

REPORT NO. NADC-89004-60



FILLING OR OUTLINING SHAPES WITH COLOR: THE EFFECTS ON A VISUAL SEARCH TASK

David Cohen
Air Vehicle and Crew Systems Technology Department (Code 6022)
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974-5000

AUGUST 1988

FINAL REPORT
Task No. W15880000
Project No. W1149
Work Unit No. WL680
Program Element No. 64221N

DTIC
ELECTE
AUG 10 1989
S B D

Approved for Public Release; Distribution is Unlimited

Prepared for
NAVAL AIR SYSTEMS COMMAND
Department of the Navy
Washington, DC 20361

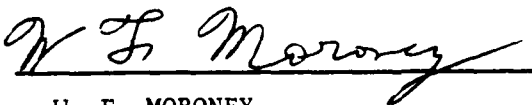
NOTICES

REPORT NUMBERING SYSTEM - The numbering of technical project reports issued by the Naval Air Development Center is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calendar year, and the official 2-digit correspondence code of the Command Officer or the Functional Department responsible for the report. For example: Report No. NADC 88020-60 indicates the twentieth Center report for the year 1988 and prepared by the Air Vehicle and Crew Systems Technology Department. The numerical codes are as follows:

CODE	OFFICE OR DEPARTMENT
00	Commander, Naval Air Development Center
01	Technical Director, Naval Air Development Center
05	Computer Department
10	AntiSubmarine Warfare Systems Department
20	Tactical Air Systems Department
30	Warfare Systems Analysis Department
40	Communication Navigation Technology Department
50	Mission Avionics Technology Department
60	Air Vehicle & Crew Systems Technology Department
70	Systems & Software Technology Department
80	Engineering Support Group
90	Test & Evaluation Group

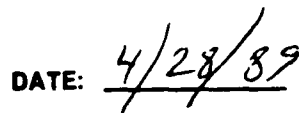
PRODUCT ENDORSEMENT - The discussion or instructions concerning commercial products herein do not constitute an endorsement by the Government nor do they convey or imply the license or right to use such products.

APPROVED BY:



W. F. MORONEY
CAPT, MSC, U.S. NAVY

DATE:



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE				Form Approved OMB No 0704-0188	
1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED			1b RESTRICTIVE MARKINGS		
2a SECURITY CLASSIFICATION AUTHORITY			3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution is Unlimited		
2b DECLASSIFICATION/DOWNGRADING SCHEDULE					
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NADC-89004-60			5 MONITORING ORGANIZATION REPORT NUMBER(S)		
6a NAME OF PERFORMING ORGANIZATION Air Vehicle And Crew Systems Technology Department		6b OFFICE SYMBOL (if applicable)	7a NAME OF MONITORING ORGANIZATION		
6c ADDRESS (City, State, and ZIP Code) NAVAL AIR DEVELOPMENT CENTER Warminster, PA 18974-5000			7b ADDRESS (City, State, and ZIP Code)		
8a NAME OF FUNDING/SPONSORING ORGANIZATION NAVAL AIR SYSTEMS COMMAND		8b OFFICE SYMBOL (if applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c ADDRESS (City, State, and ZIP Code) Washington, D.C. 20361			10 SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO 64221N	PROJECT NO W1149	TASK NO W15880000 WORK UNIT ACCESSION NO WL680
11 TITLE (Include Security Classification) Filling or Outlining Shapes with Color: The Effects on a Visual Search Task					
12 PERSONAL AUTHOR(S) David Cohen					
13a TYPE OF REPORT FINAL		13b TIME COVERED FROM: _____ TO: _____		14 DATE OF REPORT (Year, Month, Day) 1988 AUGUST	
15 PAGE COUNT					
16 SUPPLEMENTARY NOTATION					
17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	tactical symbology, color coding, visual processing, human-computer interaction, man-machine interface		
05	23	02			
19 ABSTRACT (Continue on reverse if necessary and identify by block number) Simplified tactical situation plots were created with shape symbology (i.e. ship, aircraft, submarine, unknown) outlined or filled with color to represent affiliation. Task times were recorded for subjects to identify quadrants which contained the greatest number of a specified target (e.g. hostile submarines, unknown aircraft, etc.) in each condition. Results confirmed that subjects' task times were significantly less in the color-filled condition. An explanation for the effect, how the search worked, and implications for coding tactical displays are discussed.					
20 DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS			21 ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED		
22a NAME OF RESPONSIBLE INDIVIDUAL David Cohen			22b TELEPHONE (Include Area Code) 215-441-3672		22c OFFICE SYMBOL 6022

NADC-89004-60

CONTENTS

	Page
FIGURES	iv
ACKNOWLEDGMENTS	v
INTRODUCTION	1
METHOD AND MATERIALS	2
SUBJECT	2
VISUAL DISPLAYS	2
EQUIPMENT	2
EXPERIMENTAL PROCEDURE	8
RESULTS	8
TASK TIMES FILLED VERSUS OUTLINED	8
INTERVIEW FINDINGS	8
DISCUSSION	10
REFERENCES	12



