USER INTERFACE DESIGN AND EVALUATION OF A SHIPBOARD ELECTRONIC WARFARE CONSOLE

by

Richard H. Miller

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APPROVED:

Robert J. Beaton, Chair

H. Rex Hartson

Deborah S. Hix

Paul T. Kemmerling, Jr.

Harry L. Snyder

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Richard H. Miller

Committee Chair: Robert J. Beaton

Human Factors Engineering Laboratory

Industrial and Systems Engineering

This research tested the effect of unique combinations of interface coding and presentation techniques for the redesign of the AN/SLQ-32(V) Display Control Console (DCC). The DCC provides Navy operators with bearing and threat information for radar emitters. The task of emitter identification was used to test potential redesigns. There is no research to substantiate the current or possible redesign solutions. Thus, Experiment 1 tested potential design modifications for the DCC.

The factorial combination of the following comparisons yielded eight possible design solutions: color versus monochrome coding, polar (bearing only) versus range (bearing and range) presentation, and geometric symbols versus icons. Each design was tested in three conditions of emitter density: low, medium, and high. Researchers have evaluated color and symbology with consideration to emitter display systems, but without considering how range information and emitter density effect performance. Results indicate that range information improves performance by 60%. The addition of color and the new icons also significantly improves performance (17% and 15%, respectively) as compared to the current DCC configuration (Polar, Geometric, and Monochrome). Performance was measured by time to complete a task, errors, and subjective workload.

Experiment 2 considered redesign solutions not restricted to the existing hardware or software. Although discussed frequently in the interface literature, performance differences between direct-manipulation and command-key interfaces have not been validated. In this study, two interfaces were constructed to take advantage of direct manipulation and command-key interaction (DMI and CKI, respectively) styles while adding a computer-aided

emitter library management system, an on-screen oscilloscope, a polygon display of emitter parameters, range information, icons, increased usage of color, and other design changes.

Results indicate no differences between the CKI and DMI for the time required to perform the task or for subjective workload. Although both interfaces were designed to take advantage of their respective features, operators did not perform faster with the CKI than with the DMI. However, operators did have significantly fewer errors with the DMI than with the CKI. When compared to the existing DCC and the Range/Color/Iconic design, operators using the CKI and DMI: (1) processed twice as many emitters, (2) reduced one type of error by 50% (CKI) or 67% (DMI), (3) reduced a second type of error to zero, (4) decreased subjective workload by over 50%, and (5) maintained a higher level of performance regardless of emitter density.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY

AN/SLQ-32(V) – The system is a passive receiver of radio-frequency energy that can detect and analyze signals from any bearing surrounding the ship. The unit provides an identification of the energy source and the bearing to the source from the ship.

Bias – The inclination of the emitter: Friendly or Hostile.

CAIS (Computer Aided Information System) – A term used to describe a database capable of searching and retrieving emitter information based on a variety of parameters. An advanced CAIS may employ advanced standard query capabilities, sound identification algorithms, and graphical representations of emitter tones.

Close Control – The emitter currently being processed by the AN/SLQ-32(V). Information known about the hooked emitter are Close Control Parameters.

Close Control Parameters – Parameters that identify an emitter. In this research five parameters are used: PRF, SCAN, SCAN TYPE, EFX, and FREQ.

CIC (Command Information Center) – Area on-board ship that contains the command and control functions and equipment needed to identify potential threats.

DCC (Display Control Console) – Portion of the AN/SLQ-32(V) where the operator interfaces with the machine. The principal operator input/output devices of the DCC consist of a cathode–ray tube (CRT) visual display, light emitting diode (LED) auxiliary indicator display, an alphanumeric keyboard, and assorted fixed–action function keys.

Designation Error – The incorrect designation of a real emitter with the wrong EFX number.

Designate ID – To properly identify an unknown emitter with the appropriate identification number.

Dummy Targets – An experimental definition for targets presented during experimental conditions that do not appear on the sequence list. Hooking a dummy target is an error.

EW - Electronic Warfare or Electronic Warfare Operator – Military action involving the use of electromagnetic energy to determine, exploit, reduce, or prevent hostile use of the electromagnetic spectrum. Term also commonly refers to the operator of an electronic warfare system.

EFX – A number used to designate the emitter as a specific type of platform.

Emitter – Any radar emitting craft.

Fixed Action Button (FAB) – A square 1.9 cm button located on the DCC for making selections of menus and functions.

FREQ (Frequency) – The frequency of the signal generated by the radar of an emitter. The numbers are randomly generated for this experiment.

GeoSit Display (Range display) – A geographic situational display that provides range and bearing information. Land masses can also be displayed in certain systems.

Hooking – Placing an emitter in Close Control by selecting an emitter icon from the polar display is called hooking. See Sequence Select.

Incorrect Designation – See Designation Error.

Library – The library is a list of emitters and their associated emission parameters known by the AN/SLQ-32(V). The library of DCC contains about 130 different emitters.

Library Search – A process whereby the computer searches for an emitter from the on–line library that matches the emitter selected by the operator. (See CAIS)

NTDS - Naval Tactical Display System. A computerized system linking consoles, ships, and aircraft for processing and sharing of tactical data.

Own-ship – The ship where the AN/SLQ-32(V) and the operator are located.

Platform – A platform is a land, sea, or air vehicle capable of carrying missiles.

Polar Display – The current AN/SLQ-32(V) tactical display has a polar display. The Polar display presents bearing information. The DCC also represents targets in three concentric rings to seperate the emitters by threat level; the inner ring is for known friendly emitters, the middle ring for known missiles, and the outer ring for all others.

PRF (Pulse Repetition Frequency) – The time interval between pulses emitted by a radar. The numbers are randomly generated for this experiment. PRF is the inverse of Pulse Repetition Interval (PRI).

Range display – See GeoSit.

Real Emitters – Emitters presented on the display and on the sequence list. Selection and identification of an emitter are the primary tasks of the operator in the experiment.

Scan – A number representing the rate of scanning. The numbers are randomly generated for this experiment.

Scan Type – One of four classes of radar signals generated by emitters for this experiment. The four sounds are Conical (CON), Standard (STD), Circular (CIR), and Sectional (SEC). There are dozens of sub-classes of scanning types.

Sequence List – A list of all emitters detected by the AN/SLQ-32(V), sorted by threat level. Fifteen emitters are presented at any one time. If more than 15 are present, multiple pages of emitters are created. The up and down arrows jump the list to the next and previous pages, respectively.

Sequence Select – (Also called the Sequence FAB) A FAB on the DCC that allows the operator to select emitters presented in the Sequence List. Depressing the Sequence Select button on the DCC selects the next emitter in the Sequence List. The computer selects the first emitter on the Sequence List when there was no previously selected emitter.

INTRODUCTION

In complex systems, an operator must understand many sources of information to make decisions. As the amount and complexity of information increases, the decision making process becomes more difficult.

Computers efficiently analyze large amounts of well-defined values against established criteria (e.g., IF temperature > x, THEN air = True). However, computers do not work well in fuzzy areas of logic (e.g., IF the noise picked up from the radar matches known patterns from a Boeing 737, THEN do not fire a missile). Fuzzy logic, as described by Rouse (1980), can be applied to complex systems, but many systems are so complex that human operators are still needed to interpret information and supervise control actions.

In the U.S. Navy, operators are often required to make decisions based on complex information. One system, the AN/SLQ-32(V), detects and processes passive radar emissions to determine possible threats to the operator's own ship. This research addresses how interface design changes affect operator performance in the context of the AN/SLQ-32(V). This chapter briefly introduces the reader to the AN/SLQ-32(V). A more detailed analysis of the design of the AN/SLQ-32(V) was reported in Beaton, Dyess, Miller, and Moscovic (1991). A glossary of frequently used terms can be found on page xvi.

The AN/SLQ-32(V) Electronic Warfare Console

The AN/SLQ-32(V) is a naval electronic warfare console for Anti-Ship Missile Defense (ASMD). Variations of the AN/SLQ-32(V) are found on many U.S. Navy ships. The experiments described herein examined design concepts for future versions of the AN/SLQ-32(V) Display and Control Console (DCC). Results are discussed as pertinent to the AN/SLQ-32(V) and other complex information display systems.

The DCC provides the communications and control interface between the operator and the AN/SLQ-32(V) radar detection units (Figure 1). A monochrome 30.24 cm display is used to present detected emitters to the Electronic Warfare (EW) operator in the environment. Emitter information is based on radar emissions from land, surface, subsurface, or airborne craft surrounding the ship. Missiles and missile-carrying platforms such as ships and aircraft are the primary concern of the AN/SLQ-32(V) operator. Geometric symbols are used to represent emitters on a circular three-ring display called the polar display, referred to as a "wagonwheel." Additional space around the polar display is used to present other information. The polar display represents a 360-degree view from either the ship or a remotely piloted helicopter and does not contain any range or altitude information.

The three concentric rings on the polar display are used to categorize the types of emitters (Figure 2). This representation provides operators with a two-dimensional presentation of detected emitters surrounding their own-ship (the ship where the AN/SLQ-32(V) and the operator are located). The three rings or zones are:

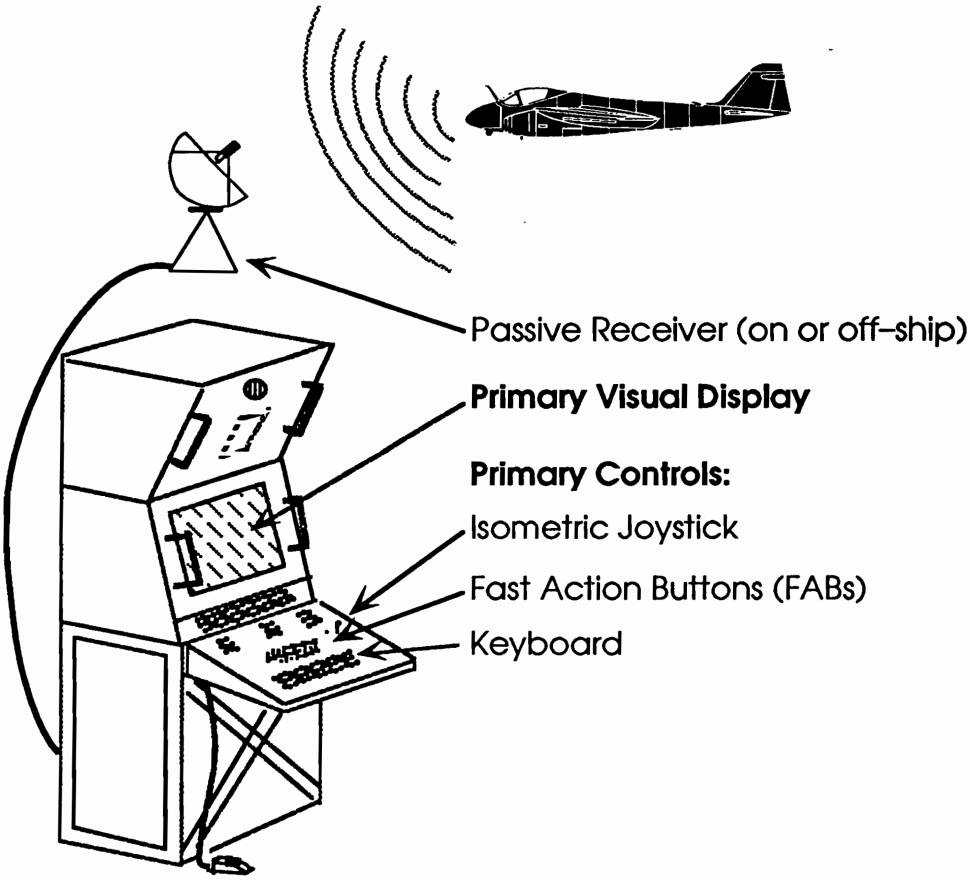


Figure 1. Display control console for the AN/SLQ-32(V).

- Unknown/Hostile Non-Missiles Zone: *outer* ring used to display unidentified or hostile non-missile emitter known to the AN/SLQ-32(V),

- Missile Zone: *middle* ring used to display the tracking of missiles known to the AN/SLQ-32(V) system,

- Friendly Zone: *inner* ring used to display friendly emitters and own-ship known to the AN/SLQ-32(V) system.

In addition to the wagonwheel, the Polar display contains several auxiliary text areas (Table 1). In addition to the Polar display, the AN/SLQ-32(V) presents a number of supplemental screens to support the operator's task objectives (Table 2). These supplemental screens (Table 2) are accessed through various Fixed Action Buttons (FABs) located above the keyboard on the DCC (Figure 1). Any activated supplemental screens replace the polar display with a tabular list format. Additionally, many of the supplemental screens contain prompts for operator menu selection and data entry.

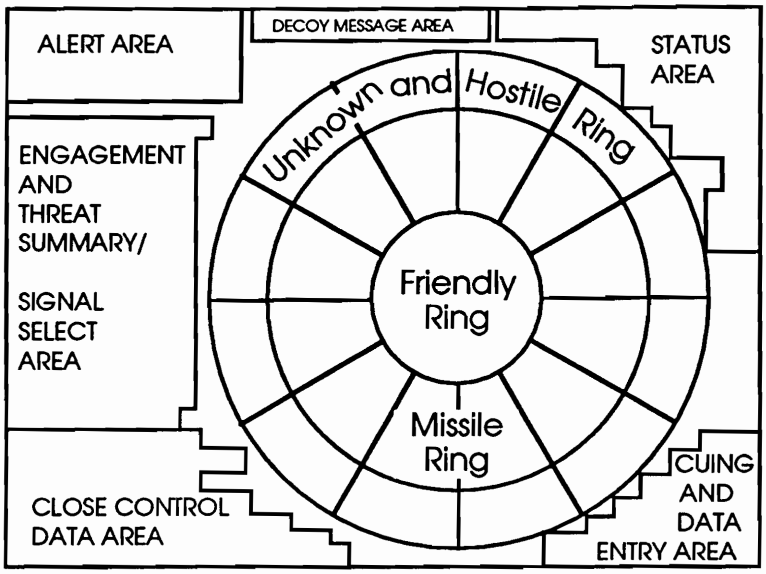


Figure 2. Primary visual display layout for AN/SLQ-32(V).

TABLE 1
Description of Polar Display Areas on AN/SLQ-32(V)

Area	*Purpose*
Alert	Various alert messages: system faults, LAMPS system faults, emitter alerts, CDS alerts, decoy alerts, tape fail alerts, interim faults, executive faults, DCC errors
Decoy Message	Instructional messages for BDA operations
Status	Various status messages
Data Entry	Data entry prompts
Close Control	Parameters for emitter(s) in close control
Engagement and Threat Summary	Parameters for known emitter(s)

The video monitor is one of many visual information sources found on the DCC. Status lights, buttons, knobs, and switches are located below the screen to provide additional sources of information about the operation of the system (see "Explanation of AN/SLQ–32(V) System," page 142 for a detailed view of the DCC layout).

TABLE 2
Description of Supplemental Displays on the AN/SLQ-32(V)

Display	Access FAB	Purpose
ESM Tactical Specification	ANAL	Tabular display of tactical bias factors, inhibited categories, and anticipated platforms
Standard/Upgraded Band 1 Control	ANAL	Tabular display of Upgraded Band 1 parameters, selection of Search or Blanking Control Tables
Band 3 Control	ANAL	Tabular display of Band 3 parameters, selection of sensitivity (High Angle Threat not implemented)
Rapid Response	ANAL	(Unknown at present time)
Band Report	ANAL	Tabular listing of CDS band reporting, selection of CDS enable/disable function
Synchro Data	ANAL	Tabular listing of synchro data sources for relative wind direction and speed, own–ship heading and roll
LAMPS Search Control	ANAL	Tabular listing of LAMPS ESM receiver frequency search controls. Selection of new sectors, report inhibits
Status	ANAL	Up to three separate tabular listing for ESM, ECM, and High Voltage Status Displays
Library Control	LIBRARY ENTRY	Tabular listing of emitter parameters, selection of create, delete, duplicate, modify, edit LAMPS, send LAMPS, transfer to tape functions
SLQ–32 ESM Reporting Inhibits Table (LAMPS ESM Reporting Inhibits Table)	INHIBIT REVIEW	Tabular listing of CDS report inhibits
SLQ–32 Platform Review (LAMPS Platform Review)	PLTFRM CORREL	Tabular listing of emitter parameters, selection of add, delete, rename, rescind functions
Decoy Status	DECOY STATUS	Tabular listing of AECM decoy parameters, selection of terminate, reinitialization, tube, and override functions

The primary controls are located below the screen and consist of a standard QWERTY keyboard, an isometric joystick, 24 FABs, an audio control group, and an Active Electronic Counter-Measure (AECM) control group. Furthermore, EW operators may have access to a 5-inch monitor, the ULQ-16, or an oscilloscope (or both). The ULQ-16 is used for frequency spectrum analysis, and the oscilloscope is used for visualization of the emitter signals. These two display devices are positioned close to the operator's seat, on the operator's left or right depending on the ship.

The AN/SLQ-32(V) requires continuous around-the-clock monitoring by at least one EW operator. The EW operator is required to perform a variety of tasks, including maintaining a library of known craft and missiles, recording hostile emitter capabilities, keeping the ship commander apprised of all threats, deploying chaff and decoys, and managing anti-electronic countermeasures. These tasks support the task of maintaining a known threat environment.

The AN/SLQ-32(V) computer detects electronic emissions and attempts classification, but the current classification system frequently is wrong and always requires operator evaluation of emitter identification. Operators use information received by other shipboard electronic systems and publications (which list parameters of known emitters) to identify emitters. Since the AN/SLQ-32(V) does not present range information, and range information can help to determine the priority of the emitter, the Naval Tactical Display System (NTDS) console is viewed for range information. The NTDS console usually is co-located with the AN/SLQ-32(V). A single operator frequently uses the two systems in tandem to determine threat and range.

The AN/SLQ-32(V) Operator's Task

The primary mission of the AN/SLQ-32(V) operator is to maintain a known system state. The operator's basic task is to (1) recognize that an emitter is present, (2) collect information about the emitter, and (3) enter an emitter identification number into the system based on the information collected. This task was identified from a functional analysis of the AN/SLQ-32(V) operator's job and is called the integrated task (IT). For details of the functional and task analysis the reader is referred to Beaton et al. (1991) and Dyess (1992). The IT is used to test changes to the DCC interface. The IT for AN/SLKQ-32(V) operators is shown in Table 3.

Although many actions are required to operate the AN/SLQ-32(V), the IT is the primary task and was the basis for evaluating redesign configurations of the AN/SLQ-32(V). Please see "BACKGROUND FOR EXPERIMENT 1," page 10 for the design considerations applicable to the redesign of the AN/SLQ-32(V). This research tested a number of alternative display configurations in a controlled laboratory environment.

TABLE 3
The AN/SLQ-32(V) Integrated Task (IT)

1	Operator hears an alert and new emitters appear
2	Operator "hooks" (selects) emitter with the isometric joystick
3	Operator assimilates the following emitter parameters: a. Close Control parameters (bearing, threat level, bias factor frequency, PRF, scan, scan type, assigned EFX) b. Auditory display of scan c. Visual representation of scan (oscilloscope, or frequency spectrum analyzer–ULQ-16)
4	Operator searches through written publications and/or on-line libraries for an ID/ confirmation
5	Operator agrees or disagrees with the system designation and identification
6a or 6b	Operator records the emitter into a log and returns to step 2 Operator searches again through library and/or publications for the correct designation
7	Operator designates the ID, otherwise the new emitter is added to the library
8	Operator records the emitter into a log and returns to step 2 for additional emitters
1	Operator hears an alert and new emitters appear

Experiment Overview

Testing Rationale

The redesign of an interface for an existing system involves many constraints. A designer must work within the constraints imposed by mechanical and electrical engineering, marketing, finance, and management. Changes in a system can be easy or difficult to implement. Easy changes might require only a small amount of programming, such as the replacement of a toggle switch with a rotary switch. More difficult changes might include the redesign of a search algorithm or the addition of a large-screen monitor. The costs and benefits of simple and complex changes must be considered when proposing redesigns. When a system is used by hundreds of operators, training costs also must be considered. A redesigned system should be easier to use, more intuitive, and prone to fewer errors. These factors should help reduce the time and complexity of training.

The AN/SLQ-32(V) has hundreds of functions, making a complete redesign of the system very complex. These experiments tested human-computer interface issues hypothesized to have an impact on usability. Previous examinations of the problems with the AN/SLQ-32(V) focused on display size, use of multiple displays, incorporation of touchscreens, use of color, and display addressability (Naval Ocean Systems Center, 1991). However, redesign recommendations made in the Naval Ocean Systems Center (NOSC) document were not justified with empirical evidence. Recommendations concerning input devices, touchscreens, color, screen resolution and addressability, audio cues, and other design decisions were not substantiated with any empirical evidence. Variables tested in this research were based on the NOSC document, discussions with Navy personnel, and the lack of experimental evidence to support the use of range, color, and iconic information on a display capable of displaying in varying densities (Beaton et al., 1991).

Purpose of Experiment 1

Experiment 1 examined the effect of several variables on the time to complete a task, the number and type of errors committed, and a subjective assessment of interface styles. The levels of independent variables included Color versus Monochrome display, Polar versus Range (a Geographic Situational or GeoSit) display, Geometric (on the current AN/SLQ-32(V2)) versus NATO iconic symbols, and Display density (Low, Medium, High).

Replacing the Polar display with a GeoSit display is warranted. First, the GeoSit display employs a known method for displaying range information, which currently is retrieved from other systems to ascertain the criticality of an emitter. Second, the GeoSit display assists the EW operator with interpreting the overall "picture" of the tactical environment by providing range information for emitters. Third, the GeoSit display is consistent with the Naval Tactical Display System (NTDS) in the Command Information Center (CIC). Therefore, compatibility between the AN/SLQ-32(V) and other CIC systems would be improved with the addition of the range information.

Experiment 1 examined whether color coding would facilitate the EW operator tasks by reducing errors and search times. The current system uses concentric rings to separate missiles, friendly targets, and hostile/unknown targets. Given the large amount of information presented to the operator and the need for efficient processing of information, Experiment 1 tested whether the addition of color would improve the operator's ability to detect emitters.

Research in icon design shows that pictures representative of the type of information to be processed are more likely to be remembered and understood (Blankenberger and Hahn, 1991). The AN/SLQ-32(V) symbol set contains abstract symbols that are not representative of emitters on the tactical display. Experiment 1 compared the current abstract symbols and a new iconic set of symbols based on the draft North Atlantic Treaty Organization (NATO) STANdardization AGreement guidelines (STANAG, 1991). Graphics for missiles (geometric–  vs. iconic– ), and airplanes (geometric–  vs. iconic– ) are two examples of the difference between the current and proposed symbols. Additionally, NATO icons would facilitate standardization within the CIC.

Purpose of Experiment 2

Experiment 2 tested two DCC configurations based on a Direct-Manipulation Interface (DMI) and a Command-Key Interface (CKI). The variables found to improve operator performance in Experiment 1 were used in designing the interfaces tested in Experiment 2. The interface designs in Experiment 2 have specific features that were known to improve performance in Experiment 1 plus new several features.

In Experiment 2, the procedure for analyzing emitter parameters was aided by a computer-assisted identification system (CAIS). This redesign had three advantages over the existing Baseline design, which is the combination of factors that reflect the AN/SLQ-32(V2) DCC (Monochrome, Polar, and Geometric design features). First, the existing library structure forces an EW operator to rely on manual searches in large publications, searches that require the operator to look away from the primary visual display. These publications are not organized by the same principles as the emitter parameters presented on the screen, in the close control area, or in the on-line library. A single search requires the operator to look at four different sets of information, each presented in a different format. The redesigns present all the parameter information using a single format in a designated area on the video display. Actual AN/SLQ-32(V) operators use more than the four parameters employed in these experiments; making search, sorting, and comparing parameters even more complex.

Second, the publications do not take advantage of a computer's ability to process, search, and retrieve information efficiently. Searching a library that contains all known emitters could decrease search time. Due to the rapid rise in computer power and available storage capacity, the entire publication could be stored and searched on-line. An added benefit of a complete on-line library would be the elimination of paper publications that increase clutter in the workplace.

Third, improving the layout and integration of the library can affect the EW operator's job. Computerized libraries with increased capabilities eliminate operator reliance on publications, allow operators to search for emitters based on a variety of parameters and parameter combinations, and serve as the platform for embedded training. A redesigned system would provide more flexibility when adding or deleting emitters from the library and allow changes in the library to be downloaded from satellite directly into the database. All ships equipped with the new system would be able to maintain a current emitter library with minimal effort by the operator.

Experiment 2 examined whether the elimination of publications and the use of different interaction methods would improve identification times and decrease operator workload. An object display was developed to assist operators in recognizing differences in an emitter's parameters. The information in the object display was based on the close control and library parameters. Color was used to link information throughout the interface. Color was extended from the common paradigm of icon coding to include the consistent use of color in the sequence list, the on-line library, and the polygon display.

The final design of an interface requires that a single redesign be selected for production. Only a limited number of factors can be tested in the laboratory. User-interface guidelines, previous experimental evidence, military specifications, and design handbooks were used to justify redesign configurations.

Objective

The overall objective of this study was to analyze combinations of important interface design methods as applied to a redesign of the AN/SLQ-32(V). This objective was accomplished by collecting empirical performance data on the usability of specific design alternatives. Experiment 1 manipulated three variables considered important to future redesign consideration: Color, a Range display, and Icons were tested over three levels of emitter density. The major difference between the two versions in Experiment 2 is based on the premise that DMIs are easier to use but slower than CKIs. Prior to this research, no studies have adequately measured the performance differences between interface styles using the same complex task. In Experiment 2, the interfaces were designed to take advantage of the benefits of either direct manipulation or command-key interaction. Emphasis in this experiment was placed on making each interface the most effective and efficient possible, given the operator's task. Specifically, this research:

- Established empirical evidence to support redesign solutions for the AN/SLQ-32(V) by testing the effect of color, symbol type, and display type on time to complete tasks, selection errors, and subjective workload (Experiment 1).

- Justify screen redesigns of future AN/SLQ-32(V) configurations that use unique combinations of known display formats. Existing display-size restrictions applied when testing usability with quantitative and qualitative measures of performance (Experiment 1).

- Validate command-based and direct-manipulation interaction styles as possible redesign solutions (Experiment 2), while addressing the common design criterion associated with the two interface styles.

- Provided statistical evidence to support performance claims for differences between the designs tested in Experiment 2 and the designs tested in Experiment 1.

- Analyzed design considerations for use in future redesigns of the AN/SLQ-32(V) (Experiment 2).

BACKGROUND FOR EXPERIMENT 1

The creation of new display designs for the AN/SLQ-32(V) requires the consideration of many factors. Research on each of the these factors was reviewed to determine their effectiveness in redesigning the AN/SLQ-32(V). The analysis of the combination of these factors has not been reported.

Configuration of ULQ-16 and the AN/SLQ-32(V) System

The AN/SLQ-32(V) as configured in a typical CIC is shown in Figure 3. The NTDS console is located to the right of the AN/SLQ-32(V). The ULQ-16 and oscilloscope are positioned near the DCC. The oscilloscope is not always available to EW operators and is occasionally borrowed from the maintenance department. The experimental design assumes the ULQ-16 is available to the operator.

Task Analysis

As part of the AN/SLQ-32(V) redesign effort, a task analysis was conducted by Beaton et al. (1991). The EW operator's primary and secondary tasks are outlined in Table 4.

Based on the analysis and scope of the project, a single operational task—the Integrated Task (IT)—was selected for the purposes of the redesign effort for the DCC. As indicated in Table 4, the primary responsibilities of the EW operator include: (1) monitoring the electronic environment, (2) detecting changes in the environment, and (3) evaluating emitters.

