to the exclusion of all reaction times beyond 10.75 seconds, in all, 9 data points out of 660, from the analysis. The result was a reduction in variance from that of the complete data set to that used in the analysis by 65 percent.

2. Analysis of Variance for Time and Condition

The data were ordered in a 2x4 block design as shown in table 2 in the previous chapter. The test used for the analysis was the 'Analysis-of-Variance test for factorial experiments', as given in Winer [Ref. 29: p. 228ff.].

The validity of the assumption of homogeneity for all variances was established by performing two tests recommended by the same author. Both Hartley's (F-max-) test with F = 3.2901 and Cochran's test with C = 0.2227 showed the differences between variances to be not significant at the 0.1-level (see Appendix D).

The results of the analysis of variance are shown in table 4. The level of significance is 0.05, if not stated explicitly otherwise.

Therefore time was accepted as having an effect on performance with significance at the 0.001-level. A computation of trend components [Ref. 29: p. 273f.] showed the main trend to be linear (see figure 4.3) with SSlin = 3.573, or 69 % of the total main effect.

There was no significant difference in the effects of the control and experimental conditions.

The interaction between time and conditions was not significant. Although figure 4.3 seems to indicate a certain change of trend between conditions in the last two intervals, a Newman-Keuls multiple range test [Ref. 29: p. 80] showed that change to be not significant.

TABLE 4

ANOVA for Time and Condition

Source	dF	SS	MS	F(obt.)
Time	3	5.1768	1.7256	9.4497
Condition	1	0.0274	0.0274	0.1498
Time x Condition	3	0.8474	0.2825	1.5469
Subjects	18	21.6396	1.2022	6.5835
Error	54	9.8609	0.1826	
Total	79	37.5520		

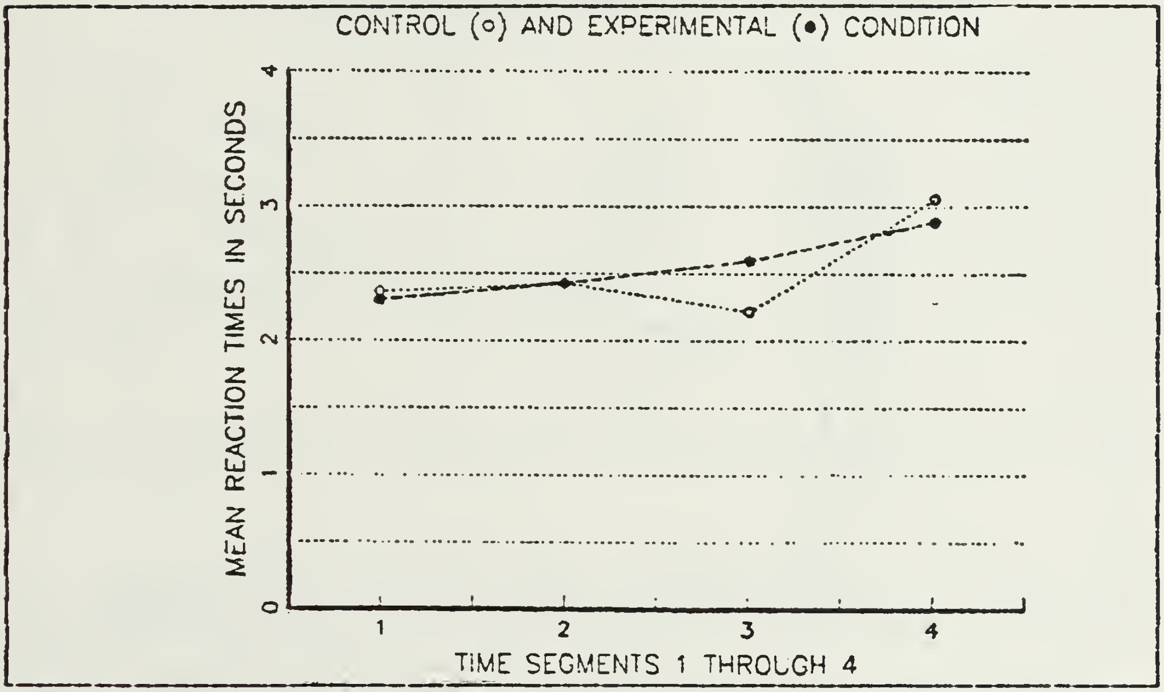


Figure 4.3 Cell Means of Time Segments and Conditions.

Differences between subjects were significant beyond the 0.001-level.

3. Effects of Signal Occurrence Situations

As for the errors, an analysis of reaction times by display characteristics at the time of signal appearance was performed. There was no evidence for negative effects by temporal or spatial uncertainty of signal occurrences. For density, however, expressed either in the number of signals (figure 4.4) or the total number of symbols (figure 4.5) on display, inspection of the data in graphical representation showed that both had a recognizable effect over time segments, leading to statistical analysis in both cases. The tests used for the analysis of time and conditions [Ref. 29] were applied again.

a. Analysis of Signal Density versus Conditions

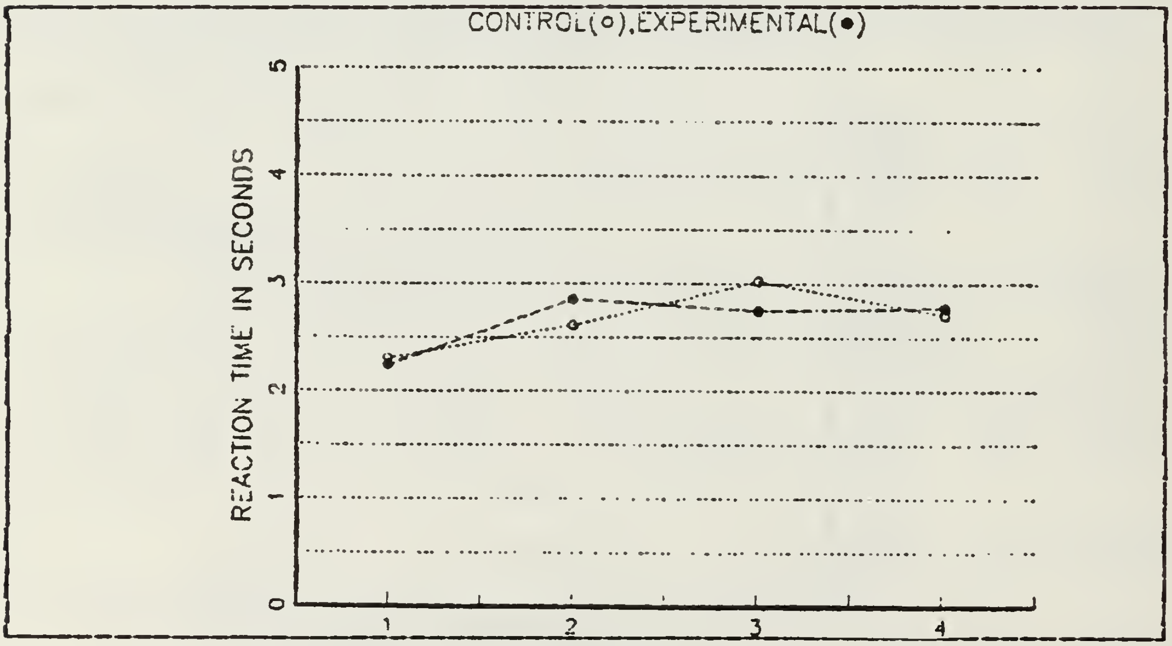


Figure 4.4 Effects of Signal Density over Conditions.