Distribution For	
GRA&I	☒
TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
and/or	
Special	
A-1	

NADC-89004-60

FIGURES

Figure		Page
1	Shape and Color Codes	3
2	Example Color-Outlined Trial Display	4
3	Example Color-Filled Trial Display	5
4	Experimenter Station: Stimuli Display (Left), Timer Output Display (Right), Video Switching Control Box (Lower Right)	6
5	Subject Station	7
6	Difference in Condition - Related Task Times Across Subjects. Note Superiority of Filled Condition.	9

NADC-89004-60

ACKNOWLEDGMENTS

The author would like to thank David Herbine, Human Factors Applications Branch, Code 6022, NAVAIRDEVCEEN, for developing the hardware configuration and computer program and Dr. Scott Weisgerber, Code 6021, for his valuable comments on this paper. Also Geoff Robson, NAVAIRSYSCOM, AIR-5313 and John Shannon, NAVAIRDEVCEEN, Code 1P41 for their support of this project. Lastly, for all the subjects who selflessly gave of their time and without whose participation this project would not have been a success.

NADC-89004-60

THIS PAGE INTENTIONALLY LEFT BLANK

NADC-89004-60

INTRODUCTION

The P-3C Orion (a land-based, anti-submarine warfare aircraft) UPDATE IV avionics system will include high resolution color displays for the presentation of tactical situation information. With the advent of color displays into a variety of airborne systems, human factors engineers must determine the optimum way to color code symbology to improve operator efficiency.

A recent study conducted at the Naval Submarine Medical Research Laboratory (Jacobsen, Rogers, and Neri, 1986) investigated contact symbology coding and found non-redundant color coding superior to redundant color coding when threat was coded only by color and platform was coded only by shape. Given that this coding scheme is implemented in UPDATE IV, the question arises as to which application of color is best for improving the proficiency of operators during search and identification tasks: outlining the shapes with color or filling the shapes with color. Filling shapes with color produces shapes of greater apparent brightness than those that are outlined in color. Ease of target detection can depend on relative brightness (Stelmach, 1984). Therefore, shapes coded with filled color should be more quickly detected and identified than those coded with outlined color. The goal of the present experiment is to investigate the effect and make recommendations based on the findings.

NADC-89004-60

METHODS AND MATERIALS

SUBJECTS

Twenty-four Naval Air Development Center employees (15 male and 9 female) served in this experiment. All subjects had normal or corrected-to-normal vision and were color-normal (trichromats). Each participated individually in a single session lasting fifteen minutes.

VISUAL DISPLAYS

Two training displays and two trial displays were created. One training display familiarized subjects with the shape and color codes employed: the shapes were those "top-down" symbols (designed to resemble the configuration of the platform when viewed from above) meaning aircraft, ship, submarine, and unknown. The colors used to code platform affiliation were: red - hostile, green - U.S., cyan (blue-green) - friendly, white - neutral, and yellow - unknown (figure 1).

The second training display and the two trial displays were simplified tactical plots that were divided into quadrants. Each contained symbols that were randomly assigned combinations of the "top-down" shapes and the threat colors. The conjunctively defined symbols were randomly positioned in a specific rotation: 0, 90, 180, or 270 degrees. The symbol density was an average five per quadrant on the training display and fourteen per quadrant on the trial displays. Both trial displays were created in a shape color-outlined condition (in which the colored outline was a pixel width) and a shape color-filled condition (figures 2 and 3). The training display contained both conditions in order to acquaint subjects with each condition simultaneously and demonstrate their equivalent meaning. These displays were created with two constraints: (1) no symbols could overlap and (2) no symbols could contact a quadrant border. The shapes were inscribed within a box 18 pixels (.39") high by 15 pixels (.33") wide on the subjects' display which yielded visual angles of 44.69 arc-minutes at 0 and 180 degrees rotation and 37.82 arc-minutes at 90 and 270 degrees rotation when viewed from 30". These visual angles were large enough to eliminate small-field chromaticity problems but small enough so that saccades would not be necessary while viewing individual symbols. The symbols were set against a dark grey background measuring .559 candelas/m². This generated a filled symbol modulation contrast range of .905 to .979 in an area with very little ambient illumination.

EQUIPMENT

Stimuli were created on an Amiga 2000 using Deluxe Paint II. The experimental set-up was located in the Naval Air Development Center Man-Machine Integration Laboratory (MMIL) and approximates the operator-display relationship in UPDATE IV. It consisted of: An obscured Amiga 2000 using a Barco CM22 monitor to format the stimuli, a separate control box to route the Amiga video (figure 4) via a RS-170A to a video switcher (VAX controlled by an RS-232) then via another RS-170A to a cockpit simulator containing a Mitsubishi 19V" High-Resolution Color Display Monitor (640 X 480). An adjustable aircraft seat was positioned so that subjects viewed the display from 30" (figure 5). A second button on the control box at the Amiga station stops the video relay to the subject display. The subject station included a single push-button box that stops a remote timer (set to record milliseconds) internal to a Digital VAX 11/785 (connected using a FORTRAN program). The timer sequence is activated by a depression at the Amiga station control box. When the subject depresses his control button, the time sequence stops and the time is displayed on a second Barco CM22 located at the Amiga station.