The IT encompasses all three of these activities. Moreover, the IT is the basis for all secondary tasks performed by the EW operator. It is important for the EW to perform the IT efficiently. Expert EW operators at Norfolk Naval Base reviewed the basic IT (detailed previously in Table 3, "The AN/SLQ-32(V) Integrated Task (IT)," page 5) for validation. The task tested in the Experiment 1 is similar to the actual IT. How the IT differs from the actual task is discussed elsewhere (see Table 9, page 32). The task in Experiment 2 was modified based on the results of Experiment 1 to improve the performance of operators (see "The Experimental Task," page 32). The goal of the IT in Experiment 2 was maintained (designating emitters), but the steps for accomplishing the goal were modified to support the advantages of the interface designs.

Color

The current system uses a monochrome cathode-ray tube (CRT) with three luminance levels: off (pixel off), standard (pixel on), and bold (pixel double intensity). A list of emitters found by the AN/SLQ-32(V) passive radar system is presented to the operator in a list ordered by threat. This list is called the Sequence List, and it contains no color coding, iconic representations, or spatial connection to the emitters presented on the polar display. Furthermore, the bearing information presented in the sequence list does not differentiate

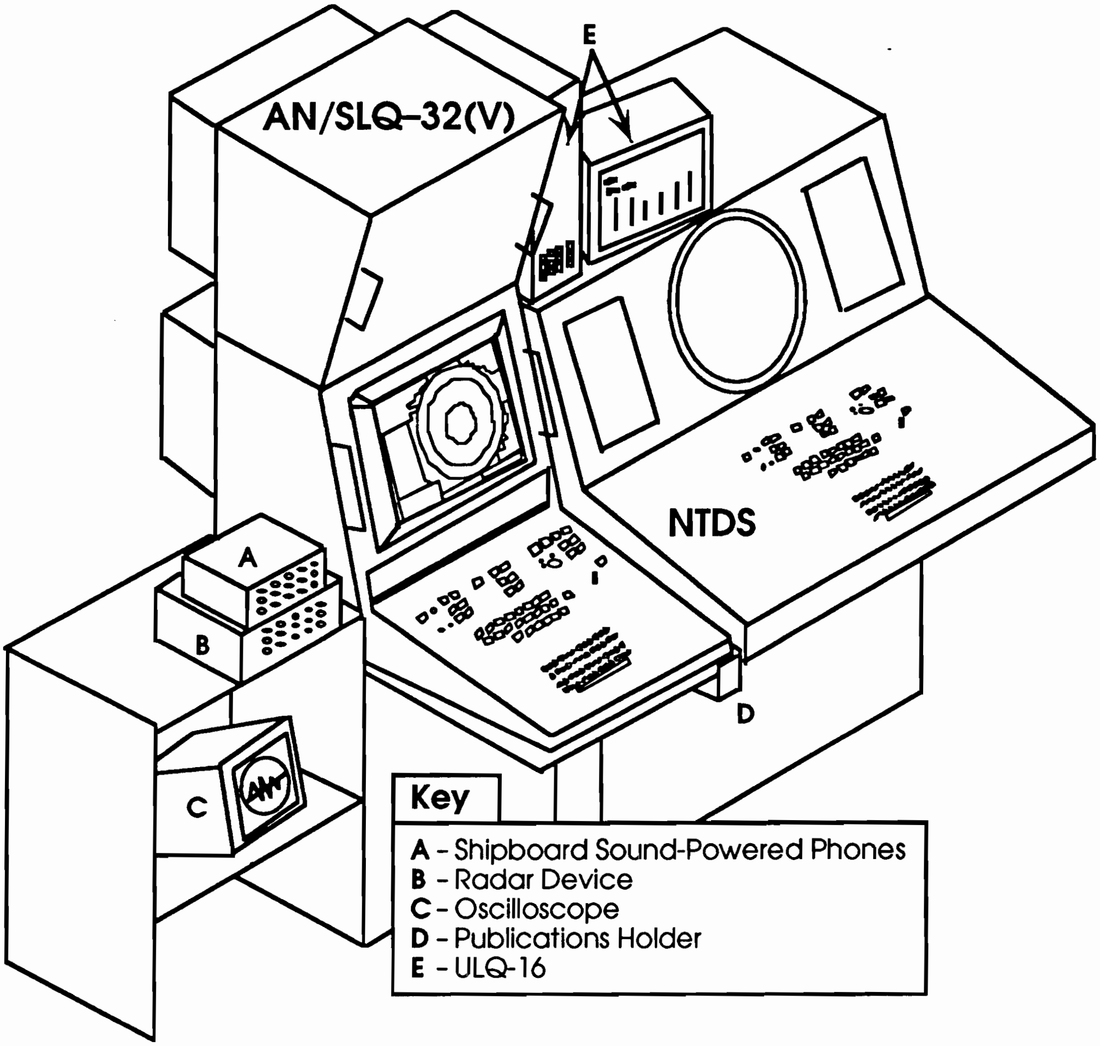


Figure 3. A typical AN/SLQ-32(V) set-up onboard ship.

the emitter position shown on the polar display. More than one emitter can appear at the same bearing. In the actual system, one symbol can represent more than one emitter at the same location along a bearing line.

Krebs, Wolf, and Sandvig (1978) reported that color coding is effective when a display is unformatted, the symbol density is high, and the operator must search for specific information. Although color was tested to determine whether it improves performance, the effectiveness of color decreases as the number of colors increase in a display (Tullis, 1983). The redesigned symbology uses color as a semi-redundant cue in conjunction with the emitter's symbol. Kopala (1979) reported that redundant color coding significantly reduced both response times and error rate for recognized threats in a dense display. As Christ (1975) pointed out, the proper use of color coding can assist in localizing critical elements.

TABLE 4
Primary and Secondary AN/SLQ-32(V) Operator Tasks

1. SLQ Operation and Emitter Management	
◆ initiation of system	Primary
◆ prepare electronic order of battle	Primary
◆ analyze available intelligence data	Primary
◆ **surveillance** *	Primary
➤ **detect emitters** *	Primary
➤ **locate emitters** *	Primary
➤ **track emitters**	Primary
◆ **emitter evaluation** *	Primary
➤ **instantaneous id of high-threats** *	Primary
➤ **auditory recognition of emitters** *	Primary
➤ **match emitters to EOB and pubs** *	Primary
➤ **manage emitter alerts** *	Primary
➤ **designating emitter identifications** *	Primary
➤ **correlating emitters to platforms** *	Primary
◆ emitter logging	Secondary
➤ written log	Secondary
➤ updating library	Secondary
2. ECM and AECM	
◆ employ ECM and AECM	Secondary
◆ missile counter-targeting	Secondary
◆ employ MK Decoy Launching System	Secondary
➤ initialize BDA	Secondary
➤ initiate/end decoy engagement	Secondary
➤ select decoy type, salvo size	Secondary
➤ select launcher and launcher tube	Secondary
➤ arm and fire each tube	Secondary
➤ verify launch	Secondary
➤ determine reseed interval	Secondary
➤ coordinate launcher reloading	Secondary
➤ conduct an IR engagement	Secondary
➤ conduct a distraction engagement	Secondary
➤ conduct a chaff engagement	Secondary
3. Communication/Coordination	
◆ coordinate with own force and LAMPS	Secondary
◆ provide early warning to ownship	Secondary
◆ respond to CIC queries	Secondary
◆ coordinate with other CIC operators	Secondary
◆ brief watch relief (tactical environment)	Secondary

* Denotes Part of the Integrated Task Tested in Experiments 1 and 2

Color Versus Monochrome in Information Displays

Previous research examining color-coded versus monochrome displays has sought to improve visual search time and improve operator performance. Boff and Lincoln (1988) reviewed research supporting color coding in specific situations; some research demonstrated that color-coding had a negligible or even adverse effect on performance. Color in the AN/SLQ-32(V) can aid the logical grouping of information on the display.

Tullis (1981) compared four different types of CRT display formats for a system that tested telephone-line conditions. The task required the operator to identify pieces of information from the display to diagnose problems in the system, a task similar to that of the AN/SLQ-32(V) operator. The formats evaluated by Tullis were narrative, tabular, monochrome graphics, and color graphics. Tullis found significant improvements in speed when using either graphic format. Accuracy, however, did not vary as a result of format type. Within graphic formats, no difference was found between the color and monochrome displays. The color-coding scheme used by Tullis was not effective in distinguishing the information needed by the operator from the other information presented on the screen. Adding color to the AN/SLQ-32(V) interface creates a cognitive link between the sequence list and emitters on the polar or range screen. The color coding presented in the sequence list will assist the search for the appropriate emitter in the range or polar screen.

Color as a Redundant Code

Kopala, Reising, Calhoun, and Herron (1983) reported that redundant color coding significantly reduces both response times and error rates for recognized threats in a high-density emitter environment on a display. They also found that the benefits of color coding increase with increases in display density. Improved performance with increased display density also was shown by Smith and Farquhar (1965), who found color coding to be more effective at higher information density levels (up to 100 items formatted in rows and columns). Although Smith and Farquhar tested color coding for a formatted display in their study, previous research by Smith (1963) and Smith and Thomas (1964) also found coding to be effective for items distributed randomly throughout the display.

Results from Shontz, Trumm, and Williams (1971) indicate that redundant color coding significantly reduces search time, counting time, and counting errors. Although the EW operator task is not a counting task, the research is applicable because the ability of an operator to count the number of icons of a specific color implies that the operator can discriminate one color from another and, therefore, assess the overall threat level of the environment. The colors represent the threat types such as those on the AN/SLQ-32(V).

Krebs, Wolf, and Sandvig (1978) presented five guidelines for the use of color in improving operator performance (Table 5). All five guidelines are relevant to the display format for the AN/SLQ-32(V) DCC. Smith and Mosier (1984) wrote, "displayed data should provide necessary information even when viewed on a monochrome display terminal or hard-copy printout, or when viewed by a user with defective color vision" (p. 184). This guideline is for general computer-based information design and does not take into account the requirements that designers can establish to allow for partially redundant coding (e.g., missiles are always red, so the icon shape is redundant with the color, but the same-ship icons can be green or orange depending on if they are friendly or hostile, also called bias). Hard-copy and other monochrome displays need not be considered.[1] The use of color as a secondary code is based on the assumption that users (especially males) have color deficiencies. Navy operators are screened for color deficiencies and other vision problems. Without this drawback, color has the additional advantage of not requiring large and more complex icons to represent emitters. Christ's (1975) survey of the literature supports the use of color over size, shape, or luminance as the most effective code for searching and symbol identification. As Christ pointed out, the advantage of color increases with the density of symbols on a display when participants know the color of the symbol prior to beginning a search.

TABLE 5
Criteria For Color Coding On Visual Displays

Criterion	Conditions on Current DCC
1) Display is unformatted	Emitters do not appear in a specific location
2) Symbol density is high	The display can contain more than 100 emitters
3) Operator must search for relevant information	Hooking requires the operator to search for the relevant emitter icon
4) Symbol legibility is degraded	Symbol legibility can be degraded by ambient lighting conditions and poor discrimination
5) Color codes are logically related to task	Limited brightness, not color coding is used
Note: Criteria adapted from Krebs, Wolf, and Sandvig (1978)	

During periods of high workload, it is not possible for EW operators to examine and evaluate all emitters. Expert EW operators maintain effectiveness during busy periods by not processing friendly and potentially hostile emitters and by processing only threatening emitters. Fortunately, emitters are order by threat level in the sequence list (highest threat first followed by probable threats, possible threats, and then friendly emitters). Accordingly, one way to decrease workload is to color code the threat levels into meaningful groups.

In a redesign of the AN/SLQ-32(V), only a few colors are needed to code emitters by threat level: red for missiles (danger), orange for hostile emitters (warning), yellow for unknown emitters (caution), and green for friendly emitters (OK). The exact color specifications for these colors are display dependent and will not be discussed here.

1. If other off-line systems used hard-copy images of the display, supplemental coding could be used for the hard-copy. There is no reason to clutter the display with coding used elsewhere.

Symbology

The current AN/SLQ-32(V) symbol set is a cryptic set of lines and dots that represent different types of emitters, as shown in Figure 4. This research compares a new iconic symbol set to the existing AN/SLQ-32(V) symbol set. Icons are a subset of symbols. A symbol can be completely arbitrary in appearance, whereas an icon is representative of the object and easy to understand (Marcus, 1992). The current symbol set requires the operator to translate the meaning of the symbol to its appropriate representation. The new icons resemble the representative emitter. When an operator sees a missile icon, no further mental processing is necessary to identify it as a missile (Blankenberger and Hahn, 1991). The independent variable "Symbols" has two levels: Geometric and NATO Iconic.

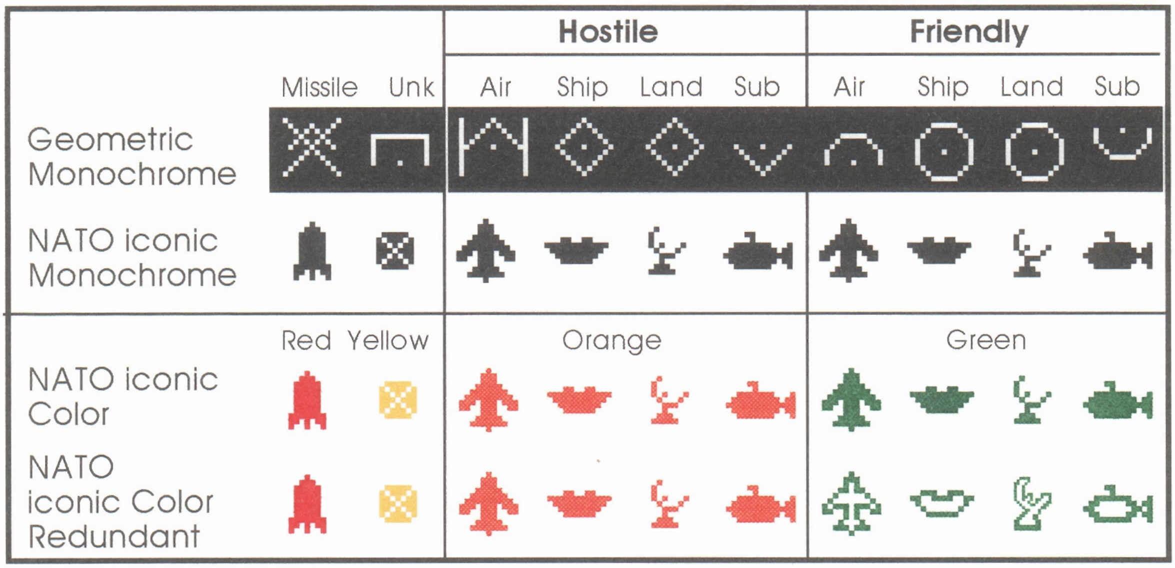


Figure 4. Current AN/SLQ-32(V2) geometric monochrome symbols, NATO monochrome icons, NATO color icons (partially redundant), and NATO color icons (redundant). (Scaled 200%)

Lodding (1983) explained how the three types of visual images (representational, abstract, and arbitrary) can be classified into three design styles (Table 6). The current AN/SLQ-32(V) uses an abstract design to represent emitters, whereas the redesigned icons are a representational design. Lodding pointed out that pictures can be recognized easily and, therefore, "easily taught, learned, and retained" (1983, p. 15). The redesigned icons invoke real-world knowledge and specific exemplars (missiles, planes). Barnard and Marcel (1984) discussed the difficulty in inferring concepts or logical relationships between abstract symbols and real-world counterparts. The relationship between the geometric symbols and their meaning must be learned and remembered and cannot be easily inferred.

TABLE 6
The Relationship Between Design and Function for Visual Images

Design	Function	Experiment
representational	picture	revised NATO icon set
abstract	symbol	current icon set
arbitrary	sign	N/A

In the current AN/SLQ-32(V) geometric symbol set, all friendly emitters have curved faces (), while the hostile emitters use angled lines (). Airborne emitters have a top face (), while subsurface emitters use the lower face (). Although not documented, the orientation probably implies an altitude rule for the type of emitter. One must assume that the dot in the center of the symbols represents the horizon. For airborne emitters the top face is above the horizon representing the craft is above the horizon (airborne). Airplanes have the additional features of two vertical lines that possibly representing wings. Missiles have a top face in addition to the "X" (). Furthermore, emitters with a lower face (below the horizon dot) are subsurface. The symbols that enclose the horizon dot () are either surface or land. Unknown emitters are represented as three-quarters rectangles ().

The NATO icons can be presented in color or monochromatically. The AN/SLQ-32(V) differentiates hostile from friendly emitters on a green phosphor display with threat level, bias, and category. In the current system, threat level is only partially redundant with the icons, so knowledge of the threat level is not sufficient to identify the emitter. The friendly and hostile NATO icons cannot be distinguished without additional coding when presented monochromatically.

The bottom set of icons in Figure 4 show a redundant coding scheme for discriminating friendly and hostile emitters. Friendly icons are outlined, while all others are filled. Hostile emitters can be found more quickly when filled than when outlined (Blankenberger and Hahn, 1991). Since the hostile icons are filled with a solid color, they are perceived as brighter than outlined emitters, which are filled with black. The brighter the icon, the more salient is the icon. Since the operator's primary responsibility is to identify emitters, the color-filled icons can be expected to improve discrimination performance. As a coding method, outlining eliminates the need for presenting bias and category on the display. Thus, icon shape and fill provide the necessary minimal cues to identify emitters—color is an additional coding dimension. The outlined icons are not tested in these experiments and are shown only for completeness.

A study reported in the STANAG 4420 Ratification Recommendations (STANAG, 1991) investigated the current NTDS symbology, NTDS color symbols with text tags, NATO color-filled icons, and NATO color-outlined icons for standardization for display symbology and colors for maritime units. These four conditions were tested for accuracy and selection speed from a cluttered screen. STANAG concluded that color-filled icons were more effective than color-outlined icons. Performance was enhanced and variance was reduced with colored icons. Figure 5 shows the relative performance between the revised symbol sets and the NTDS set. The NATO STANAG symbols were selected significantly faster than the NTDS symbols ($p < 0.01$) and the NATO outline symbols ($p < 0.05$). The results from STANAG showed the NATO color-filled symbols are learned easily and preferred over the other symbol sets.

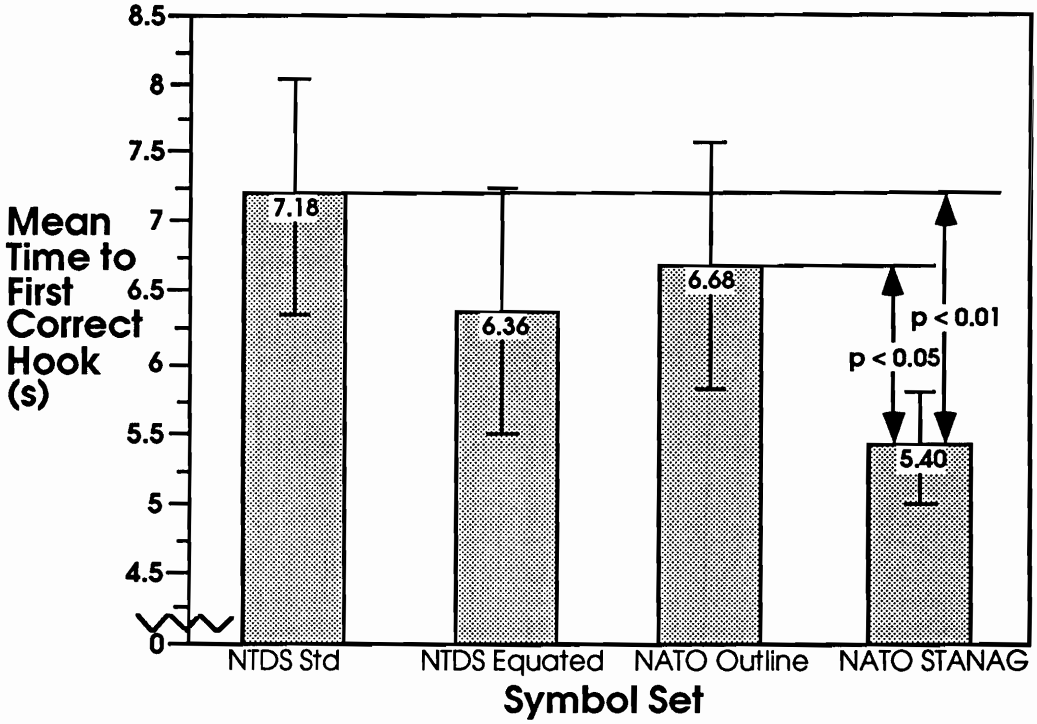


Figure 5. Mean time to first correct hook as a function of symbol set for the symbol recognition task. Adapted from STANAG (1991). Error bars show 95 percent confidence intervals for each condition.

Time is not the only important measure when designing an electronic warfare system. Reducing errors also is an important part of the design process. In the STANAG study, researchers found operators had significantly higher error rates with the NTDS symbology than with the redesigned symbol sets (Figure 6). The percentage for correctly hooking target emitters on a low-density[2] display was found to not vary among the redesigned symbol sets.

When considering improvements in both time and error rates, all three redesigns tested in the STANAG study were significantly better than standard NTDS icons (Figure 7). Participant experience was not a factor in determining symbol recognition performance.

2. "Low" density is with respect to the density variable manipulated in Experiments 1 and 2.

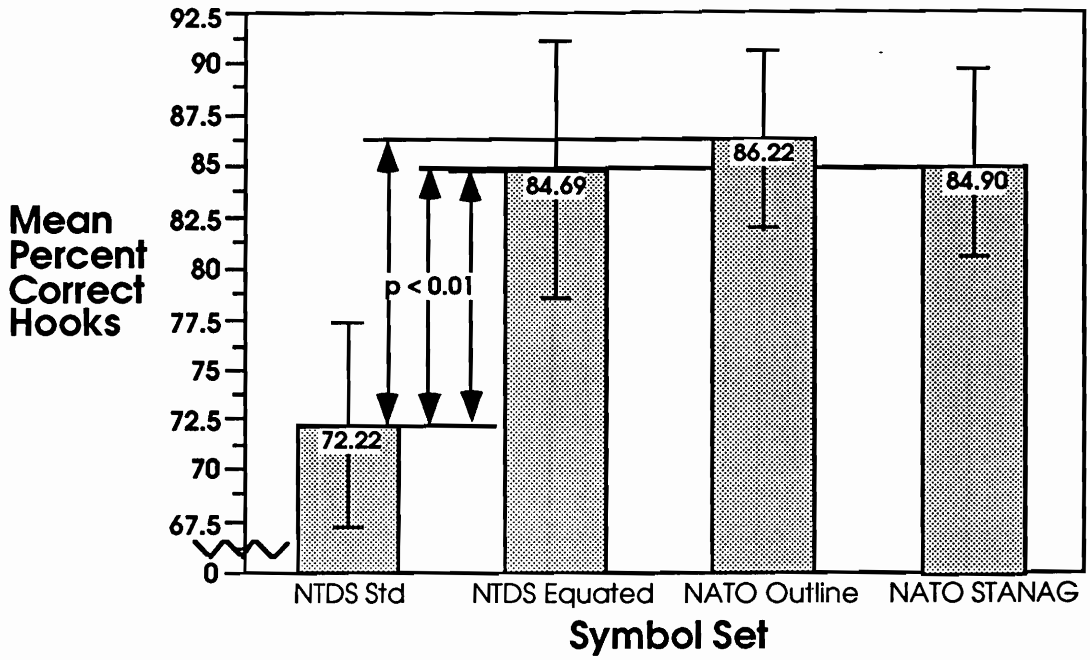


Figure 6. Mean percentage of correct hooks as a function of symbol set for the symbol recognition task. Adapted from STANTAG (1991). Error bars show 95 percent confidence intervals for each condition.

Although participants were familiar with the NTDS icons (participants had NTDS or other EW experience), they had only brief training sessions with the NATO symbology. Therefore, longer exposure to the NATO symbology could produce larger differences. Operators rated the NATO STANAG symbology as easier to use than the NTDS Standard group.

If the NATO icons are used on a range display, perceived emitter direction could be a problem because the geometric symbols do not point in any specific direction. Orientation must be maintained with the geometric symbols or the operator may confuse airplanes and subsurface craft (the symbols are similar except for a 180-degree rotation and the lines on the aircraft). Two unknowns with similar bearing but oriented to reflect headings of 90 and 180 degrees would appear on the display as similar to a hostile ship oriented with a heading of 90 degrees (i.e,  compared to , other pairs of symbols would have similar problems if rotated). The friendly symbol for a surface or land emitter () is a good example of unidirectionality of the geometric symbol set. STANAG (1991) reported that EW operators of the NTDS system were concerned with the directionality of the emitters. The NATO icons are not horizontally or vertically transitive which is important to consider when trying to create bearing coding by rotation without any additional icons or labels.

Decker, Lloyd, Kurokawa, and Snyder (1991) found that orientation does affect search time for symbols on a display. They tested 62 symbols and alphanumerics. As the size of objects increased from 7 x 9 to 9 x 11, or even to a 11 x 15 dot matrix, search times were reduced significantly from 8.39 to 5.37 seconds ($p < 0.05$). This type of performance

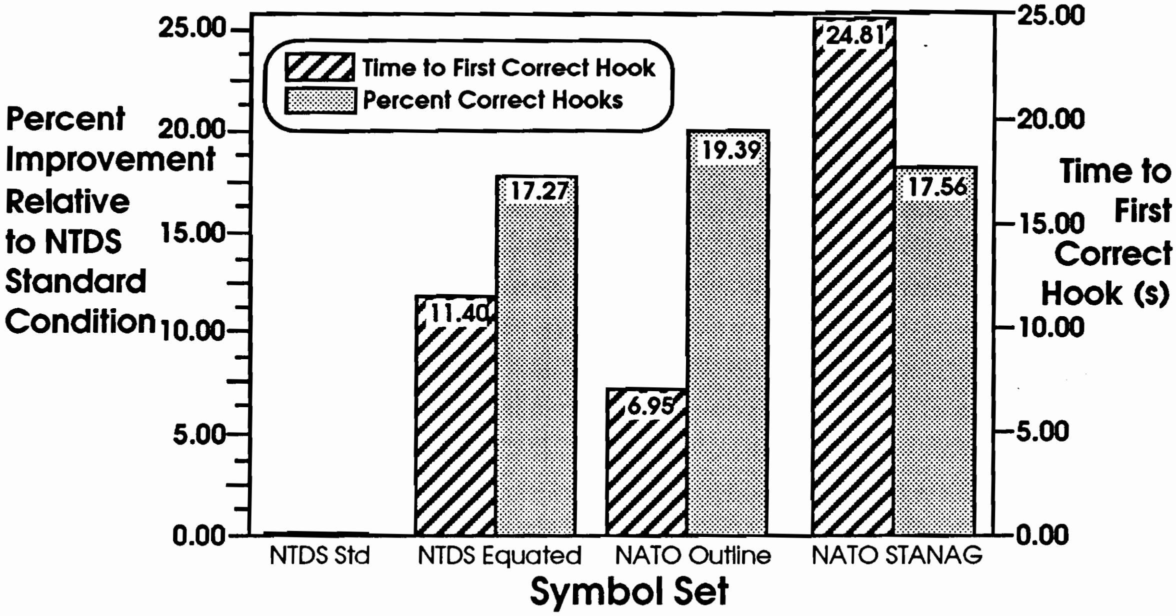


Figure 7. Percentage improvement in performance over NTDS-standard icons as a function of symbol set for the symbol recognition task. Adapted from STANTAG (1991). Error bars show plus and minus 95 percent confidence intervals for each condition.

degradation due to orientation has to be compared to the increase in clutter created by adding tracking dots, arrows, or by having the operator look at the NTDS system to determine bearing. The significant increase in search times shown by Decker et al. (1991) may be less than time differences for other methods of bearing encoding. Symbol orientation is recognized as an important visual cue and is beyond the scope of this research but should be considered in a redesign of the AN/SLQ–32(V). Similar tradeoffs concerning rotating icons to represent bearing may exist if outlined rather than filled coding is used. Other methods may increase clutter or cause more confusion than coding with outlined icons. Care should be taken to create color outlined icons with sufficient visual angle so that they can be discriminated.