The possible number of signals on display ranged from one to four, the 33 situations of signal occurrence distributed with frequencies of 15/1, 11/2, 5/3, and 2/4 over the different densities. The 2x4 block design used was similar to that used in the first analysis (see table 2), the main factors now being signal density and condition. It should be emphasized, however, that the analysis in this case was based on an unequal number of data points for the different 'density'-blocks (see above).

The differences between cell variances were found to be not significant at the 0.10-level with a F-max of 3.0067 and a Cochran's C of 0.1798 (see Appendix E). The results of the analysis are shown in table 5.

TABLE 5

ANOVA for Signal Density and Condition

Source	dF	SS	MS	F(obt.)
Signal Density	3	4.2027	1.4009	8.5769
Condition	1	0.0015	0.0015	0.0093
S.D. x Condition	3	0.7048	0.2349	1.4383
Subjects	18	22.3089	1.2394	7.5881
Error	54	8.8200	0.1633	
Total	79	36.0379		

Signal density was found to have a main effect on reaction time, significant beyond the 0.001-level, but without a significant linear trend.

The difference in the effects of the conditions was insignificant and, actually, statistically hardly detectable. There was no significant interaction between the two factors. Differences between subjects were again highly significant.

b. Analysis of Display Density versus Conditions

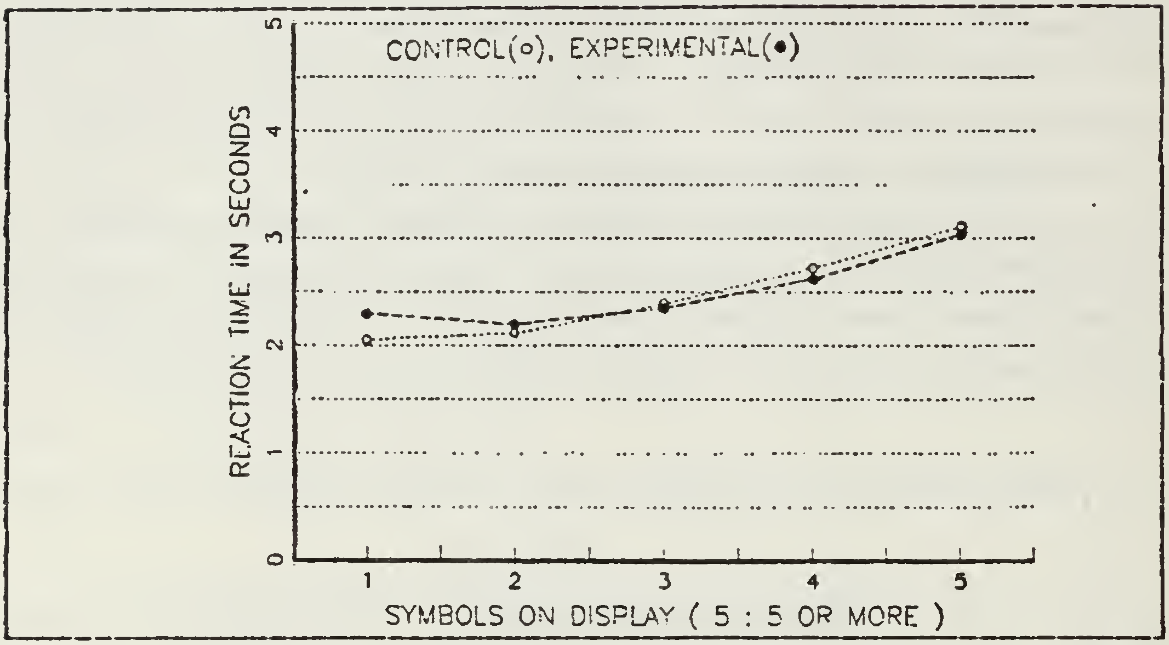


Figure 4.5 Effects of Display Density over Conditions.

Due to the fact that only a few signals occurred in 'high' (5-7 symbols) display density, five blocks were used for the seven different densities. The first four blocks contain the data points with corresponding display densities of one through four symbols, the fifth block contains all data points of 'high' density (see above). With that adjustment, the distribution of the 33 situations of signal occurrence was 4/1, 7/2, 6/3, 8/4, and 8/5+ over display density, more equal than in the case of signal density. Due to the different number of blocks, a 2x5 design was used for the analysis in this case, the main factors being display density and condition.

Again, the tests for homogeneity of cell variances showed no significant differences with a F-max of 3.4428 and a Cochran's C of 0.1587 (see Appendix F).

The results of the analysis of variance were as given in table 6.

TABLE 6

ANOVA for Display Density and Condition

Source	dF	SS	MS	F(obt.)
Display Density	4	11.9748	2.9937	29.1438
Condition	1	0.0117	0.0117	0.1134
D.D. x Condition	4	0.4015	0.1004	0.9771
Subjects	18	26.9489	1.4972	14.5750
Error	72	7.3960	0.1027	
Total	99	46.7327		

Display density was found to have a significant effect on reaction time with $p << 0.001$. Comparison of trend components showed a strong linearity with SSlin = 10.72 (= 90 %), the linear and quadratic trend together accounting for 99.6 % of the total sum of squares.

Conditions had no significant effect on reaction time. There was no significant interaction between the main factors. Differences between subjects were highly significant beyond the 0.005-level.

C. QUESTIONNAIRES

All subjects responded to the questionnaire, one set of answers (S 11) was lost.

Nearly all subjects had had an average workload on the day they participated in the experiment, most of them with the expectation to work again the next day.

All subjects reported a decline of at least one grade over time in the self-estimation of their performance.

The reported patterns of sleep/drowsiness and impaired vision were, except for one case, exactly the same for both conditions.

Although nearly all subjects from the control group complained about the brightness of the symbols in their comments, none of the experimental group did.

All subjects, however, did complain about the heat and the bad air in the experimental booth in the free-style comments which were asked for in the last questionnaire.

All subjects estimated the breaks to have positive effects, but less so from break to break.

Both groups reported approximately equal operator workloads for the same time segments with a sharp increase in perceived load in the last segment.

A marked difference was found only in the subjects' answer to the question which situation, i.e. signal appearance in the simultaneous display pattern, they had perceived as the most difficult to react to. This is shown in table 7

Although none of the subjects admitted difficulties in reaction or discrimination in the explicit questionnaire part, three of the participants in the experimental condition reported a detrimental effect on detection capability in the comments. They attributed this to an error that they called 'target fixation' and described as a disturbation of a normal monitoring pattern by focusing on and unconsciously devoting attention to signals already present on the screen before a particular signal appeared.

TABLE 7

Subject Evaluation of most difficult Situation

Situation on Screen and Signal occurrence	Control Group	Experiment Group
Single Signal (on clear screen)	5	11
S added to N-S (no other S)	10	2
S added to other S and N-S	25	22

S = signal , N-S = non-signal (background event)

V. DISCUSSION

A. EVALUATION OF RESULTS

1. Errors

The most prominent result was the high number of missed signals in the experimental condition. It should be noted that the number of ommissions is not attributable to one or two bad performers; 50 % of the subjects in the experimental condition missed at least one target (see figure 5.1).