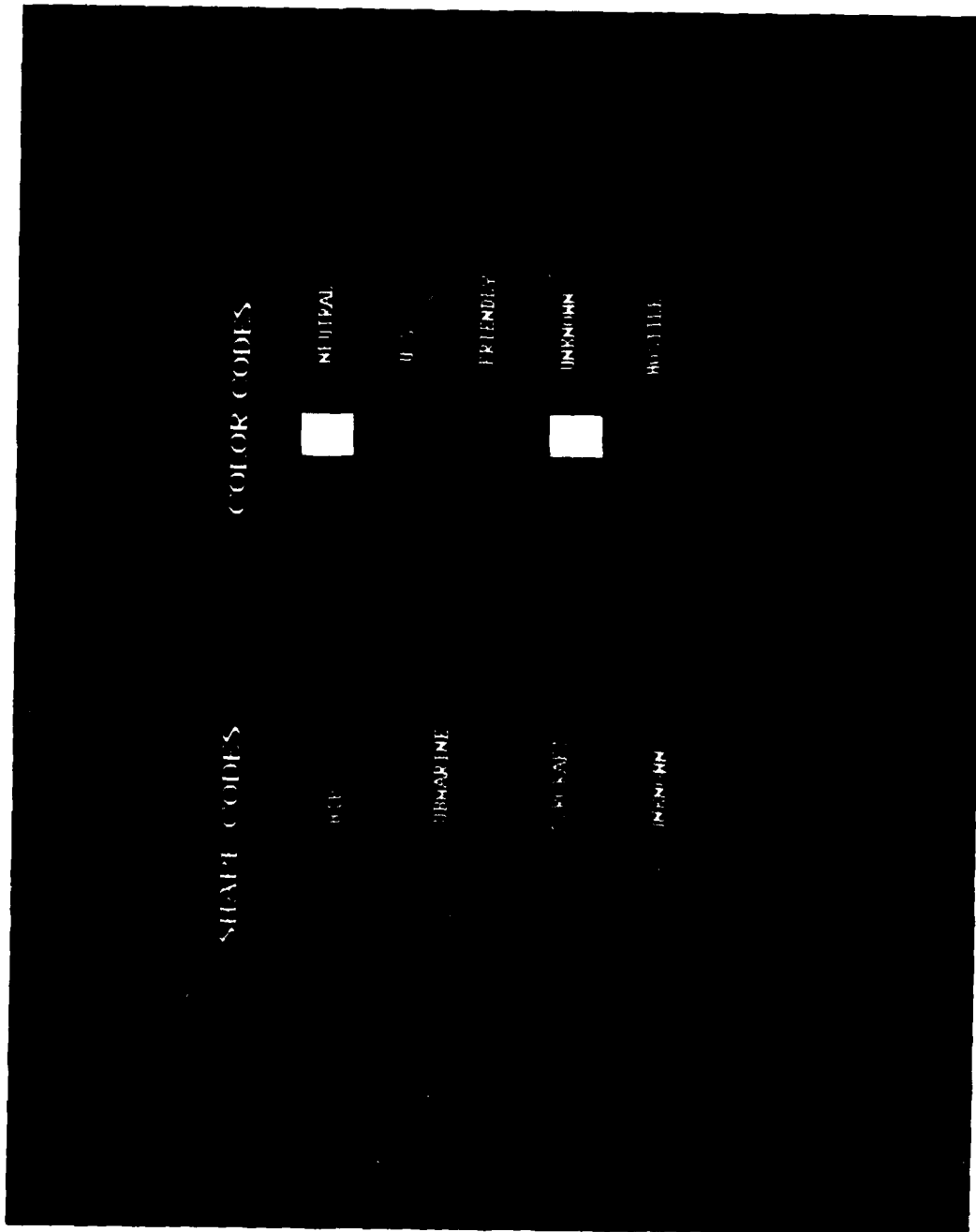


Figure 1. Shape and Color Codes.