Blackwell and Cuomo (1991) tested an icon set similar to the NATO icons tested in this research (Figure 4, page 15). They reported reduced error rates and search times for the icons after revising the proposed symbol set for the Integrated Tactical Warning and Attack Assessment systems (SIO-STD-2100A). Blackwell and Cuomo simplified shapes, shaded symbols, enhanced critical features, and created new symbol shapes. They showed that time (to search and select with a mouse) for filled icons was 7.64 seconds as compared to 8.09 seconds for hollow symbols ($p < 0.001$). A coding method other than icon filling is needed to reduce the time to search and select while maintaining a distinction between friendly and hostile emitters. Subjective ratings showed that subjects preferred the revised filled symbols over the original set.

Blackwell and Cuomo specified a minimum size of 40 arcminutes for revised symbol standards. Emitters with a height of 30 and 40 arcminutes were tested. Icon selection was significantly faster for the larger symbol set (7.4 versus 8.3 seconds). However, this result does not account for the tradeoff between size and search time. If Blackwell and Cuomo used targets with a height of 5 arcdegrees, Fitts' Law (Card, Moran, and Newell, 1983) would predict even faster selection times, but then only a few emitters would fit on the visual display. A design decision must be made that reflects the number of possible emitters, the size of the emitters, and the spacing between emitters.

The control/display (C/D) ratio of the input device also has an effect on selection times. Increasing the C/D ratio might decrease the relative difference between the two target sizes. Since Fitts' Law is based on a logarithmic scale, the 10% difference in selection times found by Blackwell and Cuomo could be negated if the input device were adjusted.

Blankenberger and Hahn (1991) discussed the relationship between symbol appearance and meaning. They found that recognition and reaction times for various symbols were affected by the incongruity across meaning and representation, referred to as the "articulatory distance." Participants had slower reaction times and were less likely to recognize symbols with larger articulatory distances. This effect was much greater for inexperienced users than for experienced users. The articulatory distance hypothesis can be used to justify the theory that the AN/SLQ-32(V) symbols require more operator information processing to identify meaning. The use of pictographic symbols could reduce this workload. Barnard and Marcel (1984) and Smith, Irby, Kimball, and Verplank (1982) supported Blankenberger and Hahn's findings in realistic applications.

Pictographic symbols, such as the NATO icons shown previously, could be used on the AN/SLQ-32(V) in both the sequence list and the library (Figure 4, page 15). In this manner, an iconic link between various locations of information may assist the operator in navigating among information sources. Once an operator has identified an emitter to select from the sequence list, that information could be used to hook the emitter in the display and to identify the emitter in the on-line library. Consistent use of the symbology in the primary display area, the sequence list, and the library can replace the arbitrary threat numbers. Instead of augmenting the threat numbers with icons, the numbers would be eliminated to reduce the amount of redundant data. From observation of AN/SLQ-32(V) system operators, it appears that operators talk in terms of "missiles bearing 30 degrees," not of "threat level one bearing 30 degrees."

Polar versus Range

Replacing the polar display with a range (GeoSit) display is warranted because it is a recognized way to display range information and rate of travel to the EW operator. With a polar display, range information is acquired from NTDS or other EW operators. The GeoSit display facilitates the EW operator's understanding of the overall "picture" of the tactical environment by giving a true representation of the location of emitters.

Figure 8 shows the current polar display (top). Note the three regions for friendly (center ring), missiles (large middle ring), and others (outer ring). In this display, the location of an emitter does not relate to the range of an emitter. An emitter in the center ring can be farther away from their own-ship than an emitter in the outer ring. Figure 8 also shows a range display (bottom). Note the concentric rings labeled from 10 to 50, indicating nautical miles. This range information is integrated into the sequence list (to the left of the circular display). Details of the screen layout are discussed elsewhere (Figure 10, page 25). The absence of the 270° mark is consistent with the display of the AN/SLQ-32(V). Screen representations for each of the Polar and Range configurations can be found in APPENDIX A: SCREEN DISPLAYS, page 127.

A range display is consistent with other display systems in the CIC, such as the NTDS. Thus, by using a range display, compatibility between the AN/SLQ-32(V) and other CIC systems would be improved. The incorporation of this information and other proposed changes being considered by the Navy might eliminate other EW consoles from the CIC. However, changing the operator's task by redesigning software or eliminating hardware requires careful study to keep from overburdening the operator.

The U.S. Navy is concerned with operators inferring range information from the display based on the distance between the own-ship and the emitter. A symbol 1 inch from the center of the polar display is not necessarily closer to the ship than a missile 3 inches from the center of the display. This is the fundamental problem of logical grouping by emitter type. It gives most of the display area to the most important emitters (missiles in the middle ring), but can cause operators to assume incorrect range information.

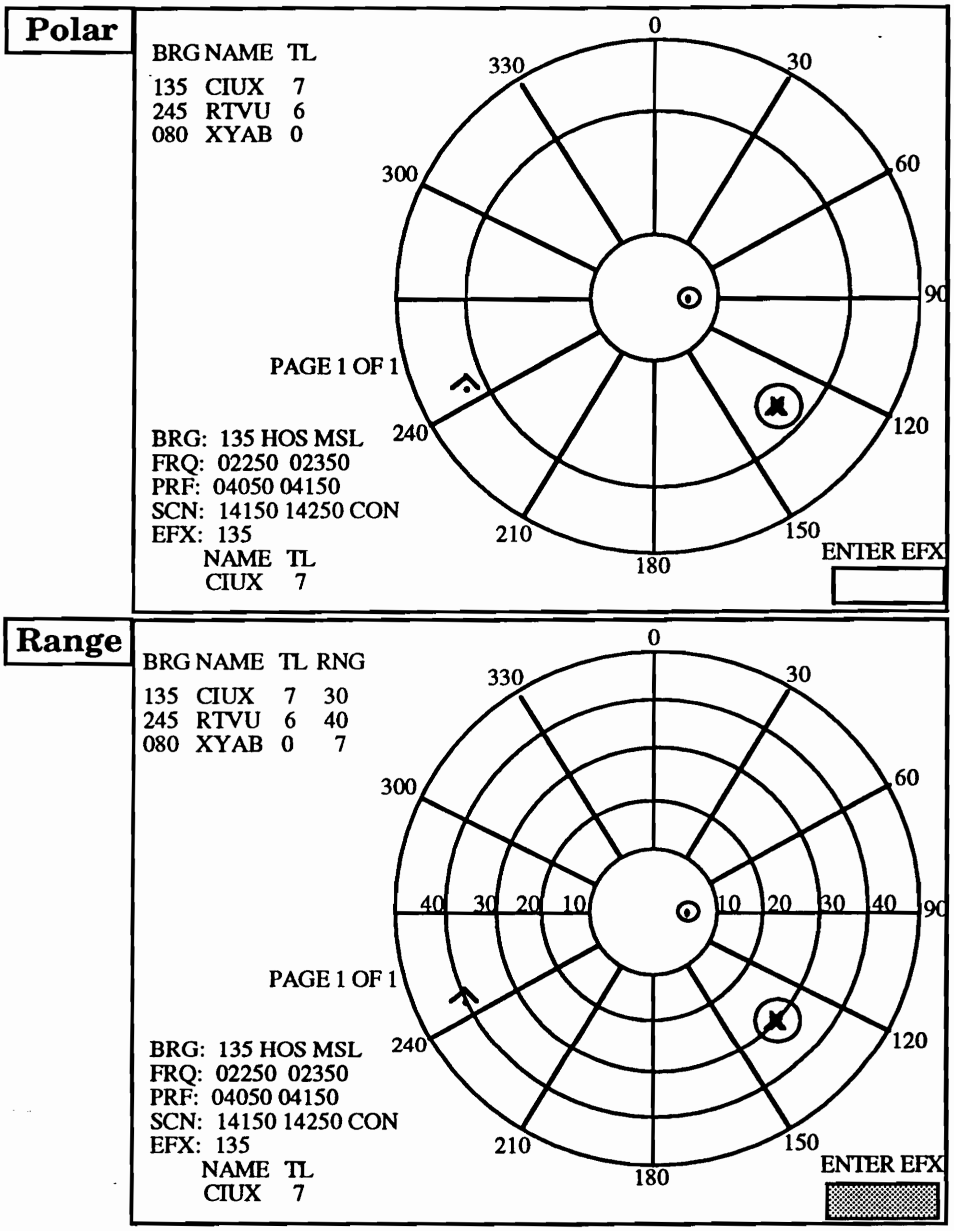


Figure 8. Display format for a Polar and Range display.

EXPERIMENT 1

Introduction

The experiment discussed in this section helps to identify DCC components for redesigns of the AN/SLQ-32(V) by examining the use of color, a set of revised icons, and different display formats. A total of eight versions of a DCC were tested. For each of the eight versions, a series of training sessions was administered before each testing session. Training was designed to teach participants how to work effectively with the interface. The first day of training was for general instructions, informed consent, and a Subjective Workload Card Sort. However, it was not necessary that the first day immediately precede the first sets of experimental trials. Following the first day, individuals participated for eight consecutive days in Experiment 1, during which one condition was administered per day.

Method

Participants

Participants for this study were students of Virginia Polytechnic Institute and State University. Twelve individuals (six males and six females), each with computer experience, were recruited for approximately 32 hours spread over a 10-day period. Participants were paid $10.00 at the end of each day, with additional $50.00 incentives for completing the entire experiment. Participants were requested to refrain from discussing the experiment with other individuals.

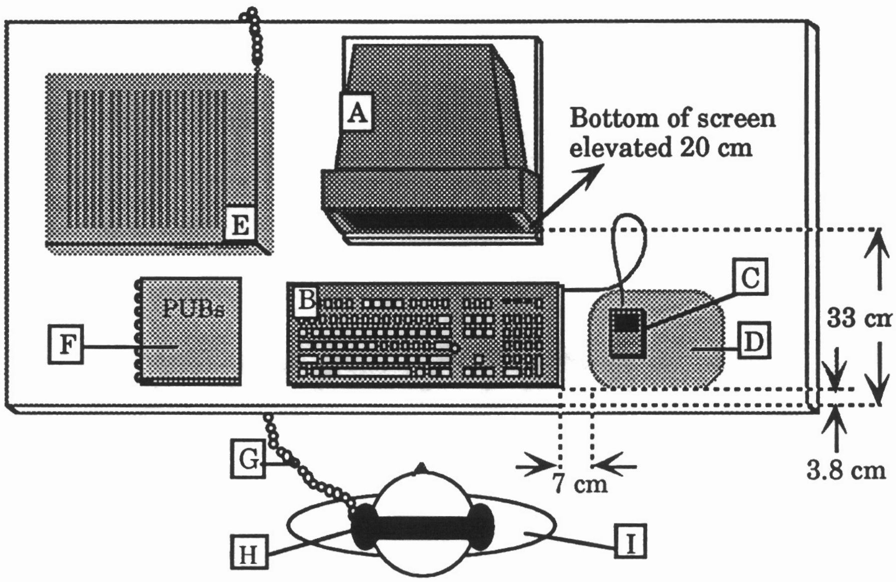
The 12 participants volunteered for the study. Each participant spoke fluent English and gave informed consent (APPENDIX C: INFORMED CONSENT FORM, page 140). Participants reported hours of computer usage per week ranging from "0 to 4" to "More than 28," with a mean of 18 hours per week. One participant regarded his typing experience as "Hunt and Peck," five considered their typing as "Hunt and Peck, but fast," two were slow touch typists, and four were fast touch typists. The age of participants ranged from 21 to 32 years, with a mean age of 25 years.

Apparatus and Equipment

The computer used to create and test the prototypes AN/SLQ-32(V) display configurations was a Macintosh IIfx equipped with an extended keyboard and a mouse. Simulations of the AN/SLQ-32(V) display were developed using Aldus SuperCard. Hooking errors, task completion times, operator subjective workload scores, and other data were collected automatically by the computer.

Configurations of the AN/SLQ-32(V) and auxiliary equipment vary from ship to ship. A common layout was discussed earlier (Figure 3, page 11). An illustration of a data collection station is shown in Figure 9. The computer was configured with a 13-inch, 8-bit color monitor (640 by 480 addressability), System 7.0.1, and 8 megabytes of RAM for the simulations. The

Fast Action Buttons (FABs) and keyboard were simulated with a Macintosh Extended keyboard (using the second highest keyboard repeat setting and the second fastest delay setting) and the Apple Mouse (using the second highest gain setting). Participants were permitted to have the mouse configured for either left- or right-handed use; however, all participants were right-handed. The UL-16 was simulated on the CRT monitor.



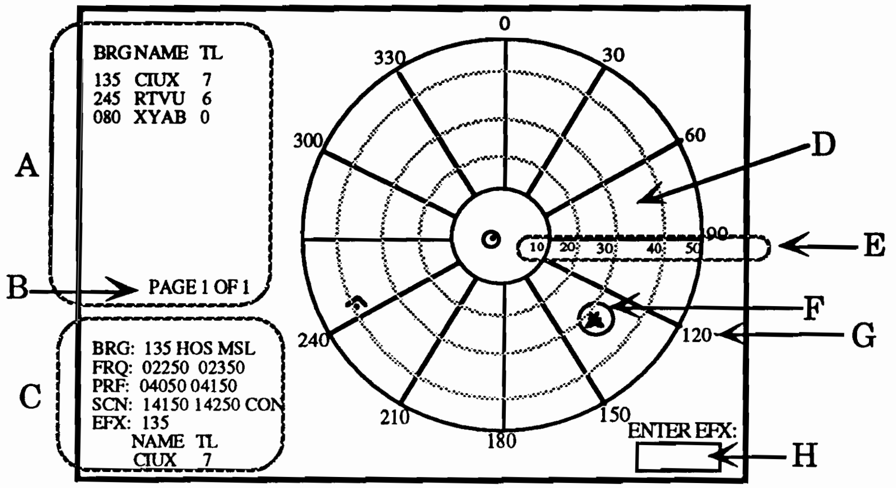
A	CRT Monitor	D	Mouse Pad	G	Headset Cord
B	Extended Keyboard	E	Macintosh FX	H	Headset
C	Mouse	F	Publications	I	Operator

Figure 9. Layout of the experimental prototype AN/SLQ-32(V) station.

The keyboard in this experiment was coded so that the operator used the numbered keys in the QWERTY portion of the keyboard just as EWs use the AN/SLQ-32(V) FABs. To designate the identification of an emitter and to listen to an emitter's scan type, the F5 and F8 function keys were used, respectively. The F5 key was covered with a key cap labeled "Desig ID." The F8 key was covered with a key cap labeled "Sig Sel" for Signal Select.

One workstation was in a small room (2 by 2.5 meters) with gray walls (to match the color on Navy ships). The second station was in a larger room but made to resemble the first by enclosing the station with two black plastic curtains as the back and side wall. Black cloth was hung over the walls to darken the room. Both rooms were dimly lit with blue-filtered overhead fluorescent lights to simulate lighting conditions in the CIC. The ambient illuminance was matched between the rooms (approximately 46 lux). Both displays were calibrated such that the space-averaged luminance was approximately 21.8 cd/m^2.

An illustration of the screen display is given in Figure 10. Operators were prevented from inadvertent switching to the Macintosh operating system by AutoLock software. A circular (ball) cursor, similar to that found on the AN/SLQ-32(V), was used. Participants wore headsets (Realistic Nova 40) to hear scan types of emitters as generated by the simulation.



	Display Item	Function
A	Threat summary list	Lists all detected emitters
B	Page information	Shows the current and total number of pages in A
C	Close control information	Shows parameters for hooked emitter
D	Polar (or Range) emitter display	Primary display; Shows emitters in relation to the ship
E	Range information	Rings represent miles to ship (on Range displays only)
F	Close control indicator	Shows current hooked emitter
G	Bearing values	Shows bearing lines to help locate emitters
H	Designate identification input field	Entry window for EFX number

Figure 10. The screen display of the Prototype AN/SLQ-32(V).

Instead of using a separate display to simulate the ULQ-16 frequency spectrum analyzer, the operator was presented with the ULQ-16 information in the center of the monitor when the "Sig Sel" key was pressed. The ULQ-16 display partially covered the information presented on the screen in Experiment 1 (Figure 11). The operator turned off the ULQ-16 by pressing the Shift key. The ULQ-16 is shown in the graphic of the Range/NATO icons/Color display (Figure 64, page 135).

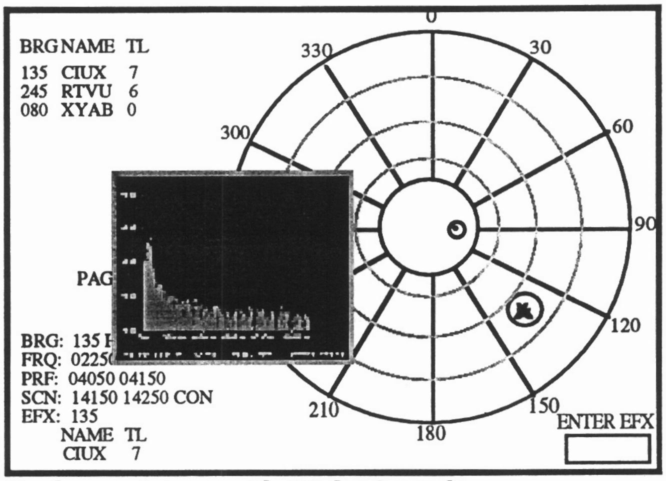


Figure 11. Screen display prototype with ULQ-16 window.

A library of 427 emitters was created and compiled into the Publications (pubs). The pubs consist of two sections. The main body of the pubs contained a list of emitters sorted by frequency (FRQ) (Figure 12). The rest of the information for each emitter was listed in columns of threat level (TL), bias factor (BIAS), category (CAT), pulse repetition frequency (PRF), scan, and cross-reference number (X-REF). After the operator matched FRQ, TL, BIAS, CAT, PRF, and scan, the corresponding X-REF number was used to look up the Emitter File Index (EFX) number from one of four X-REF pages in the front of the pubs (Figure 12).

In this section of the pubs, all X-REF numbers are listed in ascending order. There are two identical X-REF numbers, followed by the name of the emitter, scan type, and EFX. The correct EFX was obtained by looking up the correct X-REF number, choosing the correct scan type from the two identical X-REFs, and selecting the corresponding EFX. An EFX is a three-digit number that uniquely identifies known radar-emitting objects.

Experimental Design

The experimental design is a 2 x 2 x 2 x 3 within-subjects factorial. Four independent variables were manipulated in the experiment. The independent variables which were identified as priority considerations for redesigning the AN/SLQ-32(V) display (Beaton et al., 1991) are described below. Table 7 outlines the independent variables.

The experimental design is shown graphically in Figure 13. Within each trial, the number of emitters processed, the number of incorrectly hooked emitters, the number of improperly designated emitters, and the mean time for processing each emitter were recorded by the computer.

Main

FRQ	TL	BIAS	CAT	PRF	SCAN	X-REF
00050 00150	0	FND	LND	01450 01550	03250 03350	1
00150 00250	7	HOS	MSL	03150 03250	05550 05650	2
00150 00250	5	HOS	SUB	12150 12250	18450 18550	3
00250 00350	O	FND	SUR	02250 02350	19550 19650	4
00250 00350	7	HOS	MSL	16950 17050	15950 16050	5
00350 00450	7	HOS	MSL	07550 07650	08150 08250	6
00350 00450	6	HOS	AIR	07950 08050	00350 00450	7
00350 00450	4	HOS	LND	07850 07950	15350 15450	8
00450 00550	4	HOS	LND	08850 08950	18350 18450	9
00450 00550	7	HOS	MSL	10650 10750	15450 15550	10
00450 00550	7	HOS	MSL	11850 11950	10050 10150	11
00550 00650	6	HOS	AIR	03750 03850	17650 17750	12

X-Ref

XREF	NAME	TYPE	EFX	XREF	NAME	TYPE	EFX	XREF	NAME	TYPE	EFX
1	JVIF	CIR	116	34	WEGZ	SEC	064	67	VUNM	CON	097
1	QQIP	SEC	419	34	UXYP	STD	324	67	PARV	STD	280
2	OIAH	CIR	057	35	PBSG	CON	079	68	NVZB	CON	045
2	OXGA	SEC	368	35	TLLE	STD	364	68	BGCN	STD	311
3	GMLE	CON	174	36	OFSC	SEC	368	69	TIOH	SEC	287
3	CWEN	SEC	093	36	DSJX	STD	328	69	FXVF	STD	409
...				...				...			
...				...				...			
...				...				...			
31	ISZT	CIR	185	64	UDNV	CIR	330	97	PMBQ	CON	205
31	NKWQ	STD	247	64	HBTZ	CON	383	97	QMFH	SEC	159
32	VZAG	CIR	404	65	EZEZ	CON	096	98	AHCL	CON	298
32	SNCM	CON	208	65	YASX	STD	224	98	XJPX	STD	158
33	NSML	CIR	236	66	ASGY	CIR	152	99	SIZB	CIR	203
33	XSEO	SEC	217	66	SRIS	SEC	103	99	BVXU	SEC	319

Figure 12. Pages from the emitter publication main section, and X-REFs.

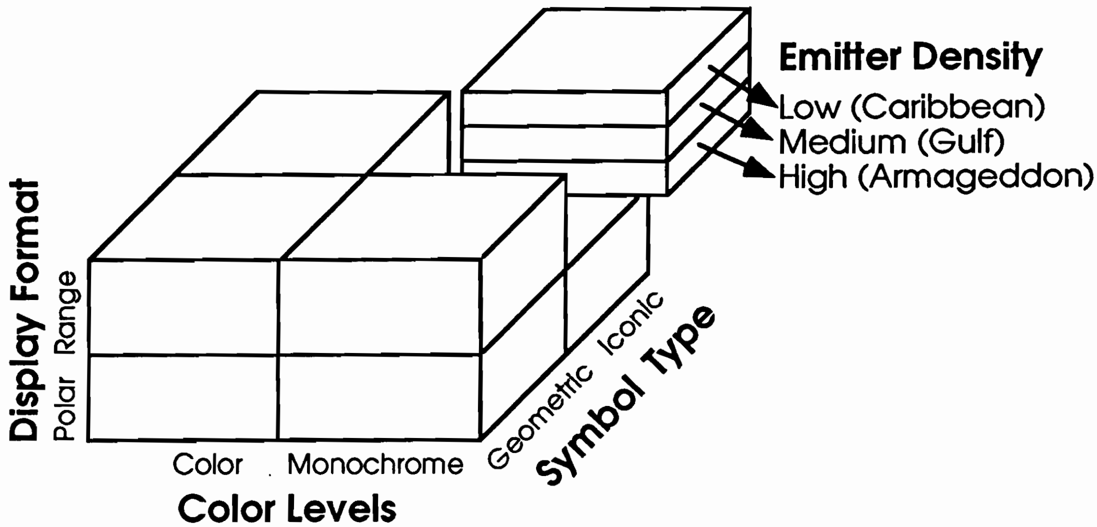


Figure 13. Experimental conditions in Experiment 1.

TABLE 7
Within-Subjects Variables in Experiment 1

A. Display Format (Polar, Range) The current Polar display and a Range display were compared. The GeoSit/Range display is compatible with current CDS displays (it displays both bearing and range information).
B. Color Levels (Monochrome, Color) The AN/SLQ-32(V)-32 is a monochrome display system with the capability to Bold text. Color were used in the symbols and Sequence List to distinguish emitters of different threat levels.
C. Symbol Set (Geometric, Iconic) This is outlined in the symbology section (Figure 4, page 15)
D. Emitter Density (Caribbean, Gulf, Armageddon) Emitter Density will have three levels: Low - characterized by the calm and limited number of emitters in the Caribbean Medium - characterized by events during the Persian Gulf war High - a large scale hot environment, hence Armageddon
NOTE: see Table 8, page 30, for the exact characteristics of the density levels.

Independent Variables

Display Format (Polar, Range). The primary source of information on the AN/SLQ-32(V) screen is the polar display. The polar display consists of three concentric rings. Each area formed by the rings holds specific types of emitters. The innermost ring contains all friendly emitters, the middle ring contains all hostile missiles, and the outermost ring contains all others (e.g., hostile aircraft, hostile submarines, and unknowns). The polar display aligns detected emitters along bearing lines. However, due to the position-coding scheme used in this format, no range information is provided. The polar display was illustrated previously (Figure 8, page 22). A full scale image of the AN/SLQ-32(V2) can be found in APPENDIX A: SCREEN DISPLAYS (Figure 57, page 128), while the experimental version can be seen in Figure 58, page 129.

The Range display resembles true-position displays used in radar systems. It presents emitters in relation to the ship with both bearing and range information. Like the Polar display, there are concentric rings, but the areas indicated by the rings indicate distances from the ship to the emitter rather than threat level. While it is known that for some tasks the EW operator must have range information, one currently obtains the information from other systems in the ship CIC. The Range display format was shown previously (Figure 8, page 22). A full-scale image of the range display (with monochrome and geometric coding) can be found on page 130 (Figure 59).

The original intent of the Polar display was to use location coding so that the missile symbols would be more salient and, therefore, quickly processed by the EW operator. However, the effects of using a Range display were examined to accommodate three needs: (1) the EW operator requires distance information for a number of tasks, (2) the EW operator must build and maintain a cognitive picture of the tactical environment, and (3) a Range display provides consistency with other system displays aboard ship.

Color Level (Monochrome, Color). The current AN/SLQ-32(V) screen uses a green phosphor with two levels of intensity coding: normal and "double-bright." The Macintosh prototypes simulated the existing display by using a color display, so the white-on-black mode was not truly achromatic, but will be referred to as monochrome. A full-scale image of the polar display (with monochrome and NATO Iconic coding) can be found on page 131 (Figure 60). The same display in color can be found on page 135 (Figure 64).

Due to the large amount of information presented to the EW operator, the use of color has the potential to effectively manage some of the information processing required by the EW operator. The color-coded display consists of four colors. Color was used to code emitter symbols and corresponding text for the purposes of distinguishing emitters of different threat levels (e.g., all hostile missiles were coded red, hostile non-missiles were amber, unknown were yellow, and friendlies were green). The Polar/Range display graphics were white as shown in Figure 61 (page 132). Note that white and black were inverted for clarity in this document. Thus, black on the pictures is white on the display, and the white background on the pictures is black on the display.

Symbol Type (Geometric, NATO Iconic). The current symbol set consists of eight geometric symbols that represent emitter categories, as shown in Figure 14. The revised symbol set was based on newly developed NATO icons and is shown in Figure 14. Supplemental coding graphics currently found on the AN/SLQ-32(V) were not included in the experiment.