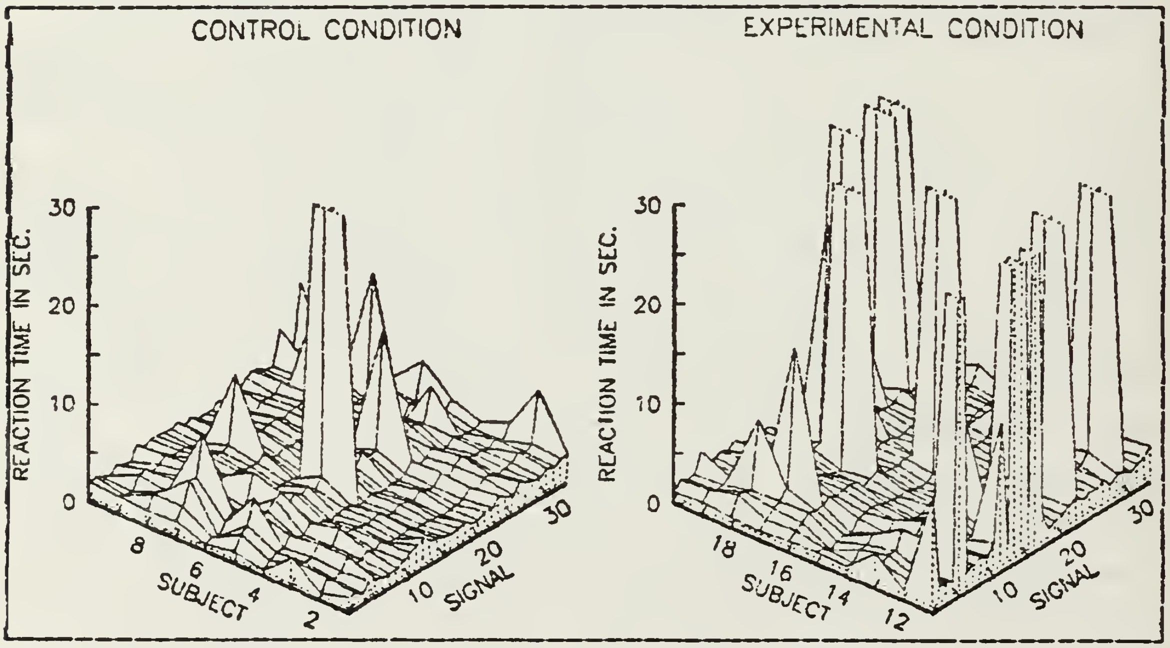


Figure 5.1 Response Surface (Plateau = Omission).

There is no comparable evidence from other experiments dealing with monitoring tasks that substantiate this result.

While the redundant colour codes of the background events had a well-defined logic relation to the respective shape-coded symbols, they might be considered irrelevant, as there was no demand on the subject to discriminate between them. This can, however, hardly be used as an explanation for the number of commissions. All available research results [Ref. 26] point to the conclusion that irrelevant colour coding has a negative effect on the processing of achromatic coded information, probably due to the different (parallel vs. serial) human processing mechanisms for those codes. Detection in the experimental condition, however, required processing of chromatic coded information.

The only applicable information are the questionnaire comments about 'target fixation' in the experimental condition. Although the description of this erroneous behaviour sounds logical and seems to appeal to 'common sense', it is not supported by the comparison of reaction times of selected situations with signal appearances spatially either very close to or very far from already displayed signals. It could be hypothesized, however, that in this context an 'old' signal's redundant colour (red) was not only irrelevant, but distracting, as it gave an 'attention'- specification to something that had been dealt with already from the aspect of the response task.

Occurrences of either of the two other types of error were neither significantly different over the two conditions nor unexpectedly high. The temporal distribution of errors of commission does not indicate an increase over time, as would be expected from field experiments with comparable time frames [Ref. 3], [Ref. 4]. On the contrary, there seems to be a possible 'learning effect' in the experimental condition.

2. Reaction Times

Although some subjects showed the expected vigilance decrements of the first 30 minutes, there was no overall significance. The effect of duration on reaction time was significant, but lower than expected from results of investigations dealing with the same time frame.

The experimental condition did not show the expected positive influence versus the control condition. Although the relation in the last interval is perceptibly different from the others, data are too few to support establishing a hypothesis about a negative trend in the control condition. The turnaround of the difference in that interval may have been caused by increasingly higher eye fatigue in the control condition, indicated by the general complaint about the high brightness of the display in the corresponding group of subjects.

The absence of differences between the mean reaction times of the two conditions, against our expectations based on the results of Oda [Ref. 23] and Kopala [Ref. 24], might be explained by expanding on the previously mentioned argument of irrelevant colours. The second part of the task was discrimination, i.e. reaction to a shape-coded information, and reaction time in the experimental condition may have suffered from the detrimental effect of irrelevancies in the redundant colour coding mechanism. The fact that all recent experiments reporting beneficial effects of redundant colour coding used a high or very high operator workload, and the contrast of their results with the one presented above raise serious questions about the generalizability of the former to an 'underload'-situation.

The significant effects of both signal and display density are unexpected at this relatively low level of density, as comparable effects have been observed only far above [Ref. 18] or, in one experiment with simultaneous signal appearances [Ref. 30], at a density level of 16 symbols. This points again to the concern about generalizability of other results towards low workload experiments.

B. OPERATIONAL IMPLICATIONS

From the point of view expressed in the initial operational setting, two results seem to be important.

1. The use of redundant colour codes does not result in a significant improvement of performance, i.e., in this case, reduction of decrement. On the other hand, the high number of ommissional errors raises serious questions about hidden disadvantages. The importance of that result cannot be expressed in its statistical significance only. An operational estimate would attribute a much higher value to an error of ommission than to either of the other two types of error. A missed reaction in 3.3 % of all cases of target appearances would be unacceptable in all operational mission scenarios.

2. Although time, i.e. task duration, was found to have a significant effect on reaction time, there was no evidence for a definite 'low' in operator performance, the decrement being much more linear over time than initially expected, and the average reaction times would be acceptable in an operational environment with an up-to-date hostile threat. This result is reassuring in view of the initially expressed concern about lows or gaps in operator performance under the time constraints used in this experiment.

The 'underload'-condition must be considered as normal in a situation with pre-conflict or conflict environments at sea for approximately 95 % of the time, and it deserves corresponding attention in further design.

The case made for the influences of irrelevant colour does, of course, not apply in the operational setting. The difference between neutral and friendly forces is quite relevant, and a hostile craft represents a threat and has to be watched as long as it is on display.

Last, but not least, the question about the validity of this experiment, influenced by its deviations from the field setting, deserves a more explicit answer.

C. LIMITATIONS OF THE EXPERIMENT

1. Environment

A major goal of this experiment was to achieve a high degree of validity for operational concepts by the duration of the experimental session and the seclusion of the subjects. The operational environment of a ship's CIC could, of course, not be totally duplicated.