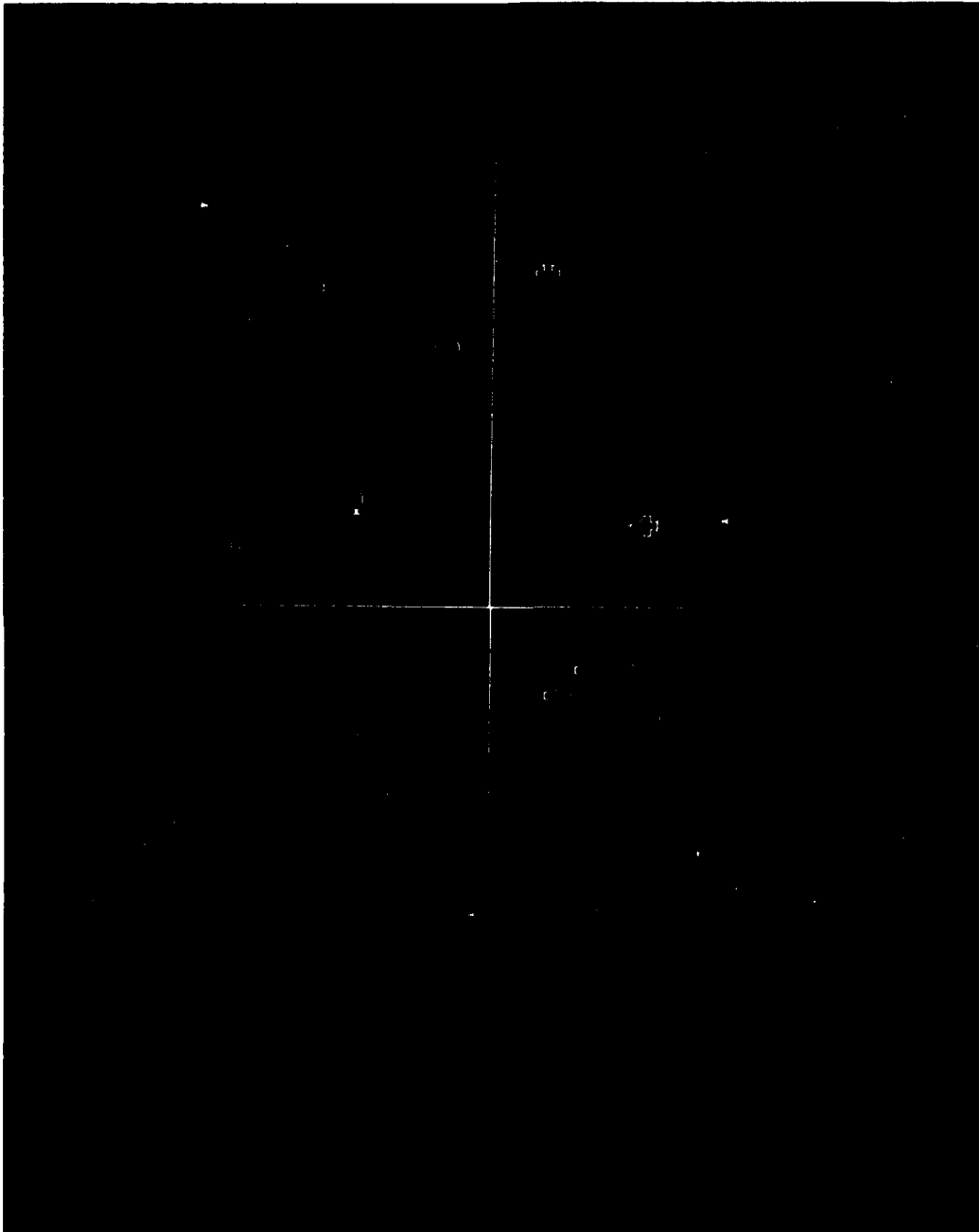


Figure 2. Example Color-Outlined Trial Display.