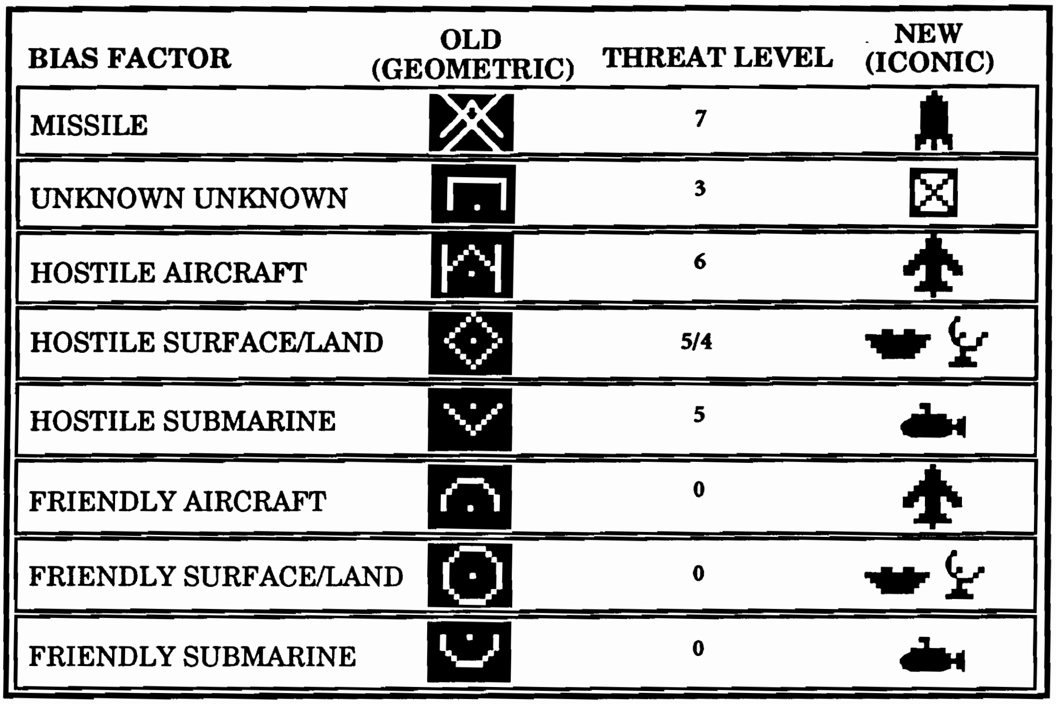


Figure 14. The Geometric symbol and the NATO Iconic sets with associated threat levels.

Emitter Density (Caribbean, Gulf, Armageddon). The redesigns were tested under three emitter densities conditions: Caribbean, Gulf, and Armageddon. Each density level varied in the number of emitters present at the start of the trial (initial density) and the amount of time before new emitters appeared (four new emitters appeared at each interval). The initial density of emitters contains emitters not listed in the sequence list. These were distracters or "dummy" targets used to increase the density on the display. The characteristics for the different density levels are presented in Table 8. Figure 58, page 129, Figure 60, page 131, and Figure 61, page 132, show examples of the Armageddon, Gulf, and Caribbean emitter density levels, respectively.

TABLE 8
Emitter Density Levels

	Caribbean	Gulf	Armageddon
Initial density (dummy emitters)	10	40	70
Time between blocks (s)	60	45	30
Number of blocks (immediately presented)	7	9	14
Number of starting blocks	2	1	1
Number of emitters (in a block)	4	4	4
Total emitters (at end of a trial)	**38**	**76**	**126**
Blocks appear at the start of each session and at the time intervals noted.			

Dependent Variables

Performance. The participant's performance was defined as a metric comprised of mean time to process an emitter and the mean number of hook errors (Moscovic, 1992). The performance score for completing each test trial was determined by the following function:

$$\text{Performance} = \frac{1}{b_1 \frac{t_i}{\sum_{i=1}^{n} t_i} + b_2 \frac{e_i}{\sum_{i=1}^{n} e_i}} \qquad (1)$$

where:

t_i = mean time to process emitters for operator i in a trial, in seconds,

e_i = total number of hooking errors for operator i in a trial, and

$b_1 = b_2 = 0.5$ (weighting coefficients for t and e, respectively).

Note that the level of performance is sensitive to deviations from the average time and error values. The performance metric approaches zero as an individual's time/error rate increases relative to the average time/error rate. Conversely, the performance metric increases unbounded as time/error rate decreases relative to the average time/error rate.

Equal beta weights (e.g., b_1 and b_2) were given to time and errors, reflecting their equal importance in the performance metric. The Performance metric is a relative measure, good only for comparing versions within a single experiment. Thus, the drawback of using this metric is that one cannot compare performance scores between experiments.

Workload Scores. The cognitive workload metric, Subjective Workload Assessment Technique (SWAT) was obtained from the Armstrong Aeromedical Research Laboratory at Wright-Patterson AFB (see Reid, Potter, and Bressler (1989) for detailed information on SWAT).

Each participant developed a workload scale by rank ordering 27 cards containing a time load, a mental effort load, and a psychological stress load. Each of these three dimensions has three possible levels: high (3), medium (2), and low (1). A Kendall coefficient of concordance of 0.77 was computed for the 12 individual scales. The concordance value indicates agreement among participants regarding the ordering of cards and thus the relative importance of each dimension (Moscovic, 1992). Therefore a single group SWAT scale was used. The group scaling solution is contained in APPENDIX B: GROUP SCALING, page 139.

At the end of each test trial, the participant gave a time load rating, a mental effort load rating, and a psychological stress load rating. The three ratings were used to derive a workload score using the rating scale developed on Day 1.

Preference Index. At the end of the final session in Experiment 1 participants compared pictures representing each of the eight configurations. Participants were shown all possible pairs of the eight pictures (28 comparisons) on the computer display. Participants were instructed to select the picture that represented the version that was easiest to use.

The Experimental Task

As explained previously, the main function of the participant (operator) in this study is to perform the IT. In the experiment, this task was performed as outlined in Table 9.

TABLE 9
Integrated Task (IT) for Experiment 1

1	Operator hears an alert and new emitters appear.
2	Operator selects an emitter with the input device.
3	Operators use close control parameters, the audio scan of the emitter, and the information presented on the ULQ-16 to identify the emitter.
4	Operator searches through publications for a cross-reference (number that agrees with the Frequency and PRF).
5	Operator searches through the cross-reference index to find the cross-reference number. Based on the type of the sound (audio scan), the operator determines the correct EFX number from the list.
6	The operator designates that emitter with the correct EFX number by selecting the DESIG ID button, entering the three-digit number, and pressing the RETURN key.
7	The operator processes the next emitter on the threat summary list (Step 2).

Procedure

Participants were required to attend a one-hour session prior to the study for informed consent (APPENDIX C: INFORMED CONSENT FORM, page 140), general instructions (APPENDIX D: INSTRUCTIONS TO PARTICIPANTS, page 142)[3], and testing for color vision deficiencies using Dvorine Color Plates. Participants also completed the SWAT rating scale development (card sort) and, finally, were scheduled for eight consecutive days to participate in Experiment 1. Experiment 2 was scheduled at a later date.

To bring the performance of the participant to a stabilized level for each configuration, a series of training sessions was given before the test trials. A sequence diagram of the events performed by participants in the experiment is shown in Figure 15.

Each day (Days 2–9) is referred to as a single session. For each of the eight sessions, a different design configuration was presented. A design configuration was a combination of the format (Polar, Range), symbol set (Geometric, Iconic), and color condition (Monochrome,

3. Instructions for *all* experimental tasks and training can be found in Appendix D.

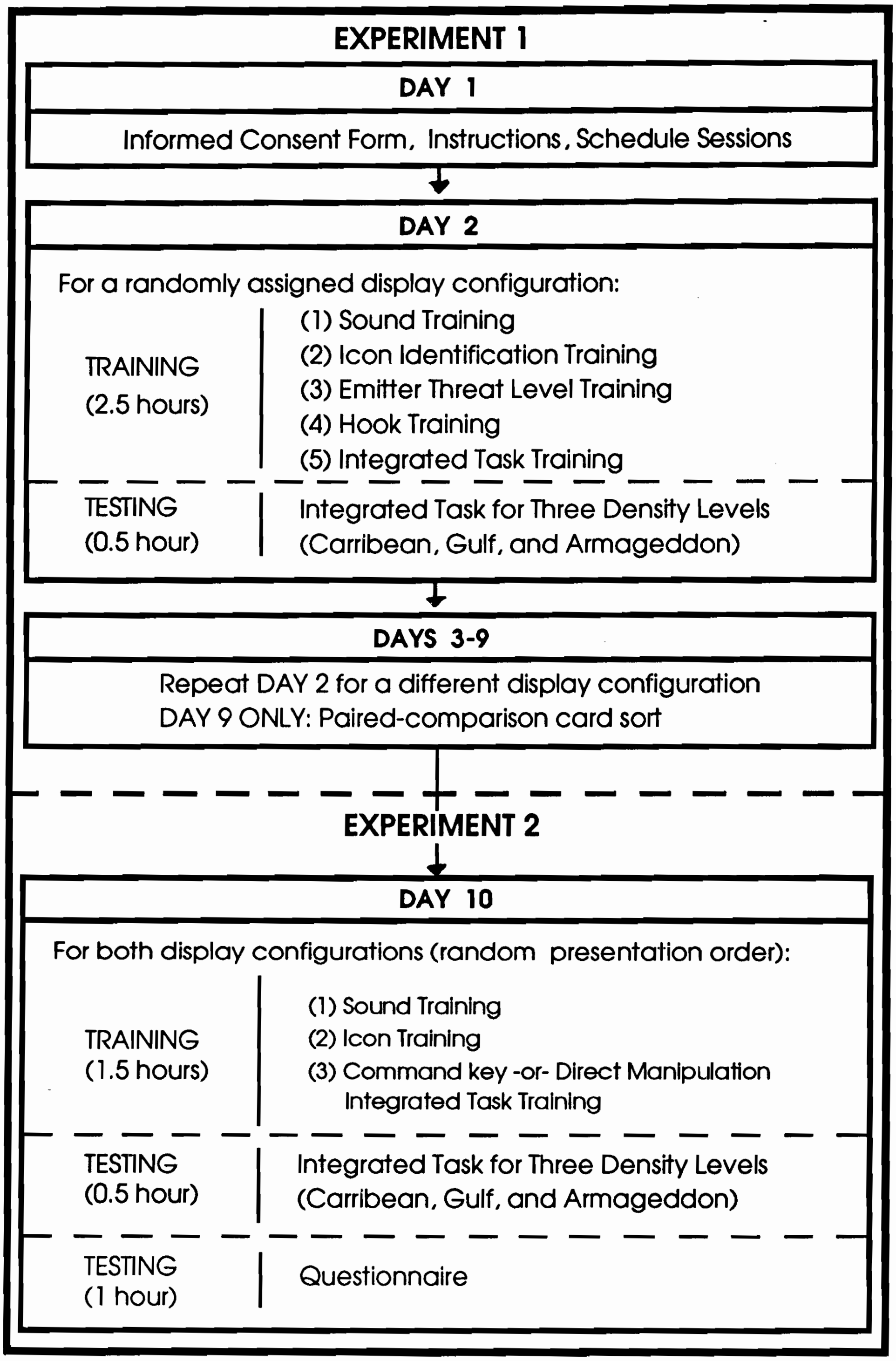


Figure 15. Sequence of events for participants.

Color). The order for the eight different display configurations was randomized across participants, and the three levels of density were presented in a random order within each configuration. During each session, participants were allowed to take breaks (usually about 5 minutes) between training sets. On Day 9, the preference ranking paired-comparison test was administered. The test compared all pairs of interfaces (two at a time) to isolate the preferred interface.

Training

Each participant completed five blocks of training per session. Training helped participants to attain a minimum performance standard. It was necessary to train participants extensively to capture the effect of "expert" operator performance. Pretest participants were used to determine the number of training trials, and the criteria established from the pretest reflects a minimum level of performance.

Index cards (4 by 8 inches) were used to familiarize participants with the symbols and threat levels, symbols and emitter types, and symbols and color coding prior to the respective training sessions. This technique helped to minimize confusion in the first training session, since the participant would know what to expect.These index cards were not available after the beginning of each training sessions.

A basic performance criterion was created from the pilot trials to ensure a minimum performance standard for all participants. Participants were required to score 92% correct selections on each of the final sound, icon, and threat level training session before proceeding to the next type of training. The mouse was used for all sound, icon, and threat level training. Since participants rushed through the training trails, and some errors were not a function of an operator's identification ability, they were allowed to miss two probes out of 25, hence the 92% criterion. This measure was used during the sound, icon, and threat level training sessions.

Participants were not timed in the training, but in pretest conditions, operators became accustomed to a "rhythm" and proceeded quickly. Since identifications take only a few seconds, pretest participants made mistakes by what was is best described as muscle memory. Rather than repeat the trial or have an undo feature, the criteria in the training sessions was adjusted to accommodate for a few errors.

The five blocks of training are described below:

(1) *Sound Training.* Participants were trained to recognize four sounds (scan types) and the associated waveform graphics that depicted the frequency spectrum of the signal. The four sounds represented the Conical (CON), Standard (STD), Circular (CIR), and Sectional (SEC) emitter scan types. Training included the simultaneous presentation of a sound and its corresponding graphic representation in a window on the computer screen. Each sound and graphic was first presented and their attributes were explained by the experimenter.

An auditory signal with its associated visual graphic was presented to the participant. Above the graphic was a set of four buttons, each labeled with one of the scan types. The participant used the mouse to select the button representing the correct scan type. Figure 16

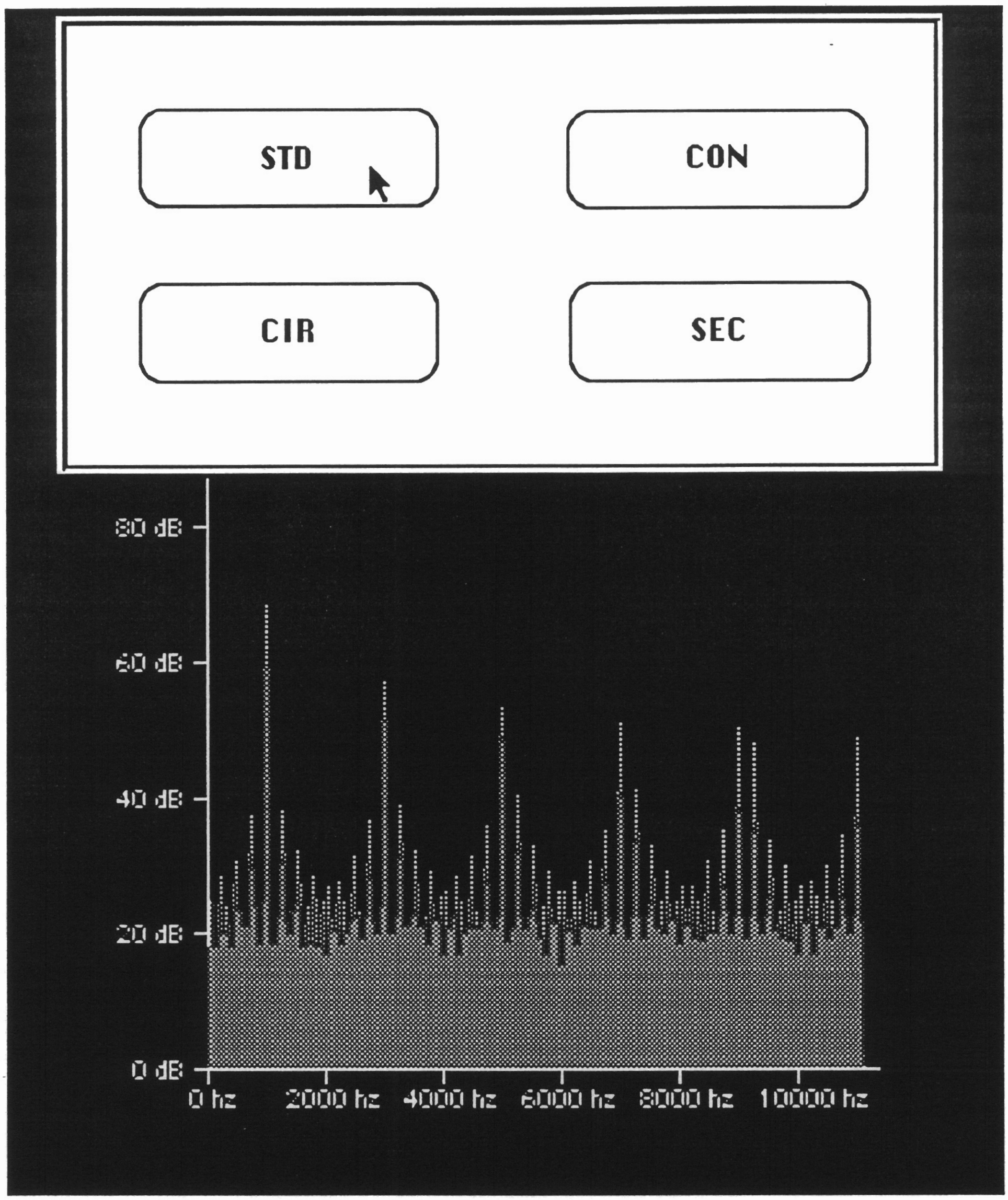


Figure 16. Screen format during sound training.

shows the sound (STD) being presented and the operator about to select the correct choice. The basic performance criterion (five trials) was used to determine if the participant passed or failed the training. On Days 3 to 9, the participants were given one set of 25 auditory signals. The same criterion was applied, so if a participant failed to make criterion, a set of signals was repeated.

(2) *Icon Identification Training*. The training for icon identification was identical to the training for sounds, with the exception that the icon set varied each day. Based on the configuration tested during the session, the participant was given an index card illustrating the symbols (icon set and color condition). Participants were allowed to study the cards as long as they desired. Subsequently, five sets of 25 probes each were presented on the screen. The basic performance criterion applied. Participants selected the correct identification using labeled buttons above the stimulus. An example of a screen display for the icon training is shown in Figure 17. The number of correct identifications was displayed at the end of each set.

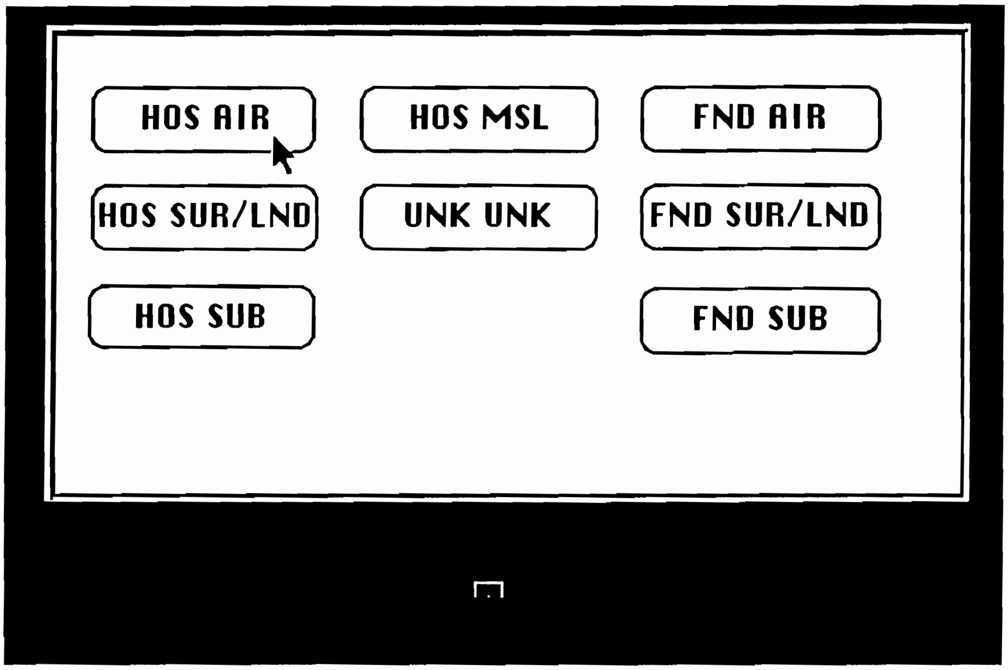


Figure 17. Example of screen format for icon identification training using the Monochrome Geometric symbol set.

(3) *Threat Level Training*. Training for threat levels was identical to training for icon identification. Participants studied cards containing threat level information for each icon. The buttons were labeled with threat levels (0–7) instead of icon names. The basic performance criterion applied for the five training trials.

(4) *Hook Training*. During hook training, the participants were presented with the primary display (Polar or Range) and a page of emitters on the threat summary list, which held 15 emitters. The beginning of each trial was marked with an audible tone. As soon as the tone sounded, the participants found the first emitter on the threat summary list and as quickly and as accurately as possible selected the corresponding emitter on the Polar/Range display

by using the mouse. When the correct emitter was selected (hooked), the participant then continued to the next emitter. The set was completed when all 15 emitters were hooked. At the end of each set, the mean time to hook an emitter was displayed to the participant. Fifty sets were completed per session (analysis of pretest data revealed that subjects reached a level of asymptotic performance at around 40 sets). During the final five sets of the block, the participant was required to complete each trial with a mean time to hook of 6 seconds. The criterion of 6 seconds was established in pilot tests with three participants and on knowledge obtained by the experimenter's use of the system. A failure to meet this level resulted in dismissal of the participant—none were dismissed.

(5) *Integrated Task Training.* Finally, participants practiced the entire IT on emitters during 5 minute trials. There were 10 trails on Day 2 (50 minutes total) and 8 trials on Days 3–9 (40 minutes total). During the IT training, the emitter density level was set at 55 emitters: the 15 real emitters (to be hooked) and 40 dummy emitters. At the end of the trial, the mean times to process an emitter and the number of errors were given as feedback and motivation. In addition, while performing the IT, the operator was given an audible chime after each designation.

Participants had to process at least eight emitters during the final integrated trial on each day. The eight emitter criterion was based on data collected from pilot participants. If a participant failed to meet the criterion the results of the trial were analyzed to determine if there was an excessive error rates during the trial. If so, the data from the seventh trial was used to determine if the participant achieved the criteria. A high number of dummy errors was an indication of many overlapping emitters in the scenario, this is a programming problem and in the event this occurred, the score at the end of the scenario was not a true reflection of the operator's ability. Thus, data from the seventh trial was used for determining if the participant performed at the criterion level. One participant was excused for failing to meet the criterion and was replaced with a new participant.

Testing

There were three test trials at the end of each session. The test trials were almost identical to the training trials except for three conditions. First, the test trials were administered under the three density conditions. Second, each of the three test trials was followed by the SWAT rating procedure instead of performance feedback. Finally, the trials lasted for about seven minutes for the three conditions. At the completion of the final trial the paired comparison test was administered.

Results

The mean performance scores and cognitive workload scores for each participant were analyzed using a 2 x 2 x 2 x 3 repeated measures analysis of variance (ANOVA) with a significance level of $\alpha = 0.10$. A Newman-Keuls comparisons was performed on significant main effects using a significance level of $\alpha = 0.05$. Simple-effects F-tests were performed on significant two-way interactions. A Newman-Keuls comparison, or mean comparison (for factors with only 2 levels) is presented for significant simple effects.

The paired comparisons were analyzed with the Kendall coefficient of agreement (u) for agreement among the participants. Binomial comparisons were conducted on the paired comparison data to reveal significant difference among the eight versions.

Performance Results

The results of the ANOVA for performance scores are listed in Table 10. The main effects of Emitter Density, Display Format, Color Levels, and Symbol Type are significant ($p < 0.10$). The interactive effect of Format and Symbol is also significant ($p < 0.10$).

A graph of the main effect of Emitter Density is shown in Figure 18. A Newman-Keuls analysis shows that performance at each Emitter Density level is significantly different from performance at every other level ($p < 0.05$, Table 11). Thus, the combination of errors and designation times increases as a function of density level.

A graph of the main effect of Display Format is shown in Figure 19. Performance is significantly higher for the Range than for the Polar format ($p < 0.001$, Table 10). The additional information provided in the range display allowed operators to locate emitters with a 60% improvement in performance (Table 12).

A graph of the main effect of Color Levels is shown in Figure 20. Performance is significantly higher for the Color than for the Monochrome display ($p = 0.003$, Table 10). Thus, the addition of the color cue improved performance by 17% (Table 13).

A graph of the main effect of Symbol Type is shown in Figure 21. Performance is significantly higher for the NATO icons than for the Geometric symbol type ($p = 0.007$, Table 10). A 14% gain in performance is attributed to the Symbol Type main effect, but the interactive effect of Display Format and Symbol Type reveals more definitive information (Table 14).

A graph of the effect of Symbol Type by Display Format is shown in Figure 22. The results of the simple-effects F-test are shown in Table 15. The mean performance scores for Symbol Type within the Polar Display Format are shown in Table 16. The mean performance score for Iconic symbol type is significantly greater than for the Geometric symbol type within the Polar Display Format ($p < 0.001$). Thus, in the absence of range information the NATO icons improve performance by 35%, but when range information is added performance gains are not significant.

TABLE 10
ANOVA Summary Table for Performance (Experiment 1)

Source	*df*	*ε*	*MS*	*F*	*p*
Subject	11		39195.40		
Format	1		2102765.08	96.18	< 0.001
Format x Subject	11		21862.33		
Symbol	1		173989.90	21.85	0.007
Symbol x Subject	11		7963.68		
Color	1		233880.17	14.63	0.003
Color x Subject	11		15982.67		
Density	2	0.94	533344.48	47.94	< 0.001
Density x Subject	22	0.94	11126.12		
Format x Symbol	1		91033.49	7.99	0.017
Format x Symbol x Subject	11		11394.98		
Format x Color	1		52574.47	2.80	0.122
Format x Color x Subject	11		18745.55		
Symbol x Color	1		4833.94	0.35	0.564
Symbol x Color x Subject	11		13686.06		
Format x Density	2	0.87	35049.99	2.56	0.109
Format x Density x Subject	22	0.87	13698.82		
Symbols x Density	2	0.90	1057.33	0.09	0.895
Symbols x Density x Subject	22	0.90	11403.60		
Color x Density	2	0.91	4516.33	0.30	0.723
Color x Density x Subject	22	0.91	14911.68		
Format x Symbol x Color	1		418.79	0.02	0.892
Format x Symbol x Color x Subject	11		21485.42		
Format x Symbol x Density	2	0.83	8919.87	0.50	0.581
Format x Symbol x Density x Subject	22	0.83	17861.59		
Format x Color x Density	2	0.93	163.19	0.01	0.982
Format x Color x Density x Subject	22	0.93	12097.23		
Symbol x Color x Density	2	0.97	11153.03	1.42	0.263
Symbol x Color x Density x Subject	22	0.97	7847.51		
Format x Symbol x Color x Density	2	0.95	7837.26	0.53	0.584
Format x Symbol x Color x Density x Subject	22	0.95	14667.99		
Total degrees of freedom	287				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Epsilon denotes the correction factor. Tabulated probabilities reflect the adjusted F-tests.