The subjects' general complaint about heat stress and sleepiness due to bad air in the booth shows that at least some environmental stress came to bear. In the case of heat, however, the influence may have been enhancing rather than detrimental [Ref. 31]. Lack of oxygen is probably not a factor in modern, air conditioned shipborne CICs.

Other environmental stress factors of work aboard a ship like motion, noise, and vibration could, however, not be simulated due to limitations in equipment. From the author's own experience, motion sickness must be considered as a major concern on small units, especially in prolonged monitoring tasks in a CIC environment. Strong high-frequency vibrations, normally very distinct aboard FPB's due to the high ratio of engine space in relation to the size of the boat, can be a factor with ambiguous influences, too, as vibrations can arouse a subject's attention as well as they can put him to sleep.

Seclusion in the experimental booth was chosen, among other reasons, to keep the 'reinforcement' by presence of a supervisor or, in this case, his absence, equal for all subjects. That situation is not typical for an operator's work in a CIC, which is routinely supervised by his superiors.

2. Sample

The subjects of both groups were taken from a very special population. The students attending courses at the Naval Postgraduate School have passed rigorous training and selection in their previous careers. They represent - and probably consider themselves - an elite among their peers, and they are highly motivated towards both their present academic and future military tasks. A more 'normal' population might present greater difficulties in motivation due to less professional attitude, ability to imagine a combat threat situation, and personal initiative.

3. Experiment

The desk-top computer used in the experiment has features rather different from those of a surveillance radar console. The screen is very small in comparison to that of a surveillance radar, and the response keys were neither labeled nor illuminated, as they are in the operational setting, e.g. a CIC. The small size of the screen, on the other hand, prevented confounding errors due to a human's weakness in peripheral colour perception, especially for red. Lack of technical feedback, like the indicator for target acquisition on a radar screen, was another factor reducing the subjects' reinforcement.

D. RECOMMENDATIONS FOR FURTHER RESEARCH

It must be emphasized that this experiment dealt only with one of a multitude of possible sets of alternate conditions. The answers and comments of the questionnaire are one of the main sources to proceed to the rational development of new experiments.

In the case of the control condition, i.e a monochromatic display, there are two definite paths visible. The first deals with different, non-white colours, which can be evaluated with respect to their power of arousal and, on the other hand, its effects on eye fatigue, a still open research topic itself. The other involves experimenting with the infinite spectrum of light characteristics, e.g. brightness and saturation of colour, with similar goals.

For the experimental condition, the multichromatic display, there remains the unsolved question about the high number of errors. This problem should be examined and its presence verified. Using the only hint available from some questionnaires, the phenomenon of 'target fixation', not known under these circumstances, should be reviewed. Two applicable types of experiment can involve breaking the attention devoted to the monitoring by either secondary tasks, or by artificial stimuli.

Common to both conditions was the very low operator workload. Although there is growing concern about investigating the 'underload'-situation, most experimenters seem to prefer test conditions with high or maximal workloads, combining a larger number of analyzable responses with a shorter task duration. The results of this experiment emphasize the concern that the effects of low workloads deserve more attention and research efforts.

APPENDIX A
QUESTIONNAIRES

Pre-test Questionnaire   Underline right answers

1. When did you get up today ? _____:_____

2. Did you have a nap today ?   Yes   No

   and, if yes, when ? _____:_____

3. Which of the normal meals did you have today ?

   Breakfast   Lunch   Dinner

4. How many hours did you work today ? _____ Hrs

5. When did you stop working today ? _____:_____

6. When do you expect to start work tomorrow ? _____:_____

7. How would you describe your workload for today ?

   Very High   High   Medium   Low   Very Low

8. How is your expected workload for tomorrow ?

   Very High   High   Medium   Low   Very Low

9. Do you expect to start a major task tomorrow ?   Yes   No

10. How would you rate your present mood ? _____

    (5 = excited --- 1 = indifferent)

Break Questionnaire   Underline right answers

1. How would you rate your performance in the last 2 hours ?
   Good   Above Average   O.K.   Below Average   Poor

2. What did you feel in your performance during the last 2 hours ?
   Improvement   No change   Decline

3. Did you feel sleepy or drowsy during the last 2 hours ?
   Yes   No

4. Did you have moments of impaired (blurred) vision during the last 2 hours ?   Yes   No

5. How would you rate the 'operator workload' in the last 2 hours ?   Very High   High   Medium   Low   Very Low

6. Which situation was most difficult to react on ?
   - Target appearance on empty screen after waiting
   - Target appearance on screen with other non-targets
   - Target appearance on screen with other targets

7. How do you feel now compared with the time before the last 2 hours ?

8. How would you rate the effect of the last break on your performance afterwards, i.e. in the last 2 hours ?
   (does not apply in the first break)
   Very positive   Positive   No effect   Negative   Very Negative

9. How would you rate your present mood ? _____
   (5 = excited --- 1 = indifferent)

Post-test Questionnaire   Underline right answers

1. How do you feel now ?

   Fully Awake   Awake   In Between   Tired   Very Tired

2. How would you estimate your ability to drive a car ?

   Very Good   Good   Fair   Poor   Very Poor

3. How would you rate your mood ? _____

   (5 = excited --- 1 = indifferent)