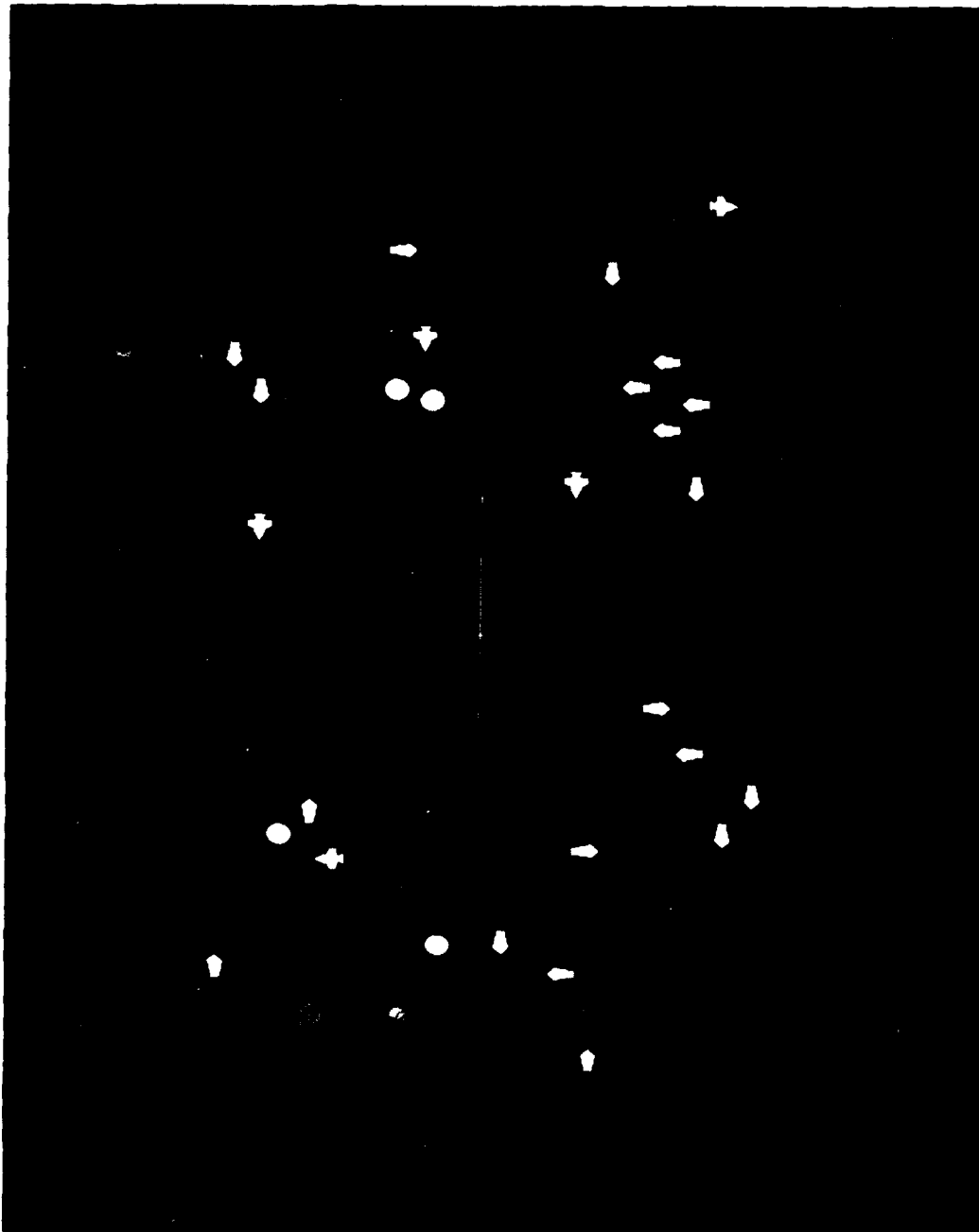


Figure 3. Example Color-Filled Trial Display.