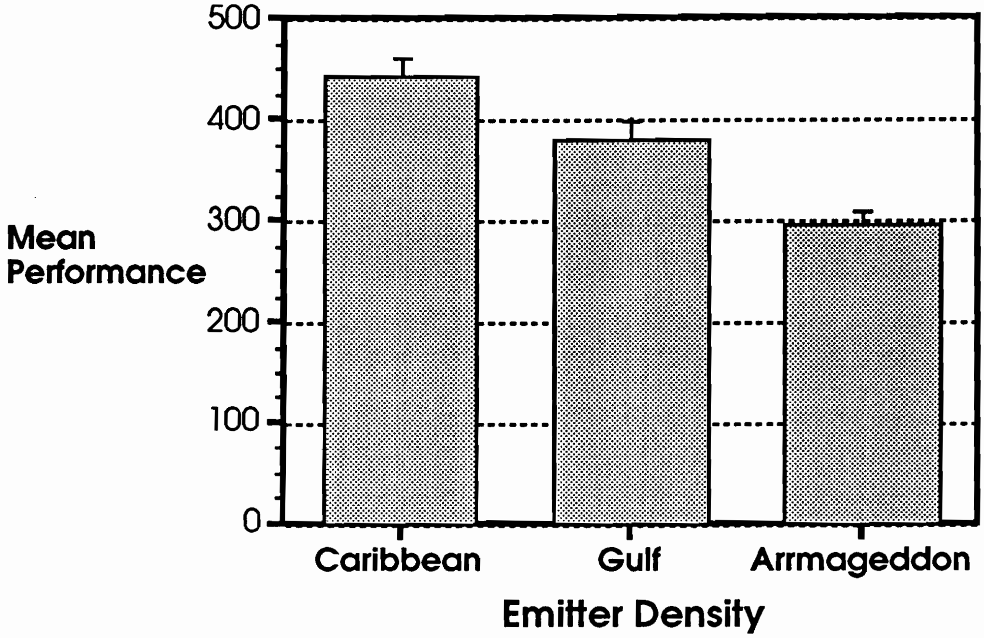


Figure 18. Main effect of Emitter Density on Performance (Experiment 1). Error bars represent +1 Standard Error of the Mean.

TABLE 11
Newman-Keuls Analysis of the Main Effect of Emitter Density on Performance (Experiment 1)

Emitter Density	*Standard Deviation*	*Standard Error of the Mean*	*Mean Performance Score*	
Caribbean	150.87	15.40	443.14	A
Gulf	161.76	16.51	380.57	B
Armageddon	148.03	15.11	294.68	C
Means with the same letter are not significantly different at p = 0.05, n = 96				

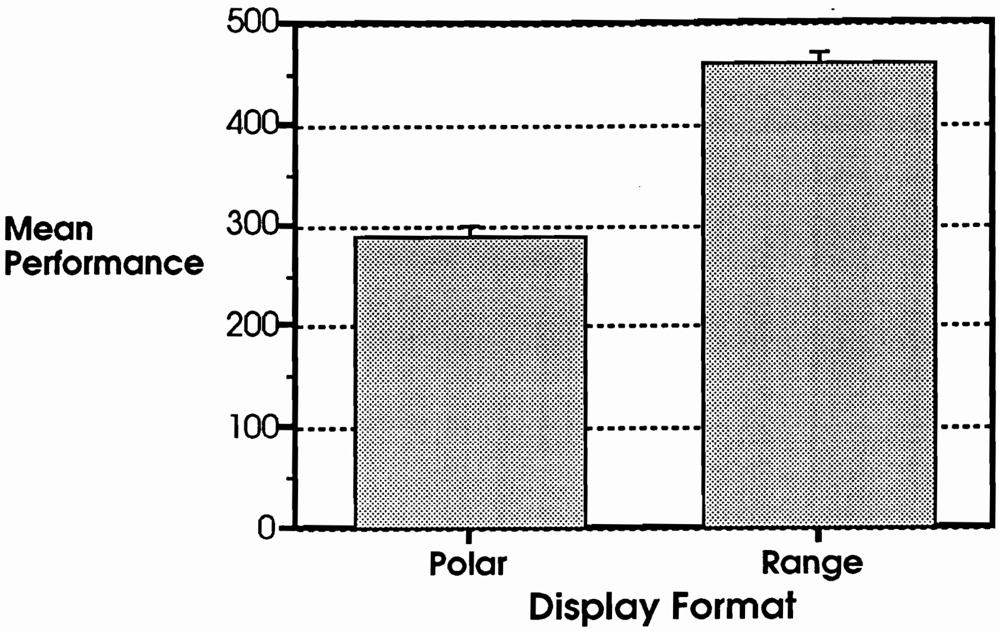


Figure 19. Main effect of Display Format on Performance (Experiment 1). Error bars represent +1 Standard Error of the Mean.

TABLE 12
Mean Performance Scores for the Main Effect of Display Format (Experiment 1)

Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Performance Score*
Polar	144	144.62	12.05	287.35
Range	144	137.48	11.46	458.24

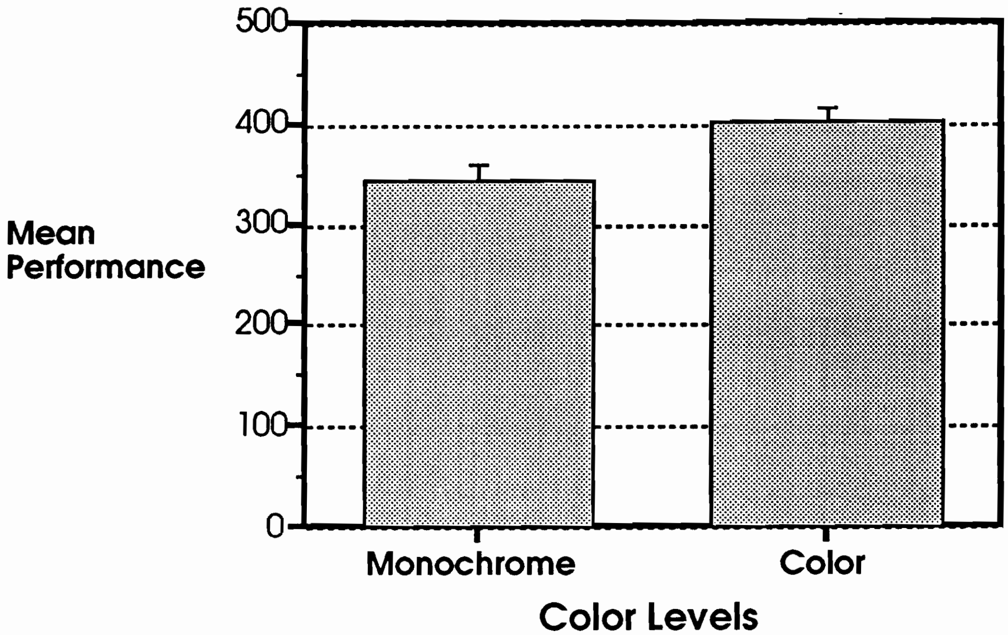


Figure 20. Main effect of Color Levels on Performance (Experiment 1). Error bars represent +1 Standard Error of the Mean.

TABLE 13
Mean Performance Scores for Main Effect of Color Level (Experiment 1)

Color	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Performance Score*
Monochrome	144	168.09	14.01	344.30
Color	144	156.94	13.08	401.29

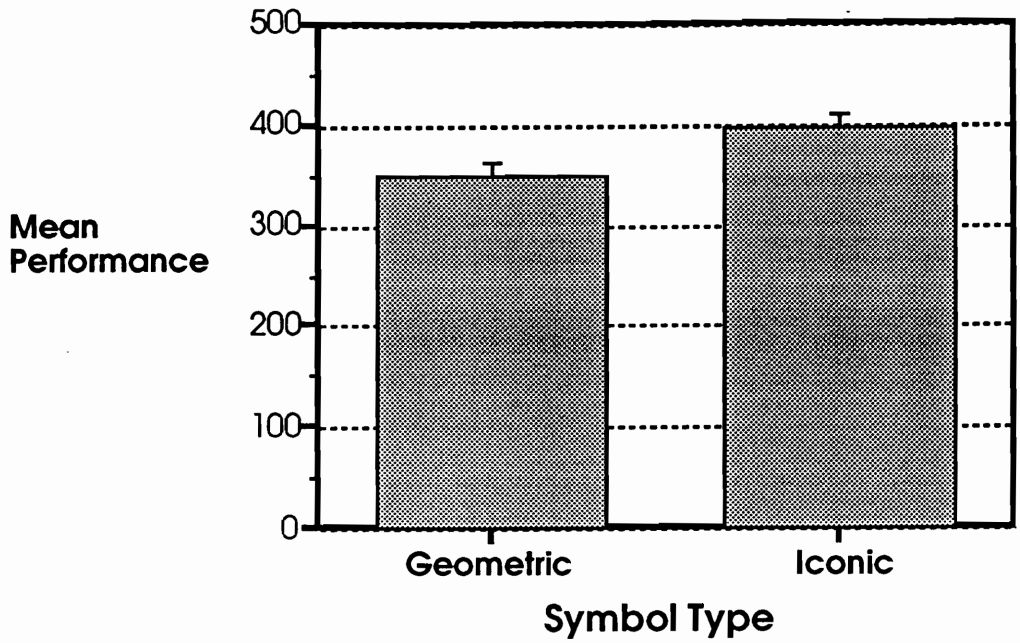


Figure 21. Main effect of Symbol Type on Performance (Experiment 1). Error bars represent +1 Standard Error of the Mean.

TABLE 14
Mean Performance Scores for Main Effect of Symbol Type (Experiment 1)

Symbol	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Performance Score*
Iconic	144	152.01	12.67	397.37
Geometric	144	173.77	14.48	348.22

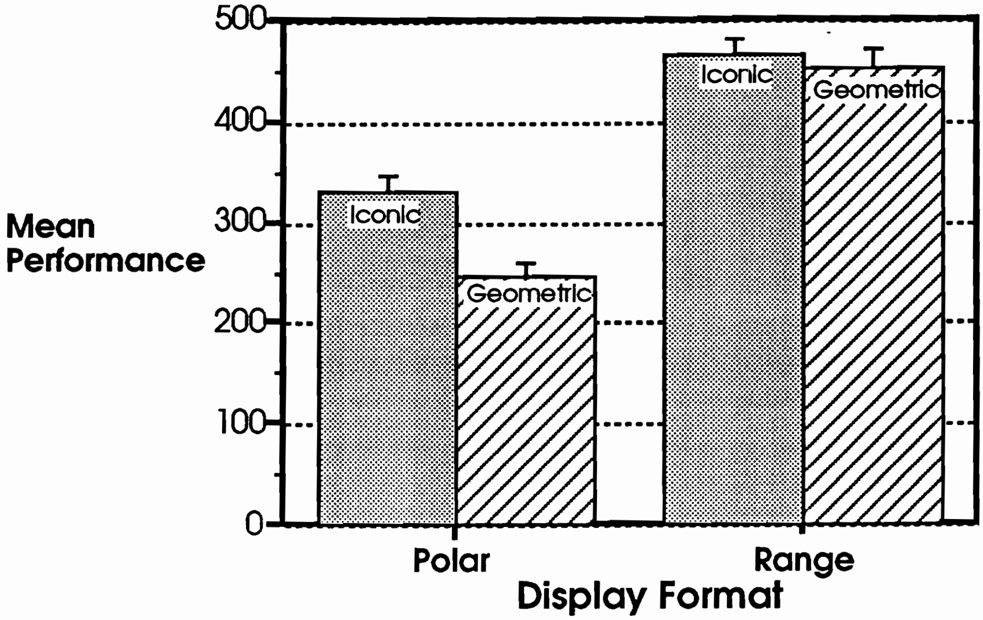


Figure 22. Effect of Symbol Type by Display Format on Performance (Experiment 1). Error bars represent +1 Standard Error of the Mean.

TABLE 15
Simple-Effects F-test of Symbol Type Within Levels of Display Format on Performance (Experiment 1)

Source	*df*	*MS*	*F*	*p*
Polar	1	258364.42	22.67	< 0.001
Range	1	6658.97	0.58	0.461
Format x Symbol x Subject	11	11394.98		
n = 144				

TABLE 16
Mean Performance Scores for the Simple Effect of Symbol Type within the Polar Display Format (Experiment 1)

Symbol Type within Polar Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Performance Score*
Iconic	72	148.04	17.45	329.71
Current	72	128.72	15.17	244.99

Subjective Workload Results

The results of the ANOVA for SWAT scores are listed in Table 17. The findings indicate that the main effects of Symbol and Emitter Density, and the Symbol by Color interaction are significant ($p < 0.10$).

A graph of the main effect of Symbol Type is shown in Figure 23. Subjective workload for the Iconic symbol type is significantly lower than for the Geometric symbol type ($p = 0.033$). The mean workload scores are presented in Table 18.

A graph of the main effect of Emitter Density is shown in Figure 24. A Newman-Keuls analysis shows that subjective workload scores for Gulf and Armageddon levels were greater than those of the Caribbean level but not different from each other ($p = 0.05$, Table 19).

A graph of the effect of Symbol Type by Color Levels is shown in Figure 25. The results of the simple-effects F-test are shown in Table 20. Participants' subjective workload for the Geometric symbol type is significantly higher than the Iconic symbol type within the Monochrome condition. The mean Subjective Workload for Symbol Types within the Monochrome Color Level is shown in Table 21.

TABLE 17
ANOVA Summary Table for Subjective Workload (Experiment 1)

Source	*df*	*ε*	*MS*	*F*	*p*
Subject	11		8370.02		
Format	1		86.79	0.60	0.457
Format x Subject	11		145.76		
Symbol	1		1477.41	5.93	0.033
Symbol x Subject	11		249.08		
Color	1		166.08	2.20	0.167
Color x Subject	11		75.66		
Density	2	0.56	10518.63	7.61	0.015
Density x Subject	22	0.56	1381.89		
Format x Symbol	1		70.11	0.20	0.666
Format x Symbol x Subject	11		355.21		
Format x Color	1		321.95	3.21	0.101
Format x Color x Subject	11		100.39		
Symbol x Color	1		825.20	13.76	0.003
Symbol x Color x Subject	11		59.99		
Format x Density	2	0.91	11.39	0.08	0.904
Format x Density x Subject	22	0.91	135.52		
Symbol x Density	2	0.78	5.19	0.03	0.947
Symbol x Density x Subject	22	0.78	186.34		
Color x Density	2	0.81	16.64	0.15	0.824
Color x Density x Subject	22	0.81	114.71		
Format x Symbol x Color	1		298.29	0.75	0.405
Format x Symbol x Color x Subject	11		397.00		
Format x Symbol x Density	2	0.82	125.88	0.95	0.389
Format x Symbol x Density x Subject	22	0.82	132.71		
Format x Color x Density	2	0.95	12.85	0.08	0.916
Format x Color x Density x Subject	22	0.95	160.82		
Symbol x Color x Density	2	0.98	235.12	1.67	0.211
Symbol x Color x Density x Subject	22	0.98	140.39		
Format x Symbol x Color x Density	2	0.78	19.54	0.21	0.760
Format x Symbol x Color x Den. x Subject	22	0.78	94.08		
Total degrees of freedom	287				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Epsilon denotes the correction factor. Tabulated probabilities reflect the adjusted F-tests.

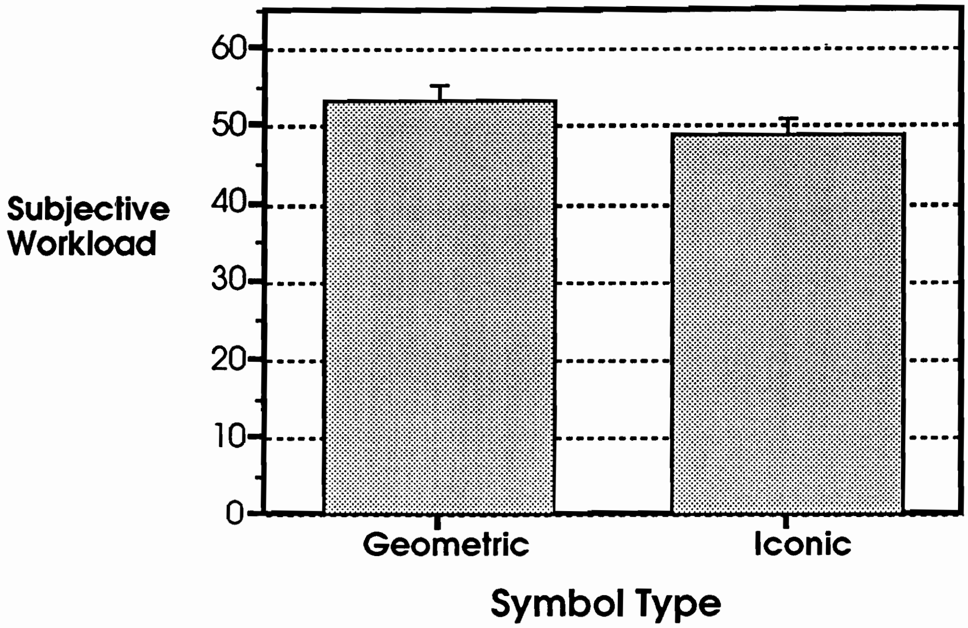


Figure 23. Main effect of Symbol Type on Subjective Workload (Experiment 1). Error bars represent +1 Standard Error of the Mean.

TABLE 18
Mean Workload Scores for Main Effect of Symbol Type (Experiment 1)

Symbol	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Subjective Workload*
Iconic	144	25.23	2.10	48.64
Current	144	25.30	2.11	53.17

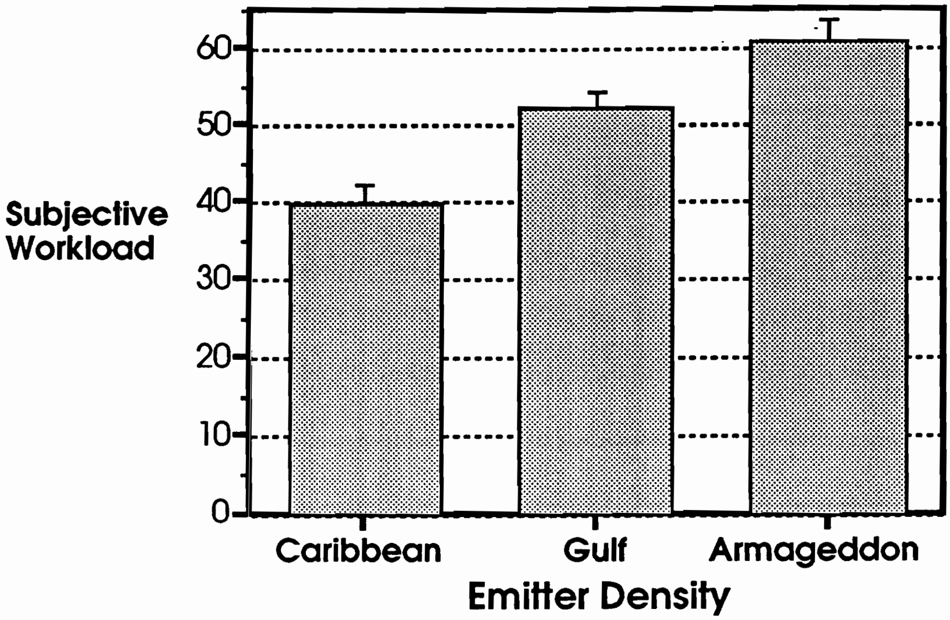


Figure 24. Main effect of Emitter Density on Subjective Workload (Experiment 1). Error bars represent +1 Standard Error of the Mean.

TABLE 19
Newman-Keuls Analysis of the Main Effect of Emitter Density on Subjective Workload (Experiment 1)

Emitter Density	*Standard Deviation*	*Standard Error of the Mean*	*Subjective Workload*	
Caribbean	23.33	2.38	39.87	A
Gulf	20.86	2.13	52.15	B
Armageddon	27.13	2.77	60.69	B
Means with the same letter are not significantly different at $p = 0.05$, n = 96				

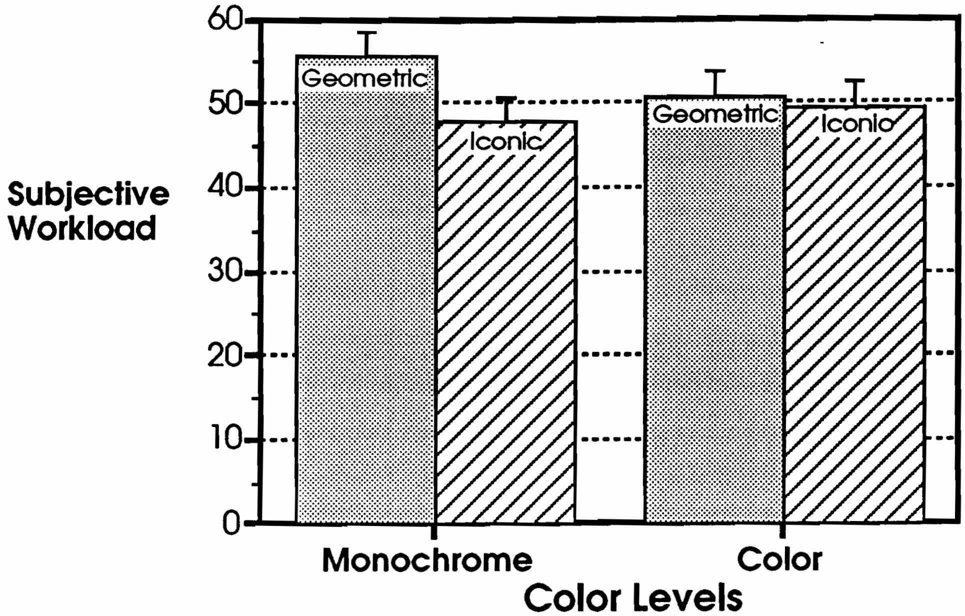


Figure 25. Effect of Symbol Type by Color Levels on Subjective Workload (Experiment 1). Error bars represent +1 Standard Error of the mean.

TABLE 20
Simple-Effects F-test of Symbol Type within Color Levels on Subjective Workload (Experiment 1)

Source	*df*	*MS*	*F*	*p*
Monochrome	1	2255.46	37.60	0.0001
Color	1	47.15	0.786	0.3943
Symbol by Color by Subject	11	59.99		
n = 36				

TABLE 21
Mean Subjective Workload scores for the Simple Effect of Symbol Type within the Monochrome Color Level (Experiment 1)

Symbol Type within Monochrome Color Level	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Subjective Workload*
Iconic	72	25.38	2.99	47.71
Current	72	25.20	2.97	55.62

Paired Comparison Results

Once a participant completed Day 8 of the experiment, they were asked to compare pictures (two at a time) representing each display configuration. The participant judged which configuration was preferred. Participants made 28 comparisons [(N*(N-1)/2, N = 8] among the pairs of images. Analysis of the paired comparison results with the Kendall Coefficient of Agreement (u) shows significant agreement among participants (u = 0.595, $p < 0.001$). That is, participants were in agreement on their preference for the interface designs. The preference matrix (Table 22) shows the number of participants who preferred a specific interface design to another. A high level of agreement tests for consistency and transitivity (i.e., if A > B and B > C, then A > C). Thus, multiple binomial comparisons were conducted to rank the eight versions. Significant differences are shown in Table 22.

The main effects from the paired comparisons were analyzed by computing z-scores based on the sum of the subjects' preference ratings. Table 23 shows that all main effects for paired comparisons are significant ($p = 0.05$). The data show the range information was the most helpful, as also shown by preference of the four range versions over the four polar versions (Table 22). The range preference was followed by the addition of color, which was preferred over the monochrome displays. Finally, the Icons were preferred over the Geometric symbols.

TABLE 22
Preference Matrix for 12 Participants (Experiment 1)

	Least Preferred ←							→ *Most Preferred*
	Polar Mono Geometric	*Polar Mono Iconic*	*Polar Color Geometric*	*Polar Color Iconic*	*Range Mono Geometric*	*Range Mono Iconic*	*Range Color Geometric*	*Range Color Iconic*
Polar/ Mono/ Geometric		10*	10*	9	12*	12*	12*	12*
Polar/ Mono/ Iconic	2		10*	10*	12*	12*	12*	12*
Range/ Mono/ Geometric	0	0	5	4		10*	11*	10*
Polar/ Color/ Geometric	2	2		9	7	6	12*	12*
Polar/ Color/ Iconic	3	2	3		8	8	12*	12*
Range/ Mono/ Iconic	0	0	6	4	2		9	12*
Range/ Color/ Geometric	0	0	0	0	1	3		9
Range/ Color/ Iconic	0	0	0	0	2	0	3	

Kendall coefficient of agreement = 0.595. Chi-square = 211.26 for u, $p < 0.001$

* Binomial test for significant comparisons for $k = 0$ ($p = 0.0$), 1 ($p = 0.002$), and 2 ($p = 0.017$). So, if more than 10 participants selected one format over another, the difference was significant at $p < 0.05$ (Note for $k = 3$, $p = 0.073$).

TABLE 23
Results of z-Scores for Preference Paired Comparisons

Effect	*Sum of Preference*	*z Value for Normal*	*z Probability*
Geometric vs. Iconic *	84	-1.80	0.036
	108		
Polar vs. Range *	19	-11.19	< 0.001
	173		
Monochrome vs. Color *	44	-7.58	< 0.001
	148		
Expected Value = 96 = N/p, Ss = 12, 28 comparisons per subject			
* Preferred main effect for each pair			

Discussion and Conclusions (Experiment 1)

The data indicate that Range, NATO Icons, and the use of Color produce significantly better performance scores than the Polar format, Geometric symbols, and the monochrome display ($p = 0.10$). Newman-Keuls analysis of a Format by Symbol interaction shows that both Iconic and Geometric symbols used on a Range Display produce superior performance scores than either symbol set used on a Polar display. Recall that in the Polar display, the Iconic symbols produce higher performance scores than the Geometric symbols used currently in the AN/SLQ-32(V). This difference between symbol sets is not present in the Range display, suggesting that the addition of range information makes the operator's performance less reliant on symbology. For this task, the Range display shows the largest improvement in performance for any of the three main effects.

Performance across all display configurations is higher in the low density scenario (Caribbean) and worst for the high-density scenario (Armageddon), with performance in the intermediate-density scenario (Gulf) in-between. The density levels used in Experiment 1 produce differences in performance scores (i.e., as the electronic environment is filled with emitters, performance decreases) but since these differences are uniform across all configurations, the data do not indicate combinations of factors that improve or degrade performance as a function of emitter density. Moreover, analyses of workload data indicate that workload was higher in both the Gulf and Armageddon density conditions when compared to the Caribbean condition.

Analysis of subjective workload shows that the geometric symbol set produces a greater workload on operators than does the NATO icons across configurations, but the format and color conditions do not influence cognitive workload ratings. The NATO icons are intuitive and are visually analogous to the emitters they represent. Thus, cognitive processing is minimized in comparison to the processing required to translate the cryptic geometric shapes into threat level.

The preference data show that the addition of Range, NATO icons, and Color are preferred. Furthermore, the ranking of the main effects (Range, then Color, then NATO Icons) can be compared to the increases in performance associated with each of the main effects (Range–60%, Color–17%, and NATO icons–15%). Therefore, participants preferred the versions that allowed for the best performance.

The costs and benefits of adding the aforementioned changes to the display should be considered. It is possible to incorporate Range information into the AN/SLQ-32(V) (NOSC, 1991). The range redesigns tested in Experiment 1 assumed the display was redesigned to organize emitters by range. That is, simply adding range to the display via appending a range field in the Close Control parameters is not the same as reorganizing the display to present range information. Adding range information may not translate into the same performance improvement if range information is added by tagging each emitter with range displayed as text (causing screen clutter, and overlap between emitters and text), or to the Close Control Parameters which are only available when an emitter is hooked. If range is added to the polar display, the effect of range on the entire system needs to be considered.

The NATO icons improve overall performance by 15%, and the Symbol Type by Color Level interaction show that in the monochrome condition NATO Iconic representations reduce subjective workload by 17%. Therefore, the NATO icons improved performance and reduced workload when color was not present in the display. The addition of color to a display containing the NATO icons does not reduce workload any further.

Color improves performance by 17%. Since the current display is achromatic, the CRT must be replaced to accommodate color. If hardware is replaced, it may be beneficial to consider solutions that may increase performance more than by adding color, range information, or NATO icons. If large increases in performance are needed and changing hardware is already being considered, then other design suggestions may be tested. The incremental changes tested in Experiment 1 show improvement from 15 to 60 percent. What if 100 or 200 percent increases in performance were needed? Experiment 2 tests two more interface designs that incorporate the display elements tested in Experiment 1. These redesigns apply advances in technology and user interface design.