4. How would you rate the target coding mechanism ?

   Very Good   Good   Medium   Poor   Very Poor

5. Did you have difficulties in discriminating target identities (Hostile, Neutral, Friendly) ?   Yes   No

6. Did you have difficulties in discriminating target types (surface craft, aircraft) ?   Yes   No

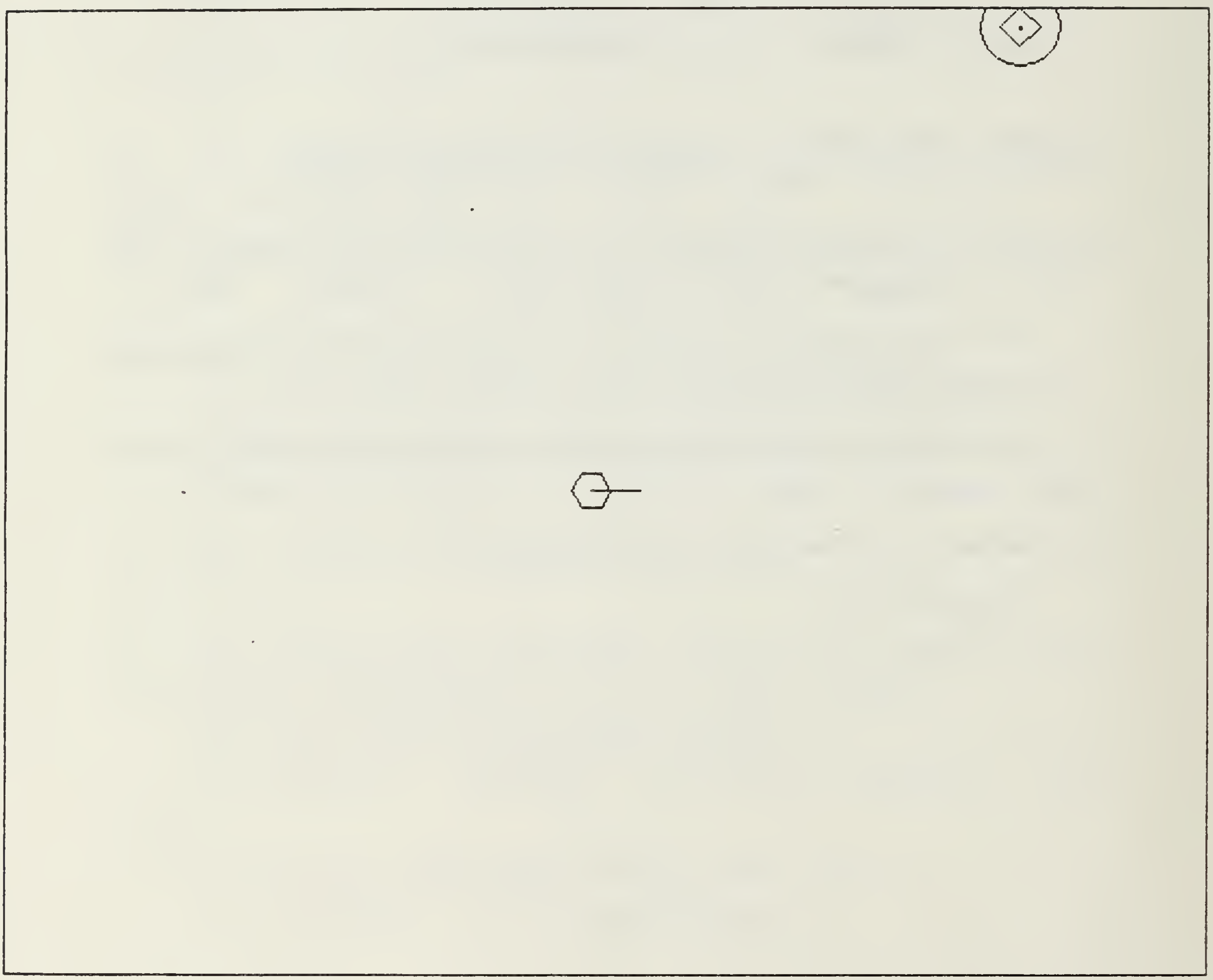
7. Did you have difficulties with the location of the reaction keys ?   Yes   No

8. Comments on the other side, please

   Thank You !!!