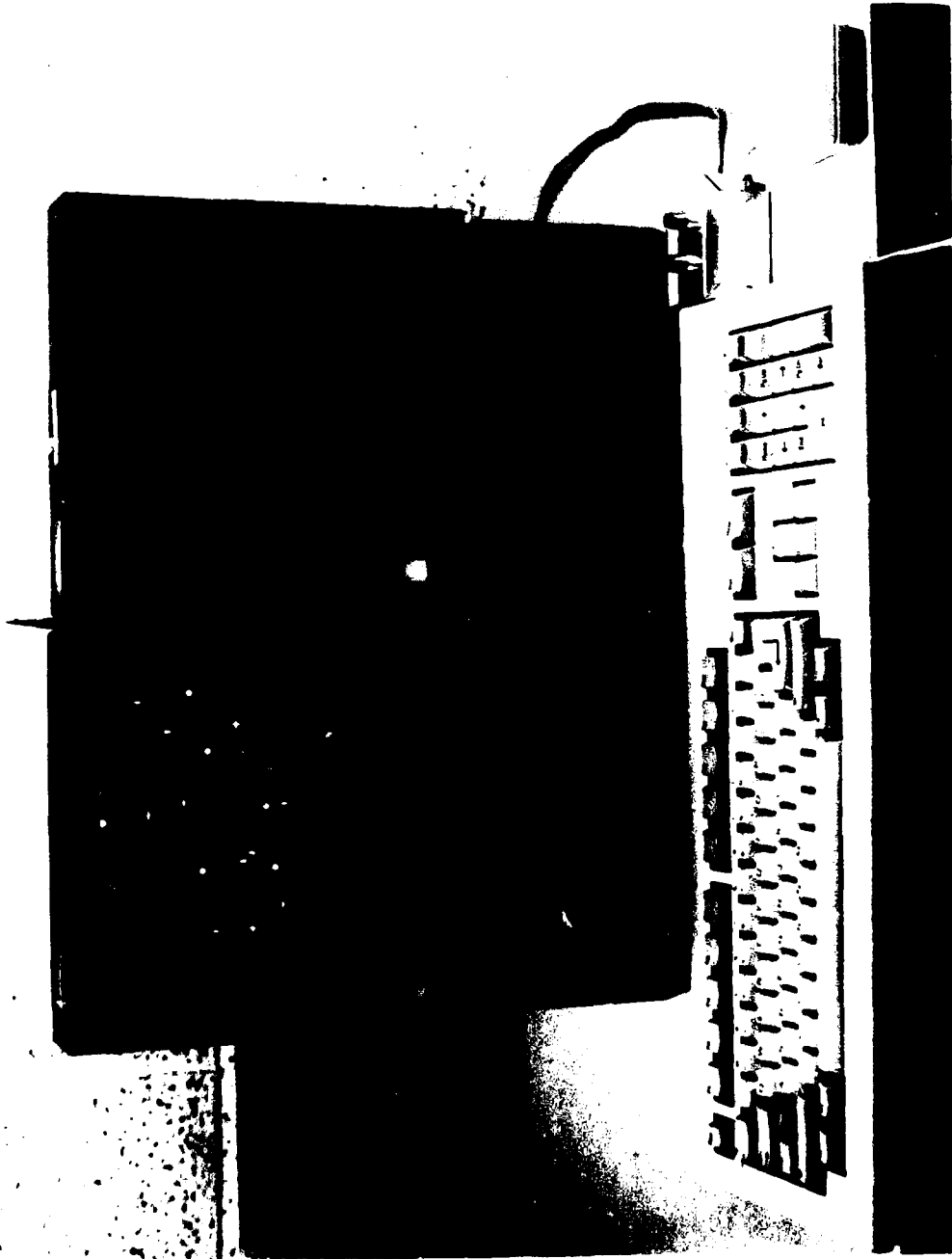


Figure 4. Experimenter Station: Stimuli Display (left), Timer Output Display (Right),
Video Switching Control Box (Lower Right).

NADC-89004-60



Figure 5. Subject Station.

NADC-89004-60

EXPERIMENTAL PROCEDURE

The procedure that was used is a variation of the procedure Hovey and Berson (1987) used to evaluate anti-submarine warfare tactical symbology. After giving their written consent, subjects were positioned in the aircraft seat and (with room lights off) were shown the display which lists the shape and color codes (figure 1). They were then given a short test to confirm their knowledge of the codes (if they failed, they were provided with additional study time). Next, they were shown the sample tactical plot. It was emphasized that the plot is divided into quadrants and that the color-outlined or color-filled conditions are equivalent in meaning.

The subjects were then instructed in the trial procedure: first, they were given instructions on the type of task (e.g. find the quadrant with the most neutral submarines); second, they were told that the tactical plot will appear on their monitor and they should then locate the quadrant satisfying the task; third, upon acquiring the correct quadrant, they should immediately depress their push-button and then point to the quadrant (at this point, the investigator blanks the display and prepares the subjects for the next task). The subjects ran through four sample tasks (more if the subject required additional practice) prior to the actual testing. They were told to work as quickly as possible without making an error.

There were two different tactical plot arrangements presented to the subjects (figures 2 and 3). Both plots appeared in a color-outlined and color-filled version as well as requiring a unique task (i.e. most hostile ships and most U.S. aircraft). Therefore, counterbalancing was achieved by alternating symbol arrangements, color condition, and associated task. This procedure worked to eliminate any sequence, task or practice effects. Subjects were debriefed and interviewed at the conclusion of the testing.

RESULTS

TASK TIMES: FILLED VERSUS OUTLINED

Three subjects out of the group of twenty-four failed to identify the correct quadrant during one task and therefore their task times had to be discarded. This negligible error rate demonstrates that the subjects worked carefully and that there is no difference in the subjects' ability to successfully complete the tasks in either condition (as it bears on this experiment). There was a significant difference in the time subjects needed to complete a visual search task in each condition (figure 6): testing at a .05 level of significance with a directional t-test, the time to complete a task in the color-filled condition was significantly less when compared with the time to complete a task in the color-outlined condition ($t = 2.121$, $p = <.025$, $x_{\text{fill}} = 6.244$ sec. and $x_{\text{outline}} = 7.359$ sec.).

INTERVIEW FINDINGS

Most subjects (75%) reported a marked preference for the color-filled condition (17% preferred the color-outlined condition and 8% had no preference). An even greater percentage (87%) reported that they perceived the color-filled condition as having a greater apparent brightness than the color-outlined condition. Indeed, most subjects stated that their preference for the color-filled condition was predicated on the additional color on the display and how this color enhanced the color and shape (definition) dimensions and improved contrast and brightness.