Thus, when designing the new interfaces for Experiment 2, range, NATO icons, and color were incorporated. Range and color improved performance in Experiment 1 and are used in the interfaces tested in Experiment 2. Since NATO icons also aid the operator's performance and increase workload when color is present (since color is used in Experiment 2), they were also incorporated in the interface designs in Experiment 2.

BACKGROUND FOR EXPERIMENT 2

Introduction

Experiment 2 evaluated two DCC configurations based on a Direct-Manipulation Interface (DMI) and a Command-Key Interface (CKI). Color, a Range display, and NATO icons were incorporated into both versions tested in Experiment 2. Other design enhancements were also added to the interfaces in Experiment 2.

The process of analyzing emitter parameters is supplemented by a Computer-Assisted Identification System (CAIS). CAIS has three possible advantages over the current design of the AN/SLQ-32(V). First, the current library structure forces an EW operator to rely on manual searches for information using large publications. This requires the operator to look away from the primary visual display. Furthermore, these publications are not organized by the same principles as the emitter parameters presented on the screen, in the close control area, or in the on-line library. A single search requires the operator to look at four different sets of information, each with a different format, and multiple formats *within* a set. The redesigns examined in Experiment 2 present all the emitter parameter information using a single format in a designated area on the video display. AN/SLQ-32(V) operators use more than the four emitter parameters used in these experiments, making searching, sorting, and comparing of emitter parameters even more complex.

Second, the publications do not take advantage of a computer's ability to process, search, and retrieve information efficiently. Searching a library that contains all known emitters could decrease search time. With the level of computer power and available storage capacity available with 1990s technology, the entire set of publications could be stored and searched on-line. An added benefit of a complete on-line library would be the elimination of clutter in the workplace caused by the paper publications.

Third, improving the layout and integration of the library could affect the EW operator's job. A CAIS has increased capabilities to eliminate an operator's reliance on publications, thus allowing operators to search for emitters based on a variety of parameters and parameter combinations. A redesigned system could provide more flexibility when emitters must be added or deleted from the library and may allow changes in the library to be made by direct downloading into the database.

Experiment 2 examined whether the elimination of publications and the use of different interaction methods would improve identification times and decreases the operator's workload. An object display was used to assist operators in recognizing differences in an emitter's parameters. The information used by the object display was based on the close control and library parameters. The CAIS supplied the object display algorithms with the necessary parameters (see "Object Displays," page 56).

Command-Key vs. Direct Manipulation

A command-key interface (CKI) supposedly provides a fast method for initiating tasks. Shneiderman (1987) indicates that a CKI has the drawback of making operators more error prone than users of a Direct-Manipulation Interface (DMI). A DMI with windows, icons, menus, and prompts provides an easy-to-use and easy-to-remember method for interaction. When a DMI contains command-key equivalents, it provides two methods for interacting with the interface (Smith and Mosier, 1984; Ziegler and Fahnrich, 1988). Although empirical evidence is limited, this belief has substantial face validity in the computer industry. A large and increasing number of desktop and workstation systems contain a DMI with command-key equivalents. Command-line interfaces typically are considered difficult to learn and operate.

In most DMIs, the operator selects commands from a menu. Thus, the operator does not have to remember the command syntax or control options (Antin, 1988). Antin suggested a combination of the two systems that allows the operator to enter selections with command keys and allows selections from a menu. Frequently used commands might be remembered easily, while lesser known and less important functions could be accessed from the menus. Antin found that the command-entry system produced performance superior to a menu selection and a combined menu-and-command interface. It should be noted that the menu selection process used by Antin was hampered by the device used to make menu selections—it required users to position a pointer using the cursor keys. Since cursor positioning with cursor keys is significantly slower than positioning with a mouse, trackball, or other types of pointing devices (Epps, 1986), it is inappropriate to generalize Antin's results and state that command entry is always faster than direct manipulation—even for Antin's own study.

Command-line systems require a user to *recall* the correct command, which, as Norman (1988) pointed out, requires "knowledge in the head." On the other hand, menus require *recognition*, thus requiring "knowledge in the world." The more burden to recall commands and the longer the period between recalls, the higher the risk for degradation in the operator's ability to remember commands (Wickens, 1992). Menu systems avoid these pitfalls by visually presenting the system options so users can recognize the appropriate selection. The implication of recall versus recognition becomes more critical as the number and diversity of functions increase. Consistency within and across applications is critical to improving performance. Consistency allows operators to use infrequent features with the same rules applied to frequently used features.

There is little evidence to justify the objective benefits of a DMI or a CKI. Whiteside, Jones, Levy, and Wixon (1985) tested the performance of novice, experienced, and transfer users on command, menu, and iconic interfaces. In their study, novices were users who had not used computers, experienced users had several months of experience to become familiar with the system being tested, and transfer users worked with computers but not with the system being tested. The interface designs lacked any controls between the versions which would make the DMI and CKI interfaces comparable. The researchers could not substantiate differences in performance among a command, icon, and menu systems.

Tognazzini (1992) offered a logical explanation as to why command keys are not necessarily faster than menus:

> ...the command-key decision is a high-level cognitive function of which there remains no long-term memory. Therefore, subjectively, keys seem faster when in fact they usually take just as long to use.
> Since mouse acquisition is a low-level cognitive function, the user need not abandon cognitive process on the primary task during the acquisition period. Therefore, the mouse acquirer achieves greater productivity (p. 181).

DMI functions and menus are visible to the user, thus making them more accessible. On the other hand, the CKI requires knowledge of exact command syntax. The combination of the visual interface with command keys gives users multiple methods for completing tasks. This combination can lead to improved subjective assessments of the usability of the interface and improved objective performance over either system individually. Design decisions such as the number of menus and command keys, the size and complexity of the screen, the control/display ratio of the input device, and the workload on the operator all affect the development of a command-based or menu-based system.

When menuing systems become large, the user must recognize or recall the location of the function in the menus, menu items, and dialog boxes. Problems in navigation and selection occur when related functions are placed in disjunct locations. Redesigning the grouping of menu functions based on frequency of use and using multiple entry points into the same functions can allow navigation to proceed faster. Mayhew (1992) explained that the menu structure should map to the task structure. Figure 26 shows two ways to structure a menu. In the *Poor* version on the left, the operator must return to the Library menu to perform multiple operations on a single emitter. In the *improved* structure on the right, the operator can perform multiple operations on the same emitter without having to re-select. This follows the noun/verb selection process recommended by commercial computer vendors (Apple Computer, Inc., 1987). In order to improve efficiency, some functions may contain linked menus, as suggested by Norman (1991). This would be equivalent to the bold line in Figure 26 connecting *Edit* and *Mark*. Thus, the operator can enter the *Edit* menu from the *Mark* menu.

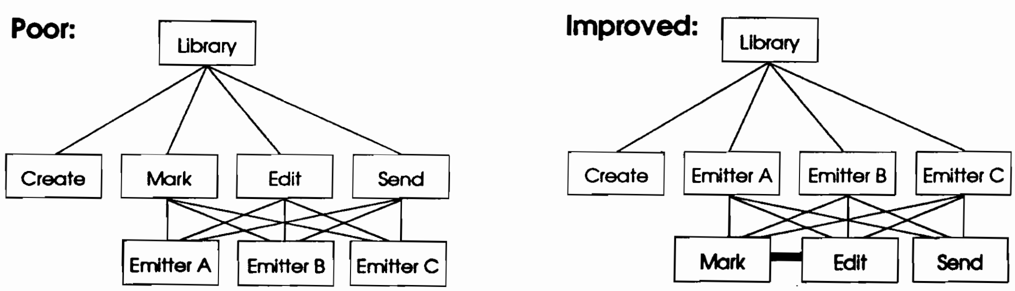


Figure 26. Matching menu structure to task structure. (adapted from Mayhew, 1992)

Object Displays

Object displays create an overall representation of a complex set of quantitative parameters, such as those describing an emitter. Specifically, these displays are useful for separating sets of parametric data into categories (Turek, 1986).

Figure 27 shows a graphical representation of emitter parameters (Frequency, Scan, PRF, and Scan type[4]). The upper two graphics in Figure 27 show a color and monochrome four-sided object display with two additional overlays. Each library listing for an emitter corresponds to one graphic overlay. The color of the overlay is the same as the color used for displaying information in the CAIS. These displays present a hooked emitter's parameters on the x and y axes. When an emitter is selected from the library, a polygon representation is placed over the hooked emitter polygon allowing multiple emitter polygons to be presented simultaneously. In Experiment 2, both redesigns used color to distinguish layers in the object display. Color is the only method for identifying layers on the object display, with no redundant forms of coding. This object display is abstract, contradicting the guideline for creating cognitive links between the data and the presentation style (e.g., using red missile icons for missiles). Pattern recognition for sound of an emitter or ULQ-16 information is based on training and experience, not on the application of specific rules. If the rules were known and reliable, it would not be necessary to display the data—the computer could analyze and interpret the information.

Turek (1986) explained that for object displays to be effective, the displayed values must be normalized to prevent judgmental errors based on absolute information. Turek suggested that a polygon display is affected less by absolute differences in data sets, which can cause undue attention for a particular parameter. Turek wrote that this allows a clearer picture of the data relationships. A polygon display with standardized values for the distance from the center to each vertex and internal radii, giving the "star" shape, provides a basis for relative judgments. With these principles in mind, it is felt that such a display may aid EW operators. A polygon display, also called a star display, uses one vertex for each data type. To represent eight variables, a polygon display requires an octagonal shape. Six variables require a hexagon. The distances from the center to the vertices are equal to data values, which are normalized such that the largest values will fit on the display. The polygon display in Experiment 2 has four sides (four variables). It is possible to increase the number of variables. Turek (1976) tested polygons with nine sides (nine variables).

Kleiner and Hartigan (1981) noted that if the order of the variables is chosen improperly, the object display can exhibit jagged edges. In the redesigned interfaces tested in Experiment 2, the object display is for helping the operator match an emitter in Close Control to an emitter in the on-line library. Since comparisons between emitters can be made by comparing the overlaying graphics, jagged edges might help operators distinguish among emitter types. The effect of a large number of overlays (5 to 10) has not been addressed in the literature.

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[4] See Glossary (page xvi) for definitions of the emitter parameters.

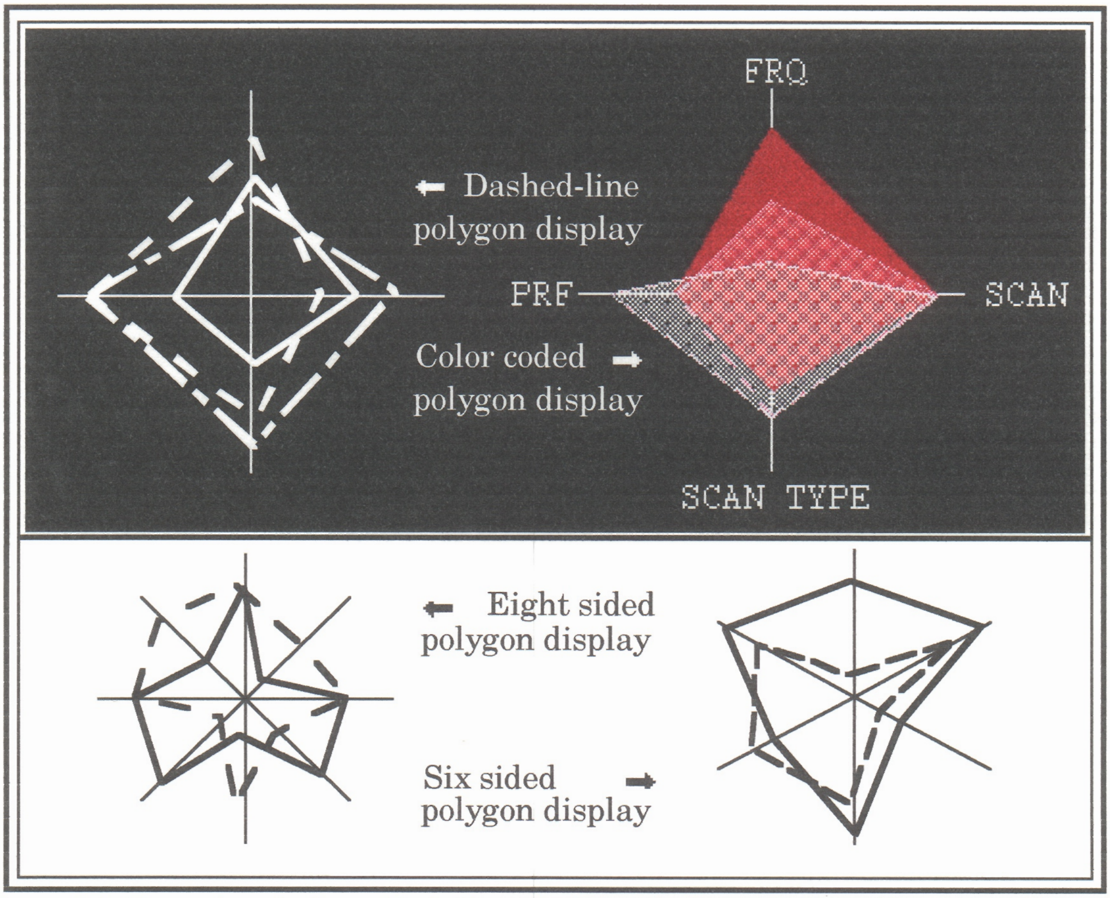

Figure 27. Examples of a four-sided object display with three object overlays (monochrome dashed-line coding and color coding), and an eight and six-sided display with two object overlays.

Garner and Fefoldy (1970) pointed out that "the benefit of integral object representation of correlated variables might be partially neutralized by the cost resulting when a single variable must be selectively perceived and other dimensions must be selectively filtered out" (p. 225). This neutralization could be partially offset by providing a textual display. Thus, general attributes could be compared in the polygon display, and specific attributes could be analyzed in the textual display. Both object and text information are provided in the Experiment 2 redesigns (Figure 66, page 137, and Figure 67, page 138).

Another design alternative was considered based on schematic faces (i.e., iconic representations of system features as expressed by changes in human facial expressions). Jacob, Egeth, and Bevan (1976) reported that the usage of schematic faces was found to be significantly more accurate than numeric representation. Examples of changes in facial expressions that denote changes in system values in Jacob et al. are shown in Figure 28. For clustering data with nine variables, users of the polygon displays were as fast but not as accurate as users of the schematic faces. The AN/SLQ-32(V) emitter library would require millions of facial expressions to represent emitters because each variable is represented by a feature, but the detail of each variable creates hundreds of possibilities. Jacob et al. had only a few levels for each variable and were only looking for general features. However, polygons can be overlaid, whereas Chernoff faces (1973) must be placed side-by-side to make comparisons. The research conducted by Jacob et al. used hard-copy plotter-generated faces. Display addressability and display area needed to compare the faces were not considered. Given a limited screen area and the need to make multiple simultaneous comparisons, Chernoff faces are an impractical alternative when they must be displayed via electro-optical visual displays.

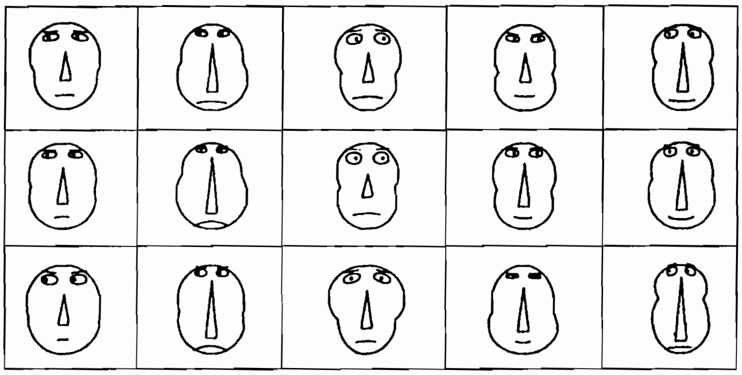

Figure 28. Example of schematic faces, originally suggested by Chernoff (1973). (adapted from Jacob, Egeth, and Bevan, 1976)

Textual and Graphic Displays

There are several design principles pertinent to the display of numeric data. When tabular data are displayed for comparisons, they should be positioned vertically (U.S. DOD, 1987). Graphical displays should be used when comparing related data (Cleveland and McGill, 1985). Furthermore, only necessary data should be displayed, and the display should be consistent (Tucker, 1984; Tufte, 1983). Tufte also asserted that a baseline (mean) should be displayed in graphical data. MIL-STD-1472D (U.S. DOD, 1987) suggests that for precise display in graphical form, numbers should be visible. This assertion implies that graphical and tabular data should be present in the AN/SLQ-32(V) redesign. The parameters of the target emitter are compared to emitters in the CAIS. Standard bar charts, for example, were not considered as a method for displaying emitter parameters. Like Chernoff faces, bar charts require more display area than the object display.

Improvements in a poor design can be partially overcome by a creative designer who understands the functionality of the system, the task of the operator, design guidelines, system capabilities, and user needs. This is exemplified by the redesigned telephone repair

```
TEST RESULTS    SUMMARY: GROUND
  GROUND, FAULT T-G
  3 TERMINAL DC RESISTANCE
    >  3500.00 K OHMS T-R
    =     14.21 K OHMS T-G
    >  3500.00 K OHMS R-G
  3 TERMINAL DC VOLTAGE
    =      0.00 VOLTS T-G
    =      0.00 VOLTS R-G
  VALID AC SIGNATURES
  3 TERMINAL AC RESISTANCE
    =      8.82 K OHMS T-R
    =     14.17 K OHMS T-G
    =    628.52 K OHMS R-G
  LONGITUDINAL BALANCE POOR
    =    39     DB
  COULD NOT COUNT RINGERS DUE TO
    LOW RESISTANCE
  VALID LINE CKT CONFIGURATION
  CAN DRAW AND BREAK DIAL TONE
```

Before
Narrative

```
          ********************************
          *                              *
          *    TIP GROUND       14 K     *
          *                              *
          ********************************

DC RESISTANCE        DC VOLTAGE         AC SIGNATURE
 3500 K T-R                                  9 K T-R
   14 K T-R          0 V T-G                14 K T-G
 3500 K R-G          0 V R-G               629 K R-G

  BALANCE                               CENTRAL OFFICE

   39 DB                                VALID LINE CKT
                                        DIAL TONE OK
```

After
Formatted (Structured)

Figure 29. A text display screen before and after redesign. (adapted from Tullis, 1983)

system described by Tullis (1983). Tullis suggested that the alignment of text fields be grouped for readability, thus improving search time. Figure 29 shows a text display for a telephone repair system before and after redesign. The narrative format of this display was redesigned to be structured so that the text fields could be chunked. Rosenthal (1979) explains that the primary difference between the narrative and formatted display should be based on the user's task. The formatted display should be used for searching tasks when the operator is not reading from left to right and from top to bottom. Note that the redesign took into account the constraints of the current hardware and software. The text is all uppercase, borders were made with asterisks (*), and color was not implemented. Even within the constraints of the phone-testing system, users showed substantial improvements in usability without the additional cost of new video displays or other hardware. After practice, average time to answer questions about the display decreased from 8.3 seconds for the narrative format to 5.0 seconds for the structured format. This statistically significant difference translated into 79 person-years saved by the telephone company over one year. Estimates of usage for the Bell System computer system indicates 344 million distinct screens are viewed each year by the users of the system (the Automated Repair Service Bureau). A 1-second increase in time needed to extract a piece of information from each screen translates into an additional 55 person-years of time per year (based on a 1737 hour per year schedule).

Design Guidelines For the On-line Library

The design of the AN/SLQ-32(V) interface was driven by technology available in the late 1960s. Part of the human interface problem can be attributed to hardware constraints imposed by the choice of available graphic systems. A scientific redesign of a system takes into account the advances in user-interface design, display and input device hardware, and software technology. Table 24 lists violations in design guidelines for the AN/SLQ-32(V). The basic guidelines for the items listed in Table 24 have been discussed by Smith and Mosier (1986), Shneiderman (1987), Galitz (1989), and Mayhew (1992).

TABLE 24
Design Guideline Violations in the On-line Library and Close Control Information Screens of the AN/SLQ-32(V) DCC

(1)	The on-line library is not formatted the same as the Close Control information.
(2)	Items in the on-line library are displayed with upper and lower bounds, (denoting a range of Scan Frequencies or PRFs) in a stacked arrangement when they should be organized left-to-right.
(3)	The items in the library are not chunked or spaced properly.
(4)	The information in the library is not organized by the operator's search strategy.
(5)	The library screens do not have smooth scrolling.
(6)	The layout of library and close control information is not compatible with the layout of the paper publications.
(7)	The library and sequence list contain a control/display incompatibility: the up arrow goes down to the next page.
(8)	There are no other methods for navigating the on-line library except the up and down arrows. One cannot move directly to the beginning or end of the library.
(9)	There are no query or search functions in the on-line library.
(10)	There is no way to visually compare the information in the on-line library and the emitter in close control. The operator must write down the parameters or try to remember all the parameters.
(11)	Once a match is found in the on-line library, there is no way of selecting that choice. The operator must remember the identification number and return to the primary screen to enter the identification number.
(12)	The library does not contain page numbering to determine the operator's current location in the on-line library.
(13)	Use of the library requires the operator to leave the main display screen, thus degrading any mental representation of the tactical environment.

Sequence Button—Access to Emitters

On the AN/SLQ-32(V), an operator can select an emitter in one of two ways. The operator may select the emitter icon using the isometric joystick or use the sequence key to toggle through the emitters presented in the sequence list. An operator processing emitters in the order they appear on the sequence list is attending to the priority of emitters as determined by the AN/SLQ-32(V). Since only fifteen emitters are listed on a single page in the sequence list, the system displays "2 OF 4" in the lower-right corner of the sequence list to show the number of pages of emitters. Thus, the operator has limited access to a portion of the possible emitters at any one time.

The operator views the sequence list to select emitters (part A of Figure 30). For example, if the current emitter is the second one on the list and the operator needs to select the 13th emitter, the operator must activate the sequence button 11 times. Operators can scan the display for the emitter and hook the appropriate icon with the joystick, but AN/SLQ-32(V) operators prefer to use the sequence FAB. If the operator overshoots the emitter with the sequence FAB, the operator must sequence to the bottom of the list and back around, starting at the top of the list. In this example, missing on a first attempt to sequence to the emitter requires the operator to press the sequence FAB 26 times to select it properly on the second pass. During interviews with EW operators (EW operators, personal interview, August 7, 1991), it was noted that during high sea conditions, the joystick was difficult to control. The only method for selecting emitters in high seas is the sequence FAB. Based on observation of operators, it was very common for an operator to press the sequence FAB very rapidly (multiple times per second). Operators are accustomed to the procedure outlined in Figure 31. A redesign of the sequence list must reduce operator errors when selecting emitters from the list. Additional keyboard activations increase emitter selection time. EW operators expressed annoyance with the inability to go backwards through the list and the slow response of the actual system when repeatedly pressing the sequence button.

Adding a modifier key to the selection process would allow operators to select emitters in reverse. Holding the shift key down while selecting the sequence button would allow operators to move backwards through the sequence list (Part B of Figure 30). This solution does not require any complex modifications to the AN/SLQ-32(V) and could be implemented immediately. There are guidelines for the use of key modifiers, also called qualifiers. Mayhew (1992) suggested their use should be minimized and used consistently when necessary. Carroll (1982), in research on creating consistent command names, emphasized the concept of *hierarchicalness* when developing rules for qualifier usage. Hierachicalness requires that the lexical elements of the command are consistent. The terms "Move up" and "Move down" are consistent, while "Move up" and "Go down" are not. Consistency can be applied to qualifiers as well. If the shift key reverses selection on the sequence list, it should reverse actions in the library and any other field operations.

Another solution, as shown in Part C of Figure 30, uses a menu structure to allow the operator to select any entry with the function keys. Additional pages of emitters use the same

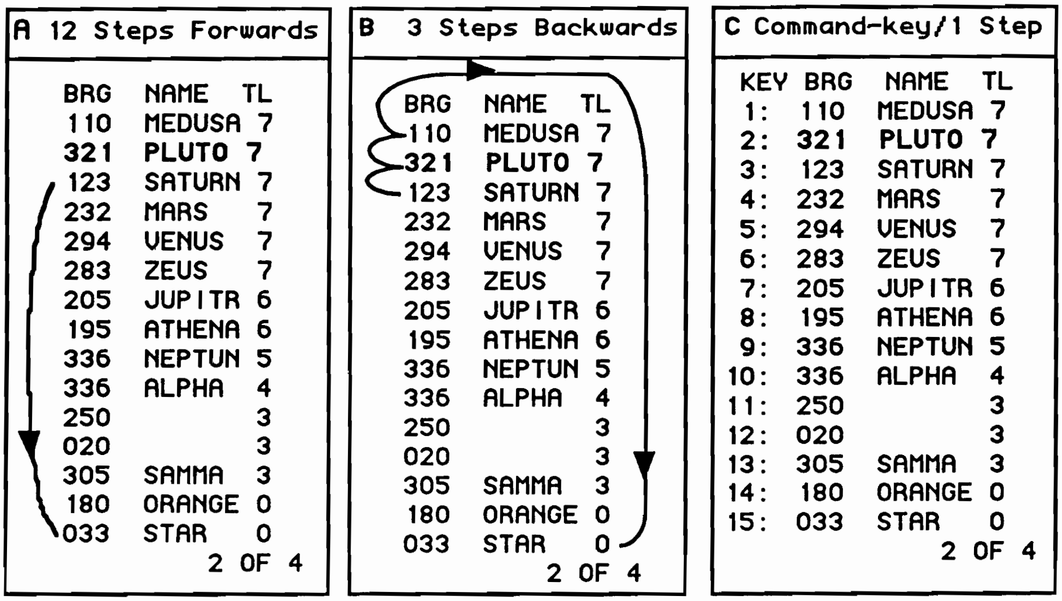

Figure 30. Current sequence list (A), sequence list with the use of the SHIFT key for reverse (B), sequence list with a command-key interface (C).

codes. Paging up and down is achieved with "page up" and "page down" keys. These same keys can be used in the CAIS and elsewhere in the system. Since emitters on the list change frequently, the menu labels (A to 0, or 1 to 15) are not associated with a specific emitter. The operational sequence diagram in Figure 31 shows the simplified process.

A DMI allows operators to select emitters by placing the cursor over the item in the sequence list and pressing the input device button. This is a one-step operational sequence diagram as compared to the six steps required for the current system or the three steps required for the CKI. The time required to position the cursor over the emitter will affect the accuracy and speed of selection. Thus, the cursor positioning time and accuracy can be predicted with Fitts law. The larger the size of the target and the less the distance the cursor has to be moved, the faster and less error prone will be the selection process. This was verified in studies of target acquisition for a display area similar to the polar display with the same mouse device used in Experiments 1 and 2 (Dyess, 1992; Han, Jorna, Miller, and Tan, 1990). Pages of emitters are accessed with a pop-up menu. The pop-up menu gives operators direct access to any page of emitters. Other selection systems were considered (e.g., scrolling fields) but were rejected (due to programming complexity) in favor of maintaining the current paging system. Selecting emitters on the current page requires only one click. Whereas the CKI maps the function keys on the extended keyboard to the 15 positions on the sequence list, the DMI allows selection by clicking directly on the emitter name in the Sequence List.