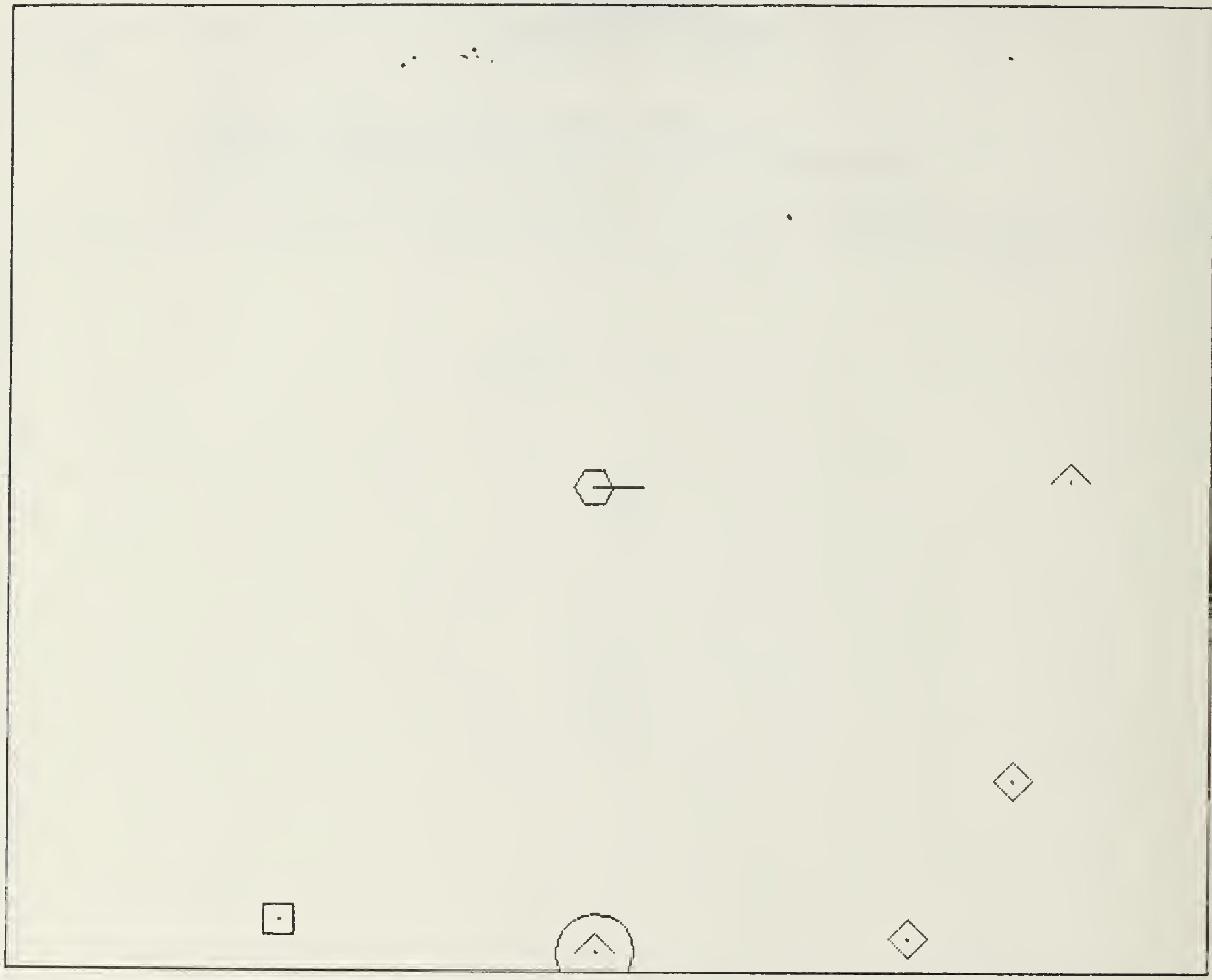
APPENDIX B
DISPLAY SITUATIONS

A. Signal Appearance on Clear Screen
(circle indicates signal that just appeared)



B. Signal Appearance cn Screen with other Non-Signals
(circle indicates signal that just appeared)

C. Signal Appearance on Screen with other Signals
(circle indicates signal that just appeared)



APPENDIX C

DISTRIBUTION OF REACTION ERRORS OVER SUBJECTS

Part 1 : Control Group

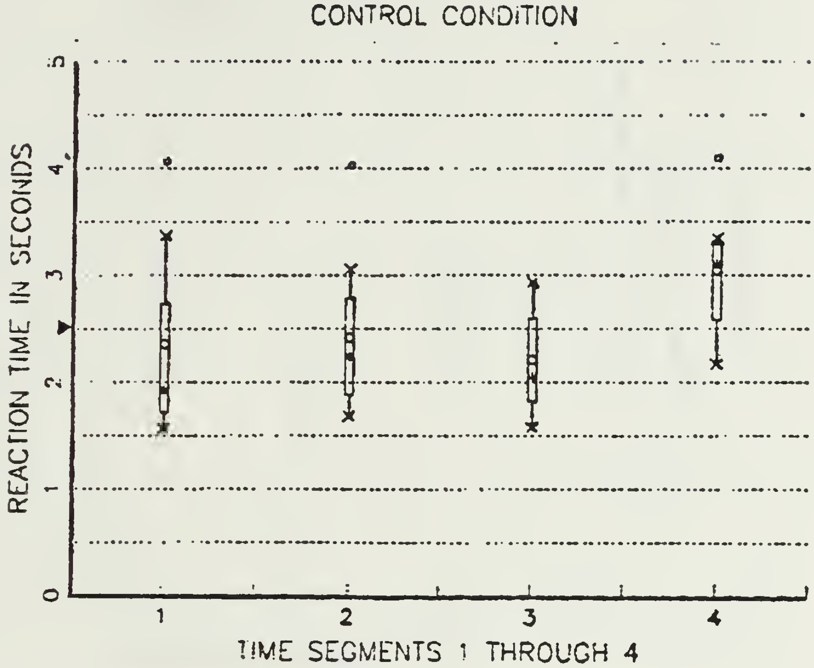
Error :	Omission	Discrimination	Commission
Subjects :			
S 1	0	0	0
S 2	0	0	0
S 3	0	0	0
S 4	0	2	4
S 5	1	0	0
S 6	0	0	1
S 7	0	0	0
S 8	0	1	0
S 9	0	0	0
S10	0	0	0
Sum	1	3	5

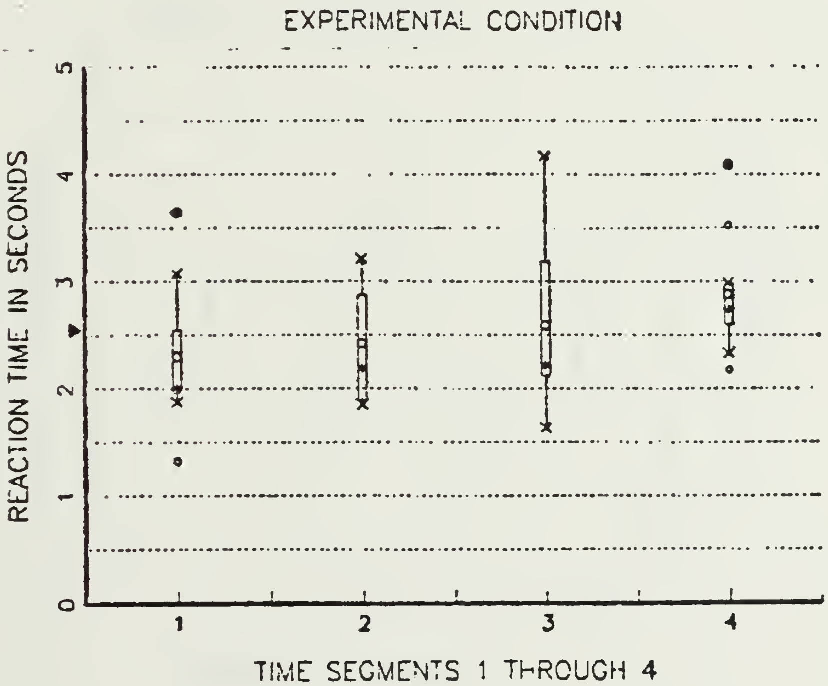
Part 2 : Experimental Group

Error :	Omission	Discrimination	Commission
Subjects :			
S 11	4	0	1
S 12	2	0	1
S 13	0	0	1
S 14	0	0	0
S 15	1	0	0
S 16	0	0	1
S 17	1	0	0
S 18	0	0	1
S 19	3	2	0
S 20	0	0	0
Sum	11	2	5