For most subjects, learning the color and shape codes did not result in a heavy memory load (especially when considering the stereotypical nature of the codes) and the tasks were deemed to be simple ones. Rare confusion did occur between the identification of the ship versus the submarine shape (these subjects tended to lump sea-going vessels together) and between the meanings of white and yellow. Also, to some subjects, the distinction between a U.S. platform and a friendly platform was

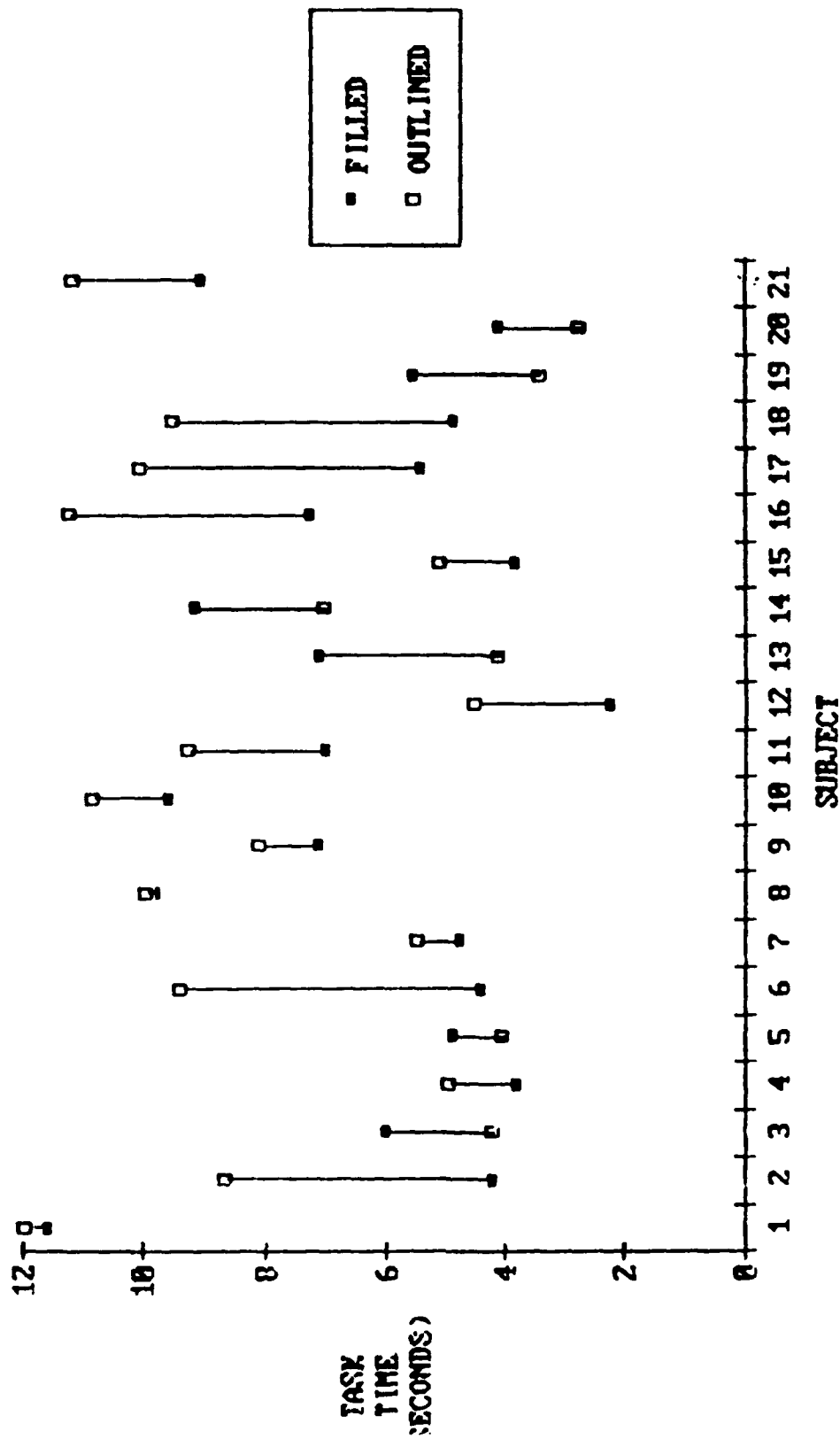


Figure 6. Difference in Condition - Related Task Times Across Subjects.
Note superiority of Filled Condition.

NADC-89004-60

not clear and therefore had to be explained. None of these problems appeared to impact the acquisition of the targets during the tasks.

DISCUSSION

This experiment examined the effect of color on the time required to conduct a visual search. An explanation of this effect will be aided by first understanding the context in which it was produced, namely, the search for the symbol targets. Triesman (1982) developed a multi-stage model of visual processing which distinguishes between two levels: an automatic level and a focused attention level. At the first level, certain features of the visual scene (e.g., symbol colors) are processed for the entire visual field simultaneously - attention is not directed to any specific location. At the second level, other features (e.g., top-down shapes) are purposefully attended to and processed serially. Egeth, Virzi, and Garbart (1984) refined this model for the case of a search for conjunctively defined targets. They conducted an experiment in which subjects searched for conjunctive targets (e.g., red O) in a field where the numbers of two distractors were unconfounded (the number of one distractor type, e.g., black Os or red Ns, was held constant while the number of the other distractor type, e.g., red Ns or black Os, varied). Egeth et al. found that the search need not proceed by a serial examination of each display item. Subjects are able to restrict search to potential targets that were the same color as the target (and possibly the same form as well). Within the set of potential targets, search may be serial.