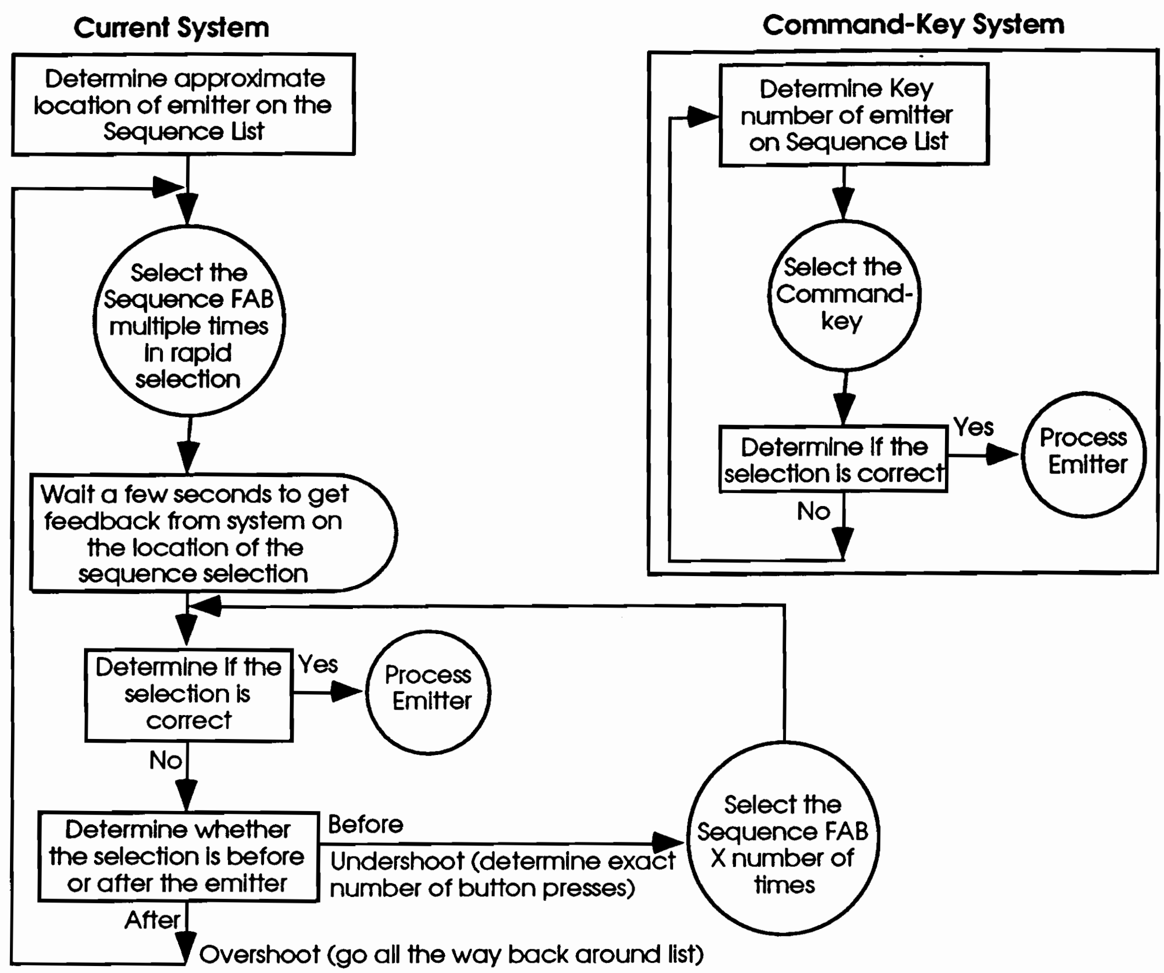

Figure 31. Operational sequence diagram for accessing emitters with the sequence FAB on the current AN/SLQ-32 (V) and a command-key system.

Large Screen Displays

Woodson (1981) recommended a small display size to reduce visual scanning times in target search tasks, but recommended larger displays (30–43 cm) to improve accuracy in tracking targets. With the potential for over 100 targets on the AN/SLQ-32(V) screen, the increase in screen diameter can help the operator discriminate among targets. There is a tradeoff between increasing the size of the display and hooking emitters. As the size of the screen increases, the time required to select emitters using direct selection also increases (Card, English, and Burr, 1978; Dyess, 1992; Han et al., 1990).

It is important that the operator views the emitter display while completing other tasks. Redesigning the interface optimizes allocation of screen area to particular functions. Galitz (1989) recommended that all elements on a screen be located in unique and consistent locations. The polar display—the primary focus of an operator—is given priority in screen size and placement in the redesigns presented in Experiment 2.

Warning messages are positioned in a specific screen area that operators see regardless of the system state or current screen complexity. The warnings must attract the operator's attention and be discernible from the rest of the screen. Galitz (1989) recommended the use of lower case characters, unique symbols, and a form of contrasting display (e.g., reverse video or highlighting) to identify error messages.

Having a screen area specifically reserved for menus reduces searching for menus on large screens. A specific screen area for menus would also allow library, polar, and other information to be presented concurrently on the screen, thus giving the operator the ability to view information relevant to the menuing task. The library and close control parameters, with their associated graphical representations, are allocated specific regions of the display. Other AN/SLQ-32(V) functions share a specific area of the screen based on their importance and function. Infrequent functions are allocated a multipurpose screen area.

Experiment 2 uses a 46 cm diagonal screen. The AN/SLQ-32(V) and the display configurations in Experiment 1 measure 30.5 cm diagonally. Figure 32 shows how the increase in the size of the screen diagonal increases the total screen area. The additional screen area must be organized to keep the screen from becoming cluttered and confusing.

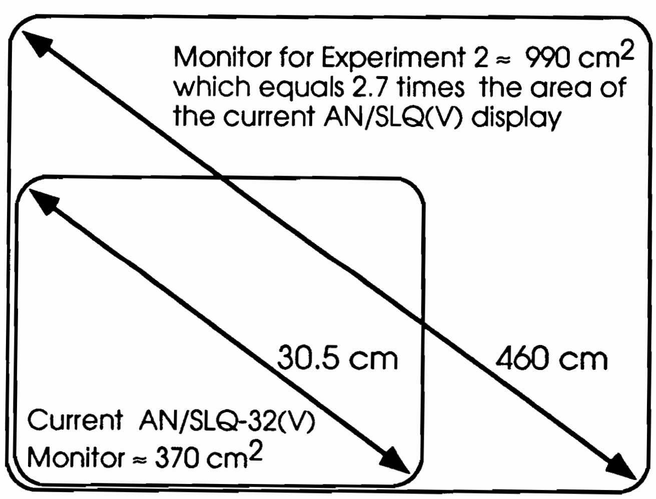

Figure 32. Existing and prototype screen sizes for the AN/SLQ-32(V).

Single Click/ Double Click Paradigm

Many direct-manipulation systems have guidelines for how selections with the mouse or other device should occur (Apple Computer, Inc., 1987; DEC, 1988; IBM, 1987). A common guideline is to use a single click to select an object and a double click (two clicks in rapid succession) for initiating an action. Some systems use multiple-button input devices to separate selection and activation. In the redesign of the AN/SLQ-32(V), a DMI uses a click to select an emitter and place it in close control. The use of a single-button mouse eliminates errors in choosing the wrong button for a task, but some researchers recommend a two-button configuration when choosing between a single-button mouse with multiple clicks versus single clicks with different buttons (Bewley, Roberts, Schroit, and Verplank, 1983; Price and Cordova, 1983). Some design decisions are based on research but the results are not available (Williams, 1983). Regardless of the basis for the research, the authors of design guidelines recommend the separation of selection and activation (Apple Computer, Inc., 1987; Shneiderman, 1987; Smith and Mosier, 1986). Since all users were familiar with the use of a mouse, it was used with the DMI to eliminate additional training.

In order to assign the meaning of a double click, a task analysis is necessary. If a double click is to have a unique and useful meaning, it must be applied to a frequent task. No research was identified that substantiated guidelines for attaching functions to a double click. The DMI in Experiment 2 was designed so the most frequent action (initiating a library search) was assigned to the double click. If many different actions follow the selection of an emitter and no single action is more likely or more important, then no action should be assigned to a double click. Depending on the paradigm for clicking, the software may require a double click for activation to maintain consistency, even in cases where activation follows selection. In an actual-system implementation of the DMI, other features would be available to the operator (beside library searching). Grayed-out menus, buttons, or tool bars may appear or become available when an object is selected to provide features other than a library search (e.g., launching chaff, jamming, editing parameters, platform correlation).

The separation of selection and activation may benefit operators in several ways. First, this paradigm defines a consistent meaning to a single click and double click throughout the interface. Other functions in the interface can rely on the same input mechanism for selection and activation. Guidelines for single (and double) clicking can be applied in other areas of the interface redesign as shown in Table 25.

Separation of selection and activation can reduce screen clutter. When an operator is checking emitter parameters but does not need to perform a library search, the library window may remain blank, thus decreasing screen clutter. Once an item is selected, functions may become available to the operator (i.e, menu or icon choices may vary depending on the selection).

Library searches consume valuable CPU cycles. Even in redesigns, memory and performance issues arise as software expands in size and complexity. By not initiating a library search, the computer can respond to other requests from the operator (or remote operators). Finally, as Navy operators become more computer proficient (all operators interviewed for this research were personal computer users), consistency with personal-computer conventions will make training simpler.

TABLE 25
Extending the Single/Double Click Paradigm to System Functions in a Redesigned DMI for the AN/SLQ-32(V)

Application	Single-Click Function	Double-Click Function
Sequence list	Places emitter in close control	Initiates a library search
Library target list	Adds/Removes graphic overlay from polygon display and highlights/ dehighlights selection	Designates the ID of the currently hooked emitter with the ID of the selected library target
Recent list	Allows operation to undo, complete, or cancel task	Opens the task window to complete or modify task
Emitter display	Places emitter in close control	Initiates a library search
Setting up a jamming region	Selects jamming region for adjustment, deletion, or pausing	Opens up window for fine-tuning jamming parameters

Modifier Keys

Common modifier keys found on a keyboard include Shift, Command, Control, Option, Tab, and Escape. How does one operationally define the functional differences among these modifiers? Unfortunately, it appears that there are few logical uses for these modifiers. As discussed previously (see "Sequence Button—Access to Emitters," page 61), extensions to personal computer paradigms can help to create a consistent interface for EW operators. In personal computer programs the Tab key is used to move forward one field, and the combination of the Shift and Tab keys move the cursor in reverses. In a redesign of the AN/SLQ-32(V), the Tab key moves to the next emitter in the Sequence List, and the Shift-Tab key combination moves the operator to the previous emitter on the list. Other lists of information are accessed using this type of keybinding. Keybinding is the process of selecting a keyboard combination of modifier keys and character keys to represent a common function. For example, Command-S is a common keybinding for the Save function. Command is used to tell the user and the computer to interpret the "S" key as a command, not as a character.

The Tab key is effective for a form fill-in interface. A complex library search request would use a form fill-in interface. The Escape (ESC) key, at the top left of the keyboard, makes it an "escape" to return the operator to a steady state or previous mode. Section 3.1.4 of Smith and Mosier (1986) lists applicable guidelines.

Walker and Olson (1988) noted that it is important to make keybindings memorable to "reduce the cognitive load in complex tasks on complex systems" (p. 201). Walker and Olson created a hierarchical command structure using the modifier keys. The Escape key was used for all system related commands, the ALT key for all deletions, and the Control key for all other types of actions. A similar method can be applied to the development of keybindings for the AN/SLQ-32(V). By assigning a specific class of operations to a modifier key, users will associate operations with specific keys. If an operator can remember and apply appropriate key combinations, then the keybindings are successful.

Walker and Olson (1988) found that their keybinding set was significantly easier to learn than a common keybinding set (called EMACS). Their keybinding set also was more resilient to negative interference from prior- and post-learning from a different set of keybindings. Walker and Olson pointed out that keybindings are a helpful addition to menu-based systems. They claimed it gives experienced users a method to circumvent the slower mouse-based interactions. They did not substantiate that keybindings are faster than a DMI for the same system, as even expert command-key operators use menus to access infrequently used functions. Keybindings for frequently used functions help to keep an operator's hands on the keyboard. This assumes that the operator needs to keep his or her hands homed on the keyboard. A DMI may use the keyboard infrequently or never, thus negating the effect of input device to keyboard hand motion on performance. Examples of keybindings used in the CKI are compared to the current procedures on the AN/SLQ-32(V) (Table 26).

TABLE 26
Examples of Keybindings for a Redesigned Command-Key AN/SLQ-32(V) Interface

Action	Current Action	Redesigned Action
Select emitter from sequence list	Tab X times based on experience and understanding the position of the item on the sequence list	Select Function-key corresponding to the number listed to the left of the emitter in the sequence list
Listen to signal select	Select Signal Select FAB	Select Command - S
Select an emitter from the on-line library	N/A	Press number key corresponding to the number listed to the left of the emitter in the library list
Access Library Search	Go to another screen, invoke a few menu choices	Select Command - L

EXPERIMENT 2

Introduction

Experiment 1 tested incremental changes on the AN/SLQ-32(V) interface that could be incorporated into the existing own-ship hardware. The second phase of this research explored redesign solutions that were not bound to the current display and interface technology embedded in the AN/SLQ-32(V). Thus, Experiment 2 evaluates two parameters: (1) the application of interface designs with a 46 cm color monitor and (2) redesigns to the presentation of information on the AN/SLQ-32(V).

The major difference between the two interfaces tested in Experiment 2 is based on the premise that direct manipulation is easier to use but slower than command-key and command-line interfaces. Experiment 2 provided interfaces optimized for direct and command interaction. Emphasis in this experiment was placed on making each interface the most effective possible, given the operator's task. Additional features were added into both interface designs as discussed earlier (see "BACKGROUND FOR EXPERIMENT 1," page 10).

Method

Participants and Apparatus

All participants had completed Experiment 1 (n = 12), no participants withdrew, and no data were excluded from the analysis.

An accelerated (55 MHz) Macintosh IIfx equipped with an extended keyboard and mouse was used to present the interface prototypes (developed with Aldus Supercard). Hooking errors, task completion times, operator subjective workload scores, and other data were recorded automatically by the computer using the same method as in Experiment 1.

The Macintosh IIfx was configured with a Radius 46 cm, 8-bit color monitor (1152 by 882 addressability), System 7.0.1, and 10 megabytes of RAM. FAB, keyboard, and mouse settings were identical those used in Experiment 1. Illustrations of the command and direct interface screen displays are shown (Figure 66, page 137 and Figure 67, page 138, respectively). Operators were prevented from inadvertently switching to the Macintosh operating system by AutoLock software. A circular (ball) cursor, similar to that found on the AN/SLQ-32(V), was used. Participants wore headsets (Realistic Nova 40) to hear emitter scan types. Experiment 2 used the same testing room and ambient conditions as Experiment 1.

Experimental Design

The experiment employed a 2 x 3 within-subjects experimental design in which each participant was tested in both interface versions on Day 10 of the experiment.

Independent Variables

Interface Format. The participants used both the Direct-Manipulation Interface (Figure 66, page 137) and the Command-Key Interface (Figure 67, page 138).

Emitter Density. The density conditions were identical to those used in Experiment 1 (see Table 8, page 30). The density conditions were presented in random order within each interface condition.

Dependent Variables

Performance. As in Experiment 1, Performance is calculated as the inverse of the normalized values of Emitter Designation Time and Dummy Errors. The performance calculation is based on normalized values. To scale the performance measures to include both sets of data requires that all the data be combined and then rescaled. However, rescaling the data creates a new normalized range of values, and so these values *cannot* be compared with the performance values from Experiment 1. Other measures of how well the participant worked, such as mean time to process an emitter, the number of designation or dummy errors, and the number of emitters processed in a session, *can* be compared between the two experiments. Furthermore, a performance measure could be constructed to compare data from both experiments, as discussed elsewhere (see "Results," page 85).

Subjective Workload. Workload was measured in the same manner as in Experiment 1 (see "Dependent Variables," page 31).

Number of Emitters Designated. The number of correctly designated emitters in one trial was recorded.

Mean Designation Time. Mean Designation Time is the mean time to designate emitters during a trial.

Idle Time. Operators attempted to work continuously during a session to designate emitters listed on the Sequence List. Once the operator finished designating all emitters listed, the idle clock was started to measure the time the operator was idle before the presentation of the next set of emitters. Once a new emitter signal was presented new emitters started to appear and the idle clock was stopped. If the operator was not able to designate all the visible emitters, the idle clock would not start and the idle time would remain at its previous count until the operator cleared all the remaining emitters.

Dummy Errors. The number of emitters selected on the display that are not required to be designated were called dummy errors. Emitters already designated and emitters on the Range display without a corresponding emitter on the Sequence List counted towards this total. Selection of emitters that were previously selected but not designated did not count towards this total.

Designation Errors. The number of emitters designated with the wrong EFX number was recorded.

Experimental Tasks

The goal of the IT was the same as in Experiment 1 (i.e., designate emitters based on information presented by the computer). The procedure was modified to be conducive to the interaction style employed by each interface format. For example, operators using the DMI clicked on the sequence list to select emitters and to designate emitters from an on-line library. In the CKI, the procedure was modified to select emitters by keyboard entry. The publications were not needed in either of the new interface designs; this information was contained in the CAIS available on the bottom portion of both the DMI and CKI. The instructions to participants, explaining the procedures, were administered prior to the start of each session (see "Experiment 2 IT Training," page 152).

Procedure

Before the experimental session, the participants were given a series of training sessions to become familiar with the IT. Instructions to participants for Experiment 2 are shown in Appendix , page 151.

Sound Training

Participants were given two sets of 25 sounds. The procedure and analysis were identical to those used in Experiment 1 (see "Training," page 34). Participants repeated the sets of sounds until they achieved the 23 out of 25 criteria. Two participants required two sessions; all other participants passed on their first attempt.

Icon Training

Participants were given one set of 25 icons. The procedure and analysis were identical to those used in Experiment 1. Participants repeated the set until they correctly identified 23 out of 25 icons.

Integrated Task Training

The IT training required the operator to become efficient in the complete IT without concern for the time pressures made by the three density conditions. A level of 40 dummy emitters and 33 real emitters was presented during each IT training session. This session was similar to a combination of the hooking and IT training performed in Experiment 1. Participants were shown how the system operates and were given a few practice trials before starting the experiment. The instruction period and practice trials took about 20 minutes.

Participants were allowed approximately 7 minutes to designate emitters in each trial. Participants used the sequence list to hook emitters with either the keyboard or mouse. Once the participant hooked an emitter, the entry on the list was dimmed. The operator activated the Signal Select and used the signal information and the object display to select the appropriate emitter listed in the on-line library. The correct emitter was always available in the library list, as it was in the publications used in Experiment 1.

Experimental Sessions

Each participant received training sessions for sounds, icons, and the IT training as outlined previously. These training sessions were similar to those completed by participants before each session in Experiment 1. Following training, participants worked for 7 minutes in each density condition. A questionnaire followed the completion of the two interface conditions. Rest breaks for a few minutes were allowed between training and experimental sessions.

During each testing session, operators experienced system pauses when new emitters appeared. If the operator attempted to interact with the system during the few seconds that the system was paused, the operators input would not be accepted. The operator was trained for this situation. In each case, the computer recorded the total time the system paused and added the time back to the total time for that session. For example, if the system required 3 seconds to display new emitters, and this occurred four times during the session, 12 seconds were added to the session. The time available to enter inputs into the system was held constant, whereas session time varied slightly.

When an operator selected emitters in Experiment 1, the Close Control information appeared on the display within 1 second. System performance did not inhibit operators by making them wait for information. In Experiment 2, the system performance was degraded due to the complexity of the software needed to process library and graphic information. Comparisons between data from Experiments 1 and 2 were made without adjusting for differences due to computer processing. This makes comparisons of performance between versions from Experiment 1 and 2 more conservative. Some difference in performance due to the added complexity of the designs in Experiment 2 might also appear in other simulations or actual designs.

The questionnaire provided subjective feedback about the interface designs. Means and standard deviations were calculated for bipolar measures. Other data, as well as suggestions made by the subjects, guided the final redesign suggestions for the AN/SLQ-32(V). The questionnaire used to obtain this feedback is shown in APPENDIX E: POST SESSION QUESTIONNAIRE, page 157. Participants were free to comment on any part of the interface format. Comments recorded from the free response questions are included for reference in APPENDIX F: QUESTIONNAIRE RESPONSES, page 160.

Results

ANOVAs were performed on Emitter Designation Time, Number of Correct Emitters Designated, Idle Time, Performance, and Subjective Workload. Designation Errors and Dummy errors were virtually eliminated. Thus, parametric analysis was inappropriate. Dummy Errors and Designation Errors were analyzed using the Binomial Test.

Number of Emitters Designated

ANOVA results for the number of emitters designated are listed in Table 27. The main effect of Emitter Density ($p < 0.001$) is the only significant effect.

TABLE 27
ANOVA Summary Table for Emitters Designated (Experiment 2)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	1057.61	96.15		
Display	1	32.00	32.00	1.46	0.252
Display x Subject	11	240.33	21.85		
Density	2	1085.19	542.60	15.17	< 0.001
Display x Subject	22	787.14	35.78		
Display x Density	2	2.58	1.29	0.16	0.854
Display x Density x Subject	22	179.08	8.14		
Total degrees of freedom	71				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Density ($\varepsilon = 0.68$), and Display x Density ($\varepsilon = 0.95$).

A graph of the differences among the three levels of Emitter Density is presented in Figure 33. Table 28 presents the results of the Newman-Keuls analysis on the main effect of Emitter Density. There is no significant difference between the Gulf and Armageddon levels. The number of emitters designated by participants was constrained in the Caribbean scenarios. On average, participants designated over 27 of the 28 possible emitters.

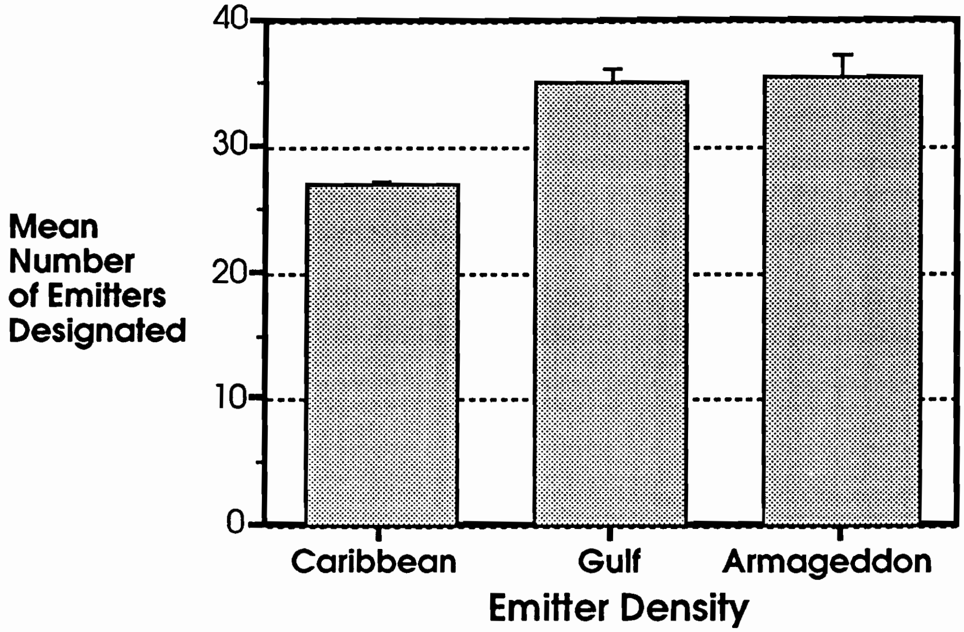

Figure 33. Main effect of Emitter Density on Emitters Designated (Experiment 2). Error bars represent +1 Standard Error of the Mean.

TABLE 28
Newman-Keuls Analysis of the Main Effect of Emitter Density on Emitters Designated (Experiment 2)

Emitter Density	*Standard Deviation*	*Standard Error of the Mean*	*Mean Number of Emitters*	
Caribbean	1.43	0.29	27.04	A
Gulf	5.21	1.06	35.08	B
Armageddon	8.41	1.72	35.46	B
Means with the same letter are not significantly different at $p = 0.05$				

Designation Time

An ANOVA was performed on Designation Time during the IT sessions and is presented in Table 29. The main effect of Emitter Density is significant ($p = 0.053$). The mean time to process an emitter is approximately equivalent to the total time for the session divided by the number of emitters processed. These results are compared to the results from Experiment 1 and reveal the same effect as the dependent variable Emitter Designations.

A graph of the main effect of Density is presented in Figure 34. The associated Newman-Keuls analysis reveals no significant differences ($p < 0.05$, Table 30).

TABLE 29
ANOVA Summary Table for Designation Time (Experiment 2)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	156.02	14.18		
Display	1	0.21	0.21	0.03	0.870
Display x Subject	11	84.02	7.64		
Density	2	18.34	9.17	3.90	0.053
Density x Subject	22	51.67	2.35		
Display x Density	2	1.23	0.62	0.27	0.664
Display x Density x Subject	22	50.66	2.3		
Total degrees of freedom	71				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Density ($\varepsilon = 0.72$), and Display x Density ($\varepsilon = 0.62$).

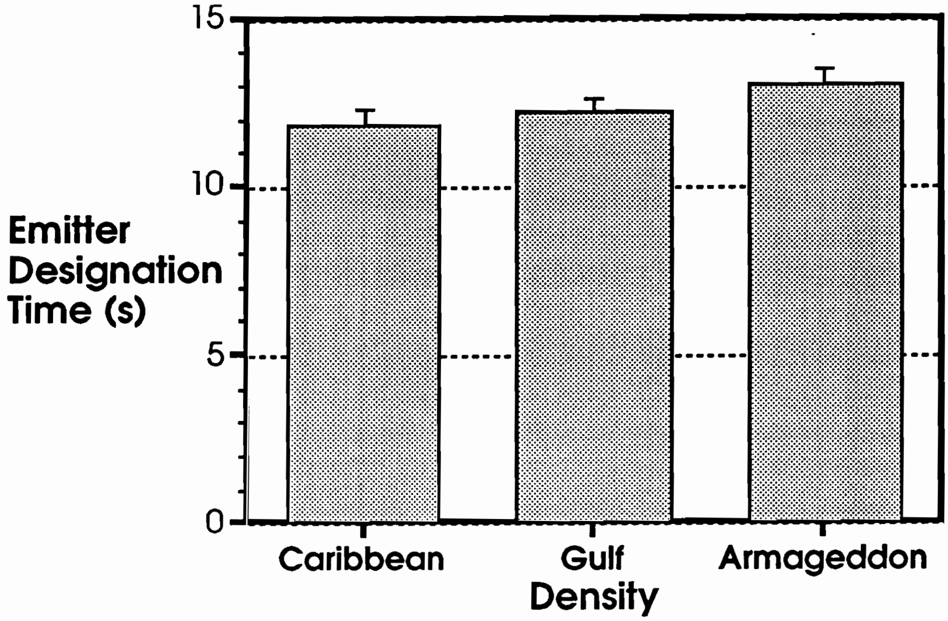

Figure 34. Main effect of Emitter Density on Designation Time (Experiment 2). Error bars represent +1 Standard Error of the Mean.

TABLE 30
Newman-Keuls Analysis of the Main Effect of Emitter Density on Designation Time (Experiment 2)

Emitter Density	*Standard Deviation*	*Standard Error of the Mean*	*Mean Designation Time (s)*	
Caribbean	2.54	0.52	11.79	A
Gulf	1.92	0.39	12.18	A
Armageddon	2.19	0.45	13.00	A
Means with the same letter are not significantly different at p = 0.05, n = 24				

Idle Time

ANOVA results for the amount of Idle Time are listed in Table 31. The main effect of Emitter Density ($p < 0.001$) is significant and is graphed in Figure 35. Table 32 presents the results of a Newman-Keuls test on the main effect of Emitter Density. Participants have significantly more idle time in the Caribbean scenario than in the Gulf or Armageddon scenarios. In fact, each level of density is significantly different from the other two ($p < 0.05$). The number of emitters designated by participants was constrained in the Caribbean scenarios, averaging over 27 of the 28 possible emitters.