APPENDIX D

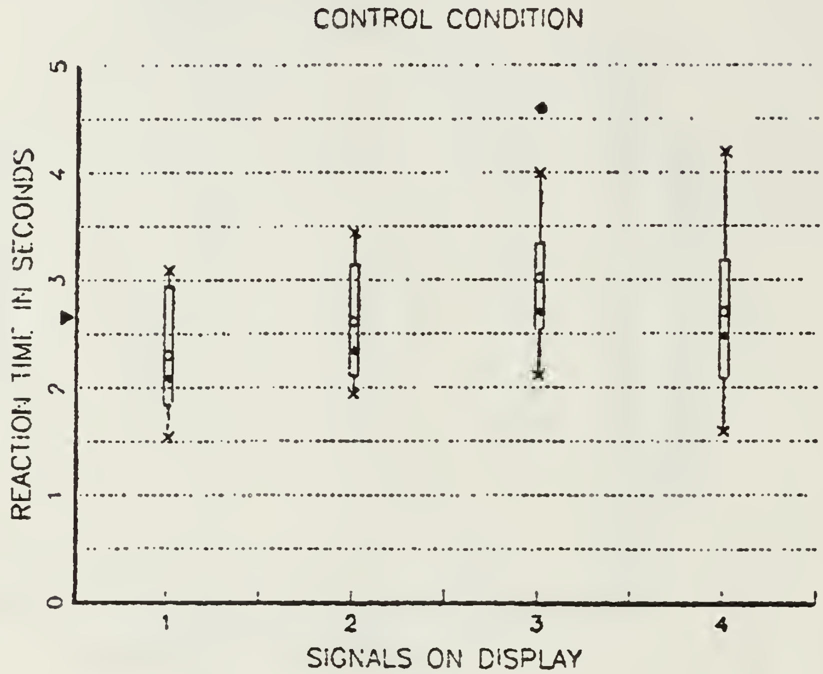
BOXPLOT OF CELL VARIANCES FOR ANOVA 1

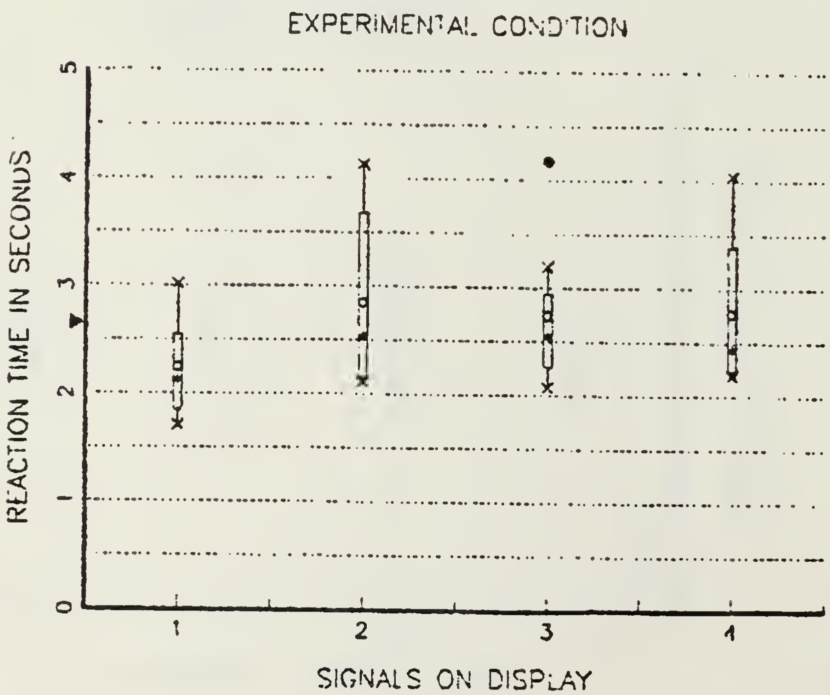




APPENDIX E

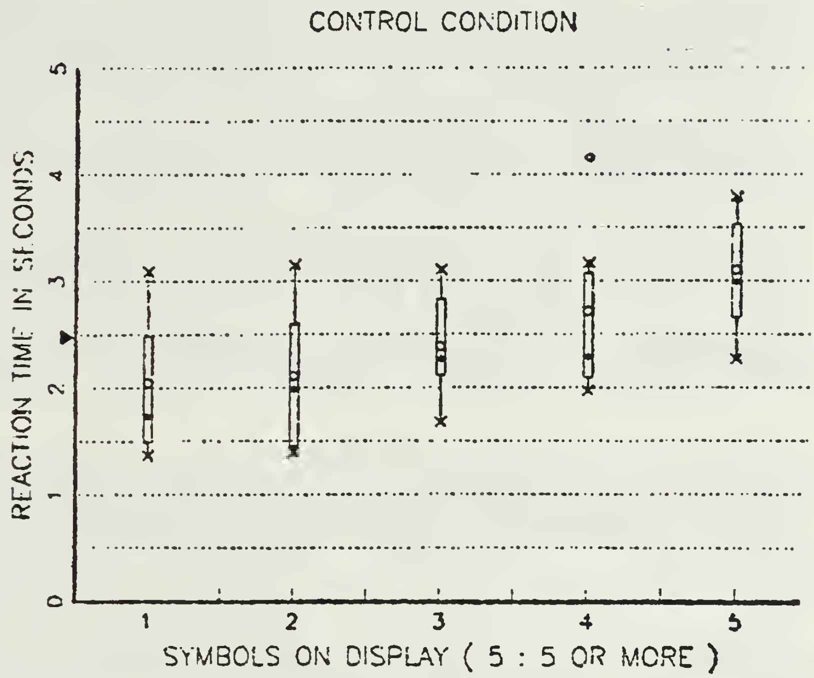
BOXPLOT OF CELL VARIANCES FOR ANOVA 2

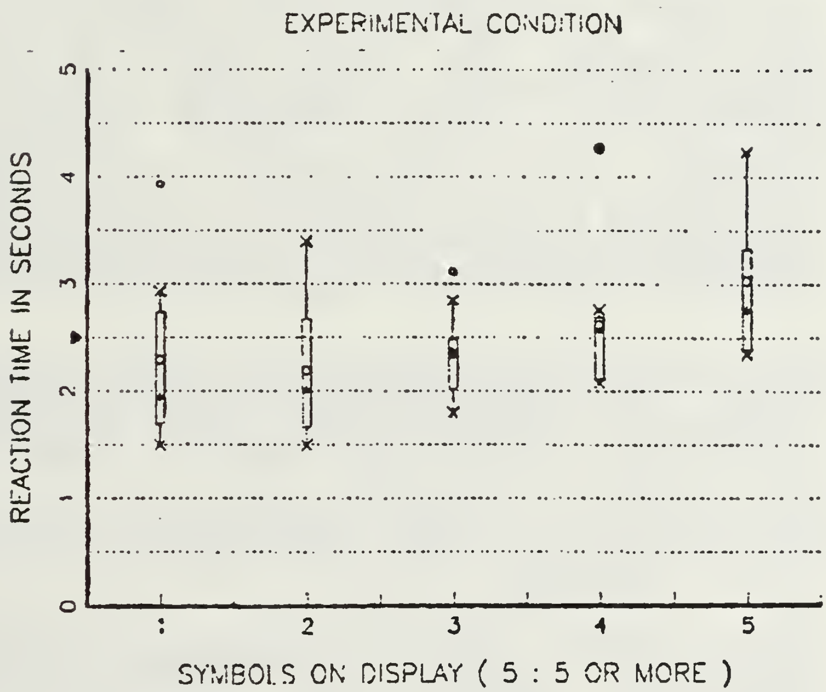




APPENDIX F

BOXPLOT OF CELL VARIANCES FOR ANOVA 3





LIST OF REFERENCES

1. Miller, J.C., and Mackie, R.R., Vigilance Research and Nuclear Security: Critical Review and Potential Applications to Security Guard Performance, Human Factors Research, Inc., Goleta, California; prepared for : Consumer Ergonomics Group, Consumer Science Division 761, Center for Consumer Product Technology, National Bureau of Standards, Washinton, D.C., 20234, Final Report, June 1980

2. Coates, G.D., Interactions of Continuous Work and Sleep Loss with the Effect of the Circadian Rhythm -- II, in : Morgan, B.B., and Coates, G.D. (Eds.), Sustained Performance and Recovery during Continuous Operations, Int. Technical Report ITR-74-2, Norfolk, Virginia, p. 22-38

3. Hildebrandt, G., Rohmert, W., and Rutenfranz, J., "Twelve and 24-hour Rhythms in Error Frequency of Locomotive Drivers and the Influence of Tiredness", International Journal of Chronobiology, 1974, 2, p. 175-180

4. Kogi, K. and Ohta, T., "Incidence of near Accidental Drowsing in Locomotive Driving during a Period of Rotation", Journal of Human Ergology, 1975, 4, p.65-76

5. Riemersma, J.B.J.,Sanders, A.F., Wildervanck, G., and Gaillard, A.W., Performance Decrement during Prolonged Night Driving , in: R.R. Mackie (Ed.), Vigilance: Theory, Operational Performance, and Physiological Correlates, New York, Plenum Press, 1977

6. O'Hanlon, J.F., and Kelley, G.R., Comparison of Performance and Physiological Changes between Drivers who perform well and poorly during Prolonged Vehicular Operation, in: R.R. Mackie (Ed.), Vigilance: Theory, Operational Performance, and Physiological Correlates, New York, Plenum Press, 1977

7. Klein, K.E., Herrmann, R., Kuklinski, P., and Wegmann, H.M., Circadian Performance Rhythms: Experimental Studies in Air Operations, in: R.R. Mackie (Ed.), Vigilance: Theory, Operational Performance, and Physiological Correlates, New York, Plenum Press, 1977

8. Poulton, E.C., "The Performance of Junior Hospital Doctors following Reduced Sleep and Long Hours of Work", Ergonomics, 1978, Vol 21, No 4, p. 279-296

9. Smith, W.J., A Review of Literature Relating to Visual Fatigue in: Proceedings of the Human Factors Society 23rd Annual Meeting, Human Factors Society, Santa Monica, California, 1979, p. 362-366

10. Swets, J.A., Signal Detection Theory applied to Vigilance, in: R.R. Mackie (Ed.), Vigilance: Theory, Operational Performance, and Physiological Correlates, New York, Plenum Press, 1977

11. Vickers, D., Leary, J., and Barnes, P., Adaptation to Decreasing Signal Probability in: R.R. Mackie (Ed.), Vigilance: Theory, Operational Performance, and Physiological Correlates, New York, Plenum Press, 1977

12. Teichner, W.H., Predicting Human Performance III : The detection of a simple visual signal as a function of time of watch. Technical Report 72-1, Prepared under Contract for Engineering Psychology Programs, Office of Naval Research, Arlington, Virginia, 22217; New Mexico State University, Departement of Psychology, Las Cruces, New Mexico, 88001, June 1972