The validity of the feature integration theory, described above, is in jeopardy, however. Recent research (Pashler, 1987) supports a model postulating that dense displays of conjunctively defined items are searched by a "serial self-terminating search over relatively large clumps of items, and a parallel search within those clumps." This suggests that the nature of the attentional mechanisms formulated by Triesman (1982) for handling feature conjunction in the item-by-item serial processing hypothesis may not be correct. More research is needed to conclusively validate either of the opposing models.

The performance increment witnessed in the color-filled condition of the present experiment might be explained by the greater apparent brightness available. Specifically, the assumption made is that brightness mediates the rates of target detection and processing (see Stelmach, 1984). More research is required to provide an adequate explanation of what processes are at work here (as well as confirm the results at a larger sample size) and if the brightness difference can be attributed to an achromatic or chromatic channel.

Operationally, the results of this experiment suggest that the use of color-filled tactical symbols opposed to color-outlined tactical symbols would be beneficial. Color-filled symbols will provide more brightness and discriminability given the same pixel luminance as an outlined figure and will improve operator performance during search and identification tasks. It is recommended that all color coded symbols be filled (at least when the display will have the tested symbol density or lower) or that the color-filled condition be reserved for designating high value units. The state of tactical situation formatting probably makes the second choice more viable at this time.

The results of this experiment are strongly supported by the recent findings of Lyons, Powers, Vala-Rossi, Purcell, and Schieber (1988). Their study examined the interaction effect that occurred when subjects searched for varying colored targets (presented as solid or line figures) against solid colored backgrounds or located at the intersection (border) of two different colors. They found a significant advantage in response time for solid targets (color-filled shapes) versus line targets (color-outlined shapes) and go on to recommend their use.

Returning to the present experiment, recall, however, that an experimental constraint was that no symbols could overlap. Herein lies a problem. When color-filled shapes come into contact with each

NADC-89004-60

other the original shapes are obscured and new shapes are formed (especially when the shapes are the same color). Work needs to be done to minimize this problem. Options include: (1) defilling symbols when they overlap, (2) not allowing symbols to overlap, (3) using the color-filled condition sparingly (i.e. for high value units) and (4) using a transparent shading fill to produce a "ghost" that allows the fill to be present but does not obscure what is behind it (this option is hardware dependent). These options must be evaluated and the problem satisfactorily addressed before color-fill can be implemented in the P-3 UPDATE IV or in any other tactical display.

REFERENCES

- Egeth, H.E., R.A., and Garbart, H. (1984). Searching for conjunctively defined targets. Journal of Experimental Psychology: Human Perception and Performance, 10(1), 32-39.
- Hovey, C.K. and Berson, B.L. (1987). Evaluation of ASW tactical symbology. In Proceedings of the Human Factors Society 31st Annual Meeting (pp. 1403-1407). Santa Monica, CA: Human Factors Society.
- Jacobsen, A.R., Rogers, W.H., and Neri, D.F. (1986, January). The effects of color coding in GEOSIT displays II. Redundant versus non-redundant color-coding. NSMRL Report Number 1069. Groton, CT: Naval Submarine Medical Research Laboratory.
- Lyons, R.D., Powers, J.M., Vala Rossi, M., Purcell, D.G., and Schieber, F. (1988, April). Utilization of color contrast in electronic tactical display maps. In Proceedings of Psychology in the Department of Defense - Eleventh Symposium (pp. 355-359). Colorado Springs, CO: USAF Academy Department of Behavioral Sciences and Leadership.
- Pashler, H. (1987). Detecting conjunctions of color and form: Reassessing the serial search hypothesis. Perception and Psychophysics, 41(3), 191-201.
- Stelmach, L.B. (1984). Does rate of processing determine ease of target detection? Journal of Experimental Psychology: Human Perception and Performance, 10(1), 108-118.
- Triesman, A.M. (1982). Perceptual grouping and attention in visual search for features and objects. Journal of Experimental Psychology: Human Perception and Performance, 8(2), 194-214.

NADC-89004-60

DISTRIBUTION LIST Report No. NADC-89004-60

No. of Pages

Defense Technical Information Centers	2
Cameron Station, Bldg 5	
Alexandria, VA 22304-6145	
Naval Air Systems Command	1
Washington, D.C. 20361	
1 for AIR-5313D	
Naval Air Test Center	2
Patuxent River, MD 20670	
1 for K. Sola, Code SY-80	
1 for LT Stenzowski, Code FW51B	
NAVAIRDEVCEEN	18
Warminster, PA 18974-5000	
2 for Code 8131	
15 for D. Cohen, Code 6022	
1 for J. Shannon, Code 1P41	
Center for Naval Analyses	1
4401 Fort Avenue	
P.O. Box 16268	
Alexandria, VA 22302-0268	