13. Wagenaar, W.A., and Sanders, A., The Use of Artificial Signals during Sonar Watch, (DDC users only IZF-1978-25), 1978, (NTIS No. AD-B040-007)

14. O'Hanlon, J.F., and Beatty, J., Concurrent Electroencephalographic and Performance Changes during a Simulated Radar Watch and some Implications for the Arousal Theory of Vigilance , in: R.R. Mackie (Ed.), Vigilance: Theory, Operational Performance, and Physiological Correlates, New York, Plenum Press, 1977

15. Wiener, E.L., Individual and Group Differences in Inspection, in C.G. Drury and J.G. Fox (Eds.), Human Reliability in Quality Control, New York, Halsted Press; London, Taylor and Francis, 1975

16. Loeb, M., and Alluisi, E.A., An Update of Findings Regarding Vigilance and a Reconsideration of Underlying Mechanisms, in: R.R. Mackie (Ed.), Vigilance: Theory, Operational Performance, and Physiological Correlates, New York, Plenum Press, 1977

17. Christ, R.E., and Corso, G.M., "The Effects of Extended Practice on the Evaluation of Visual Display Codes", Human Factors, 1983, 25(1), p. 71-84

18. Carter, R.C., Jr., Visual Search and Color Coding, in: Proceedings of the Human Factors Society 23rd Annual Meeting, Human Factors Society, Santa Monica, California, 1979, p. 369-373

19. Smith, D.L., A Human Engineering Guide for Using Color in CRT Command and Control Displays, Lockheed, Sunnyvale, California; Report No. D66834, 1978

20. Christ, R.E., "Review and Analysis of Color Coding Research for Visual Displays", Human Factors, 1975, 17(6), p. 542-570

21. Eriksen, C.W., and Hake, H.W., "Multidimensional Stimulus Differences and Accuracy of Discrimination", Journal of Experimental Psychology, 1955, 50, p. 153-160

22. Wagner, D.W., Experiments with Color Coding on Television, Technical Report NWC-TP-5952, Naval Weapon Center, China Lake, California, 1977

23. Oda, D.J., "The Benefits of Color in an Airborne Integrated Tactical Display System", Information Display, December 1977

24. Kopala, C.J., Symbology Verification Study(U), Bunker-Ramo Corp., Westlake Village, California; AFWAL-TR-82-3080, January 1983

25. Noble, M., and Sanders, A.F., "Searching for Traffic Signals while engaged in Compensatory Tracking", Human Factors, 1980, 22(1), p. 89-102

26. Luder, C.B., and Barber, P.J., "Redundant Color Coding on Airborne CRT Displays", Human Factors, 1984, 26(1), p. 19-32

27. Krebs, M., Wolf, J.D., and Sandvig, J.H., Color Display Design Guide, Honeywell Systems and Research, Minneapolis, Minnesota; ONR-CR213-136-2F, N 00014-77-C-0349, Arlington, Virginia, October 1978

28. Conover, W., Nonparametric Statistics, 2nd Edition, New York, Wiley & Sons, 1982

29. Winer, B.J., Statictical Principles in Experimental Design, New York, McGraw-Hill, 1962

30. Thackray, R.I., Bailey, J.P., Touchstone, R.M. The Effect of Increased Monitoring Load on Vigilance Performance Using a Simulated Radar Display, Federal Aviation Administration, Office of Aviation Medicine, Report No. FAA-AM-77-18, Washington, D.C., June 1977

31. Poulton, E.C., Arousing Stresses Increase Vigilance, in: R.R. Mackie (Ed.), Vigilance: Theory, Operational Performance, and Physiological Correlates, New York, Plenum Press, 1977

BIBLIOGRAPHY

Bell, R.A., Symington, L.E., and Bevan, W., "Watchkeeping Performance as a Function of Certain Properties of the Reviewing Situation", *Human Factors*, 1974, 16(1), p.65-69

Buck, L., "Sleep Loss Effects on Movement Time", *Ergonomics*, 1975, Vol. 18, No. 4, p. 415-425

Childs, J.M., "Signal Complexity, Response Complexity, and Signal Specification in Vigilance", *Human Factors*, 1976, 18(2), 149-159

Colquhon, W.P., "Evaluation of Auditory, Visual, and Dual-Mode Displays for Prolonged Sonar Monitoring in Repeated Sessions", *Human Factors*, 1975, 17(5), 425-437

Craig, A., and Colquhon, W.P., *Vigilance: A Review*, in: C.G. Drury and J.G. Fox (Eds.), *Human Reliability in Quality Control*, New York, Halsted Press; London, Taylor and Francis, 1975

Davies, D.R., and Tune, G.S., *Human Vigilance Performance*, American Elsevier Publishing Inc., New York, 1969

Haslam, D.R., "Sleep Loss, Recovery Sleep and Military Performance", *Ergonomics*, 1982, Vol.25, No.2, p.163-178

Hoops, H., *The Advantage of the Color-Coding-Modality versus Alpanumeric and Symbol Code*, Master's Thesis, Naval Postgraduate School, Monterey, California, March 1980

Mackie, R.R., (Ed.) *Vigilance : Theory, Operational Performance, and Physiological Correlates*, New York, Plenum Press, 1977

Naitoh, P., and Townsend, R.E., "The Role of Sleep Deprivation Research in Human Factors", *Human Factors*, 1970, 12(6), p. 575-585

Shontz, W.D., Trumm, G.A., and Williams, L.G., "Color Coding for Information Location", *Human Factors*, 1971, 13(3), p. 237-246

Teichner, W.H. and Krebs, M.J. *Predicting Human Performance V : Visual Search for Simple Targets*, Technical Report 72-3, Prepared under contract for Engineering Psychology Programs, Office of Naval Research, Arlington, Virginia, 22217; New Mexico State University, Departement of Psychlogy, Las Cruces, New Mexico, 88001, December 1972

Wilkinson, R.T., and Glenville, M., "The Effects of Sleep Deprivation and Night Shift on the Performance of Computer Operators", *Ergonomics*, 1979, Vol.22, No. 8, p. 927-933

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943	2
3.	Asst.Prof. Charles W. Hutchins, Jr., Code 55Hu Departement of Operations Research Naval Postgraduate School Monterey, California 93943	1
4.	Asst.Prof. Douglas E. Neil, Code 55Ni Departement of Operations Research Naval Postgraduate School Monterey, California 93943	1
5.	Prof. Gary Poock, Code 55Pk Departement of Operations Research Naval Postgraduate School Monterey, California 93943	1
6.	LCDR Patrick A. Sandoz, USN, Code 30 Departement of Operations Research Naval Postgraduate School Monterey, California 93943	1
7.	Mr. Earl Wiener 1700 Willow Road # 411 Palo Alto, California 94304	1
8.	Dokumentationszentrum der Bundeswehr Friedrich-Ebert-Allee 34 5300 Bonn Federal Republic of Germany	1
9.	Kapitaenleutnant Urs Hessling 7.Schnellbootgeschwader Stab 2300 Kiel Federal Republic of Germany	3

210247

Thesis
H5252 Hessling
c.1 Shape with and without redundant colour as coding mechanism for simulated radar displays in a time-extended simple vigilance task.