TABLE 31
ANOVA Summary Table for Idle Time (Experiment 2)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	60981.22	5543.75		
Display	1	288.96	288.96	0.45	0.516
Display x Subject	11	7069.45	642.68		
Density	2	132647.55	66323.78	64.04	< 0.001
Density x Subject	22	22784.15	1035.64		
Display x Density	2	716.00	358.00	0.95	0.370
Display x Density x Subject	22	8259.07	375.41		
Total degrees of freedom	71				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Density ($\varepsilon = 0.83$), and Display x Density ($\varepsilon = 0.65$).

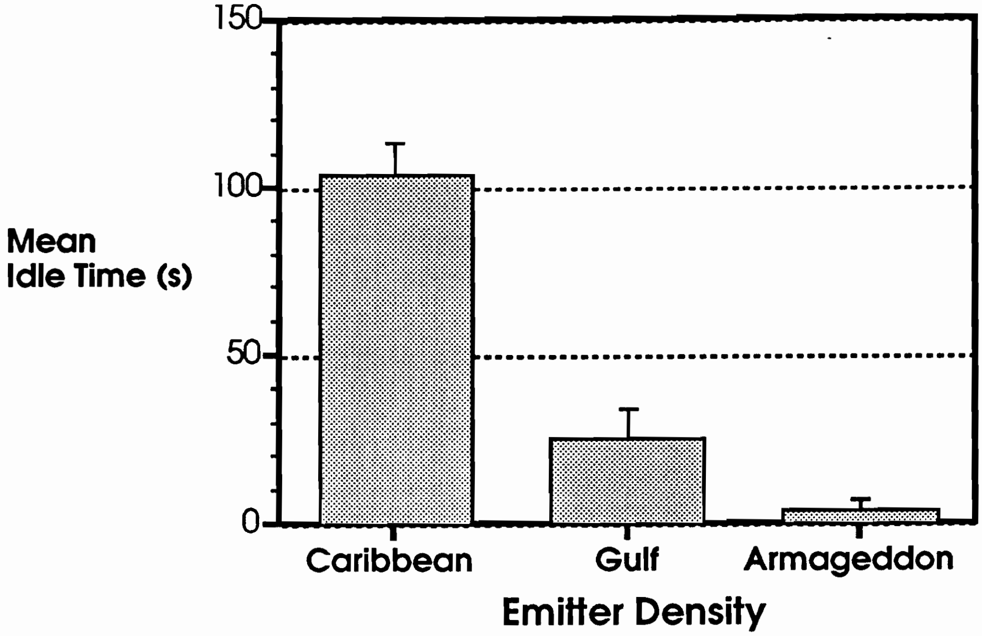

Figure 35. Main effect of Emitter Density on Idle Time (Experiment 2). Error bars represent +1 Standard Error of the Mean.

TABLE 32
Newman-Keuls Analysis of the Main Effect of Emitter Density on Idle Time (Experiment 2)

Emitter Density	*Standard Deviation*	*Standard Error of the Mean*	*Mean Idle Time (s)*	
Caribbean	48.30	9.86	103.39	A
Gulf	41.48	8.47	24.97	B
Armageddon	17.28	3.53	3.53	C
Means with the same letter are not significantly different at $p < 0.05$				

Dummy and Designation Errors

Operators of the DMI committed 1 Dummy Error in 1147 designations, while operators of the CKI committed 17 errors in 1195 designations. A Binomial comparison of Dummy Errors reveals that operators of the CKI commit significantly more dummy errors than when using the DMI ($p < 0.001$).This error rate reflects the number of incorrect key selections operators made in the 1195 designations. In all trials, only one selection error was made by an operator. Therefore, direct selection is less error prone than the command selection procedure.

Designation errors were also very few. Operators using the DMI committed 9 and 17 Designation Errors when using the DMI and CKI, respectively. A Binomial comparison of Designation Errors reveals that operators of the CKI commit significantly more designation errors than when using the DMI ($p = 0.01$). Thus, over the 72 trials, participants averaged about one error per two trials.

Performance

The results of an ANOVA for Performance are presented in Table 33. There are no significant effects. Since errors occur infrequently in the CKI and DMI and are weighted equally with Designation Time in the Performance score, the occurrence of one error can cause large fluctuations in the performance measure for that cell. Thus, the lower the error rate the more impact on the performance score. Thus, the problems caused by one or two errors when an operator is not expecting an error is greater than the problem of one additional error when many errors are expected.

TABLE 33
ANOVA Summary Table for Performance (Experiment 2)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	41472.52	3770.23		
Display	1	3971.57	3971.57	1.94	0.191
Display x Subject	11	22517.56	2047.05		
Density	2	1339.35	669.68	0.31	0.715
Density x Subject	22	47196.80	2145.31		
Display x Density	2	4507.92	2253.96	1.30	0.292
Display x Density x Subject	22	38203.95	1736.54		
Total degrees of freedom	71				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Density ($\varepsilon = 0.91$), and Display x Density ($\varepsilon = 0.84$).

Subjective Workload

The results of an ANOVA for subjective workload are presented in Table 34. The main effect of Density is significant at $p < 0.001$.

A graph of the main effect of Density is shown in Figure 36. A Newman-Keuls analysis shows that subjective workload increased for each increase in density ($p < 0.05$, Table 35).

TABLE 34
ANOVA Summary Table for Subjective Workload (Experiment 2)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	18554.20	1686.75		
Display	1	67.67	67.67	0.28	0.604
Display x Subject	11	2613.76	237.61		
Density	2	21053.44	10526.72	31.90	< 0.001
Density x Subject	22	7260.30	330.01		
Display x Density	2	184.93	92.47	0.53	0.578
Display x Density x Subject	22	3819.40	173.61		
Total degrees of freedom	71				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Density ($\varepsilon = 0.59$), and Display x Density ($\varepsilon = 0.91$).

TABLE 35
Newman-Keuls Analysis of the Main Effect of Emitter Density on Subjective Workload (Experiment 2)

Emitter Density	*Standard Deviation*	*Standard Error of the Mean*	*Subjective Workload*	
Caribbean	21.16	4.32	14.29	A
Gulf	18.68	3.81	27.46	B
Armageddon	24.83	5.07	55.31	C

Means with the same letter are not significantly different at $p < 0.05$, n = 24

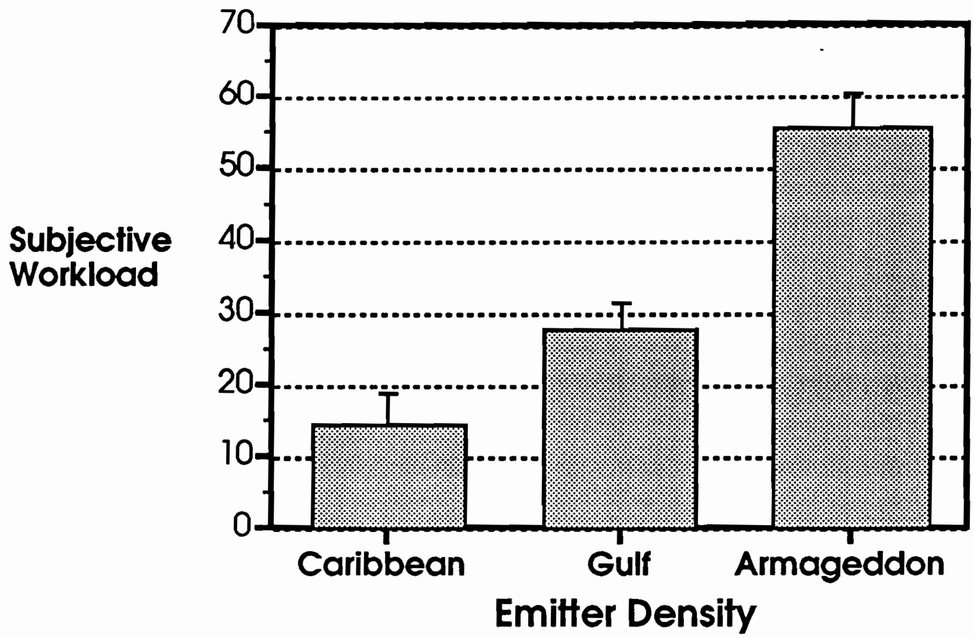

Figure 36. Main effect of Emitter Density on Subjective Workload (Experiment 2). Error bars represent +1 Standard Error of the Mean.

Discussion and Conclusions

Performance, Time, and Number of Designations

The analyses of Experiment 2 reveal no differences between the CKI and DMI with regard to performance, designation time, or the number of designations.

Error Rates

The levels of dummy and designation errors were very low. One design goal was to try to minimize errors when creating the CKI and DMI. In only 1 out of 1147 designations did an operator use the DMI to select a previously designated emitter. In the CKI, operators selected previously designed emitters 17 times (out of 1195 designations). This difference, although important, is mostly a nuisance to the operator and is not as critical as a designation error.

Operators using the DMI (9 errors) are less likely to make a designation error than when using the CKI (17 errors). Although the level of errors is less than 1 designation error per two trials, these errors can lead to taking counter measures against friendly aircraft. The direct-selection process allows operators to watch the interaction of their input into the system (the mouse click on the library entry to make a designation), while the user of the CKI must either touch type or look away from the display to choose the key corresponding to the library entry. The visual selection process with the DMI is less likely to cause an operator error.

Idle Time

Participants maintained a pace that allowed them to process emitters faster than the presentation of emitters in the Caribbean scenario. During this scenario, participants had over 100 seconds free during the approximately 450-second testing session. The testing sessions began as a 7-minute (420 second) session. However, as new emitters were presented, the computer added time to the session to compensate for locking operators out of enter inputs. Approximately 4.5 seconds were added to the total time of a Caribbean session for every new set of emitters. In total, participants were idle 22 percent of the time. For an operator wishing to do other tasks, this period of time occurs in blocks of approximately 15 seconds in this scenario. This is more free time than operators had during any of the sessions in Experiment 1, in which operators had zero idle time.

The Gulf scenario was more demanding, allowing only 25 seconds of total free time during each session. This amounted to a few seconds of free time at the end of every 30 seconds (new emitters appeared every 30 seconds).

The Armageddon scenario required the operator to always process emitters to keep up with the presentation of new emitters. With a mean of 35 emitters processed during each session, the average participant had 15 unprocessed emitters on the screen at the end of the session. During conditions of heavy emitter densities, no idle time is available to perform operations such as adding new emitters or launching chaff, without ignoring new emitters. Operators would have to delay or put aside other tasks to be able to process all emitters in the high density conditions. It is illogical to expect operators to work 100% of the time processing emitters. Therefore, some idle time should be available to the operator. Both the CKI and DMI are better than any of the versions tested in Experiment 1, since operators never had idle time in any condition in Experiment 1.

Subjective Workload

Subjective workload did not vary between the versions of the interface tested in Experiment 2. As the density of the tactical environment increases, participants are able to process emitters as fast as during low density conditions, even when reporting significant increases in workload.

One might have expected the CKI interface to have a higher level of subjective workload due to additional cognitive overhead needed to translate choices on the screen to keyboard entry. The DMI is known for being "direct," (i.e., it allows the operator to make decisions with a minimal amount of decision making). The results do not support this hypothesis. Comparisons between the versions tested in Experiments 1 and 2 may be more revealing (see "Subjective Workload," page 103).

Observational and Questionnaire Results

Observational and questionnaire data helped to determine why operators reported that they did not use the object display. The analysis of the object display is confounded with the addition of the direct and command interaction styles. Participants found it too time consuming to compare graphical objects when text information was available. One may conclude that the task was not sufficiently complex to require the operator to compare more than one or two variables at one time.

Operators mentioned that they found the object display too slow. Participants reported that the percentages of time using the object display were 1.3% and 5.3% for the CKI and DMI, respectively. From observation it appears participants only glanced at the object display for feedback. That is, when operators selected emitters for a library search or designated an emitter, the object display was updated to reflect user inputs. Thus, it provided a large target (relative to the size of an emitter listed in the Sequence List) to glance at and confirm whether the operator's input was processed. Note that the operators were not required to use the object display. They were shown how to use it and under what conditions it might provide a means of determining the emitter designation, but they had the option to use the object display, the library list, or both. As a percentage of time spent scanning the display, participants reported minimal time on the object display.

Overall, participants reported spending the most time in the Library, followed by the Signal Select and Sequence List areas of the display (Figure 37). Dyess (1992) performed a resource allocation analysis of the operator while using the AN/SLQ-32(V) to designate emitters (Table 36). A comparison between the subjective results found in the questionnaire and those reported by Dyess show an increase in the time spent on the Signal Select function. Without the Signal Select information, designation was very difficult when more than one emitter appeared in the library. Part of the reduction of time spent in the library (i.e., the electronic publications) can be attributed to the computer-assisted search algorithms. In the publications, it is the responsibility of the operator to determine how to search through thousands of possible emitters. In the redesigns, the library's CAIS narrows the search to a few possible emitters. The percentage of time for Signal Select increases, but the time required for this action decreases. The time operators spend using each portion of the interface is useful for optimizing the allocation of screen space, location, and accessibility.

TABLE 36
EW Operator Attentional Resource Allocation (Adapted from Dyess, 1992)

Area of EW Work Space	Tasks in Experiment 2	Percent of Operator's time with AN/SLQ-32(V)
AN/SLQ-32(V) CRT Screen/ DCC	Range Display/Sequence List	20
O-Scope/ Listen to Audio Signal	Listen to Audio Signal	6
ULQ-16	ULQ-16	11
Publications	On-line Library/Object Display	63

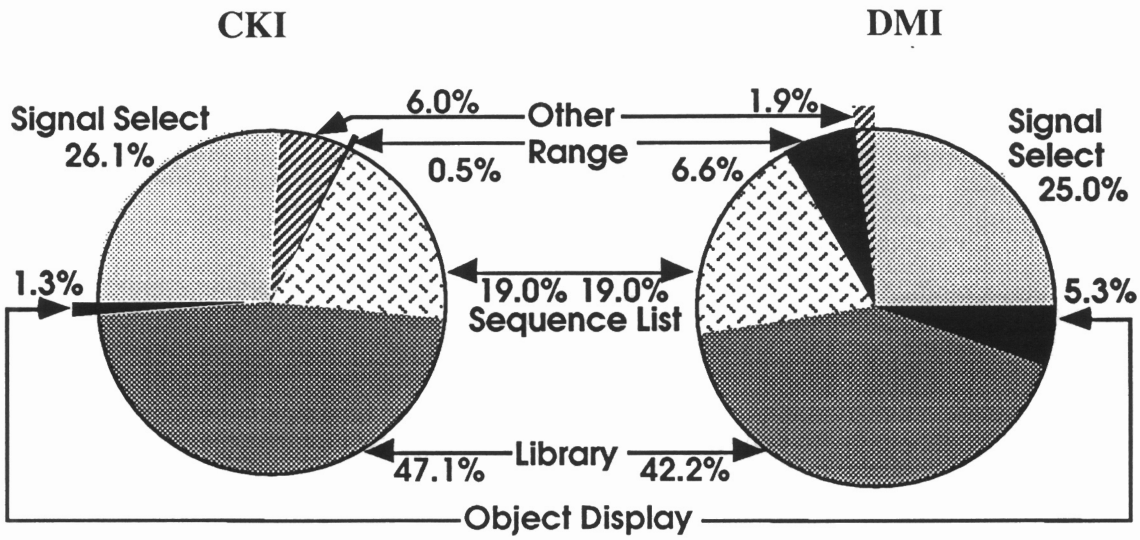

Figure 37. Comparison of the percentage of time spent in each area of the CKI and DMI. Percentages are self-reported

Subjective Ratings

Figure 38 shows the participants' ratings of the two Experiment 2 interfaces on four bipolar scales (a numeric scale from 1 to 7 anchored by two semantically opposite terms). Comments focused on how the system responded to user actions. Due to the simulation software, participants had a difficult time double clicking and shift-selecting. Although operators were trained on the software to minimize the occurrence of problems, the participants were accustomed to commercial software that responded differently to similar actions. Therefore, the participants expected the AN/SLQ-32(V) simulation software to act in a fashion similar to the commercial software to which they were accustomed and were unable to overcome this bias during the training session.

The analysis of the subjective judgments from the questionnaire showed seven participants preferred the CKI and five preferred the DMI. While seven felt they made more mistakes with the DMI, five thought they made more mistakes with the CKI.

Although participants are college students, and the target population is Navy personnel, all are computer users. Navy EW operators use PC-based software during training, to write reports, and for fun. Thus, it behooves designers to consider operators' knowledge, skills, and abilities acquired from their use of other computer systems.

Comparing the Interfaces of Experiments 1 and 2

The results from Experiment 2 show very little difference between the CKI and DMI. It may be of interest to the reader to see how these versions compare to some of the versions tested in Experiment 1. In Experiment 1 it was concluded that the addition of range

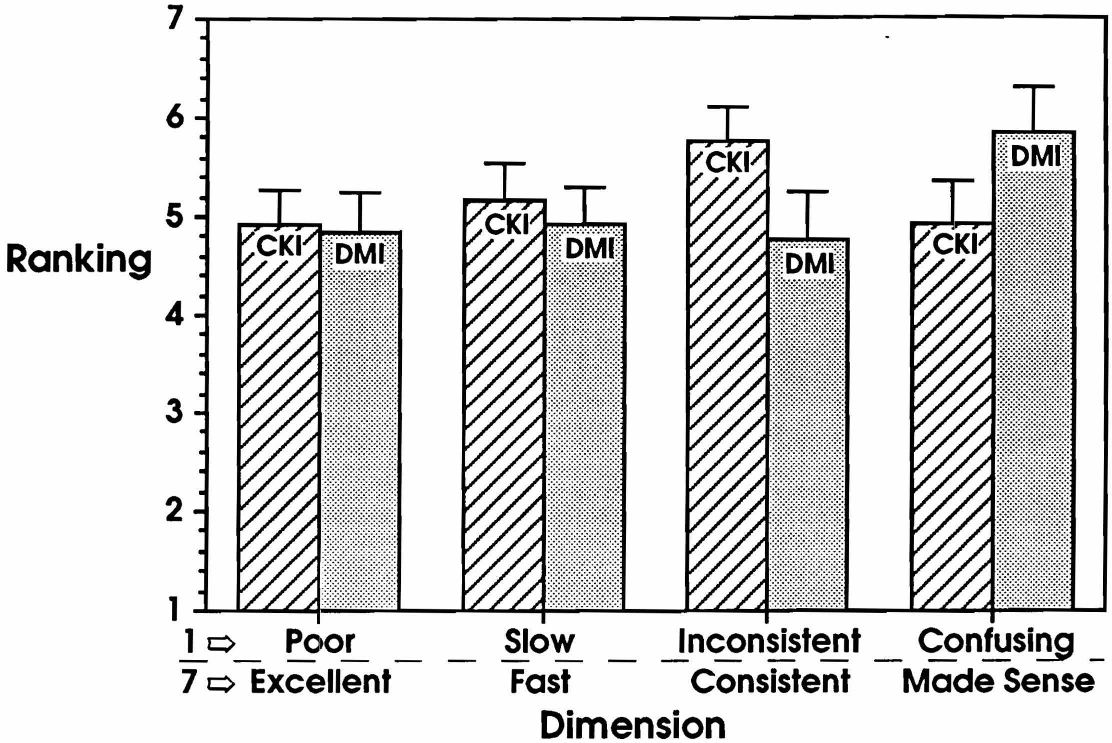

Figure 38. Comparison of bipolar question ratings for Experiment 2. Error bars represent +1 Standard Error of the mean (n = 12).

information, color, and NATO icons improved performance over the Baseline condition. The versions tested in Experiment 1 were tested because it is possible to implement them with "minimal" redesign of the existing AN/SLQ-32(V), minimal in the sense that the changes would not require replacing the system. Experiment 2 tested how redesigning the display interface may improve the operator's ability to detect and identify emitters. With this in mind, a comparison among the Baseline, Range/Color/NATO Iconic versions, and the CKI and DMI will reveal how performance measures vary across the interfaces.

SUBJECTIVE AND COMPARATIVE RESULTS

Introduction

The results of Experiments 1 and 2 were combined to compare the Baseline interface to the CKI and DMI. Since the Range/Color/NATO Iconic version (also referred to as the R/C/N) used in Experiment 1 was determined to contain interface elements known to improve performance and decrease subjective workload, it also is compared to the Baseline, CKI, and DMI display formats. This analysis was performed for the following measures: emitter designation time, number of emitters designated, designation errors, dummy errors, the composite performance measure, and subjective workload (see "Dependent Variables," page 69).

Results

Emitter Designation Time

The results of the ANOVA on emitter designation time are presented in Table 37. The main effects of Display Format ($p < 0.001$) and Emitter Density ($p < 0.001$) are significant, as is the Display Format by Emitter Density ($p = 0.063$) interactive effect.

A graph of the main effect of Display Format on the emitter designation time is presented in Figure 39. The associated Newman-Keuls analysis reveals that designation time is significantly less ($p < 0.05$) for the Command-Key and Direct-Manipulation interfaces than for either the Baseline or Range/Color/NATO Iconic formats of the interface (Table 38).

The main effect of Emitter Density on emitter designation time is presented in Figure 40. The Newman-Keuls analysis for Emitter Density is presented in Table 39. The comparison of emitter designation time reveals that participants designation times are significantly larger ($p < 0.05$) for the Armageddon density level than for the Gulf and Caribbean density levels.

A graph of the effect of Display Format by Emitter Density is shown in Figure 41. The results of a simple-effects F-test are shown in Table 40. Participants time to designate an emitter significantly increases as density increases in the Baseline condition ($p < 0.001$). A Newman-Keuls analysis of the Baseline format reveals the differences between the Caribbean and other density levels are significantly different ($p < 0.05$, Table 41).

TABLE 37
ANOVA Summary Table for Emitter Designation Time (Experiments 1 & 2 Comparisons)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	1076.98	97.97		
Format	3	6220.83	2073.61	68.54	0.001
Format x Subject	33	998.37	30.25		
Density	2	128.45	64.23	11.55	0.001
Density x Subject	22	122.38	5.56		
Format x Density	6	72.16	12.03	2.39	0.063
Format x Density x Subject	66	331.49	5.02		
Total degrees of freedom	143				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Display Format ($\varepsilon = 0.59$), Density ($\varepsilon = 0.80$), and Display Format x Density ($\varepsilon = 0.68$)

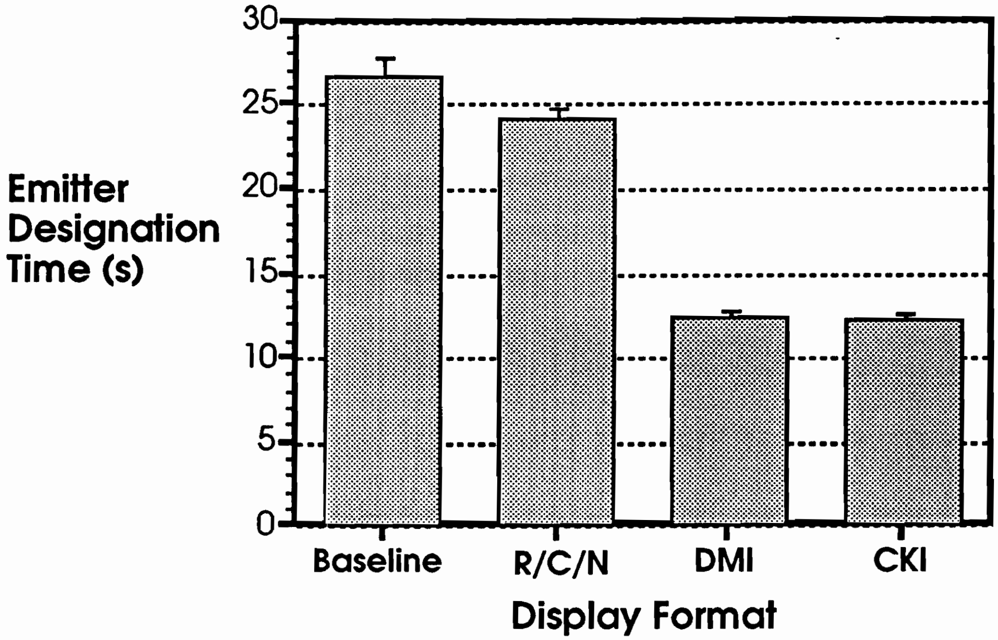

Figure 39. Main effect of Display Format on Emitter Designation Time (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 38
Newman-Keuls Analysis of the Main Effect of Display Format on Emitter Designation Time (Experiments 1 & 2 Comparisons)

Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Emitter Designation Time (s)*	
Baseline	36	7.26	1.21	26.57	A
Range/Color/NATO Iconic	36	3.87	0.64	24.14	A
Direct-Manipulation	36	2.33	0.39	12.38	B
Command-Key	36	2.22	0.37	12.27	B
Means with the same letter are not significantly different at $p < 0.05$					

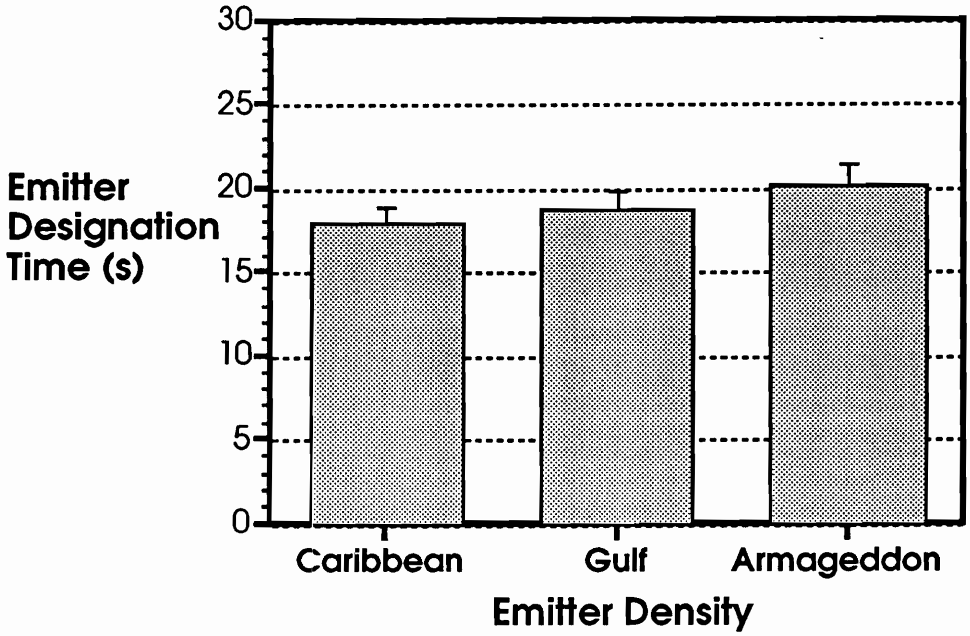

Figure 40. Main effect of Emitter Density on Emitter Designation Time (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 39
Newman-Keuls Analysis of the Main Effect of Emitter Density on Emitter Designation Time (Experiments 1 & 2 Comparisons)

Emitter Density	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Emitter Designation Time (s)*	
Caribbean	48	7.13	1.03	17.81	A
Gulf	48	7.85	1.13	18.62	A
Armageddon	48	8.68	1.25	20.09	B
Means with the same letter are not significantly different at $p < 0.05$					

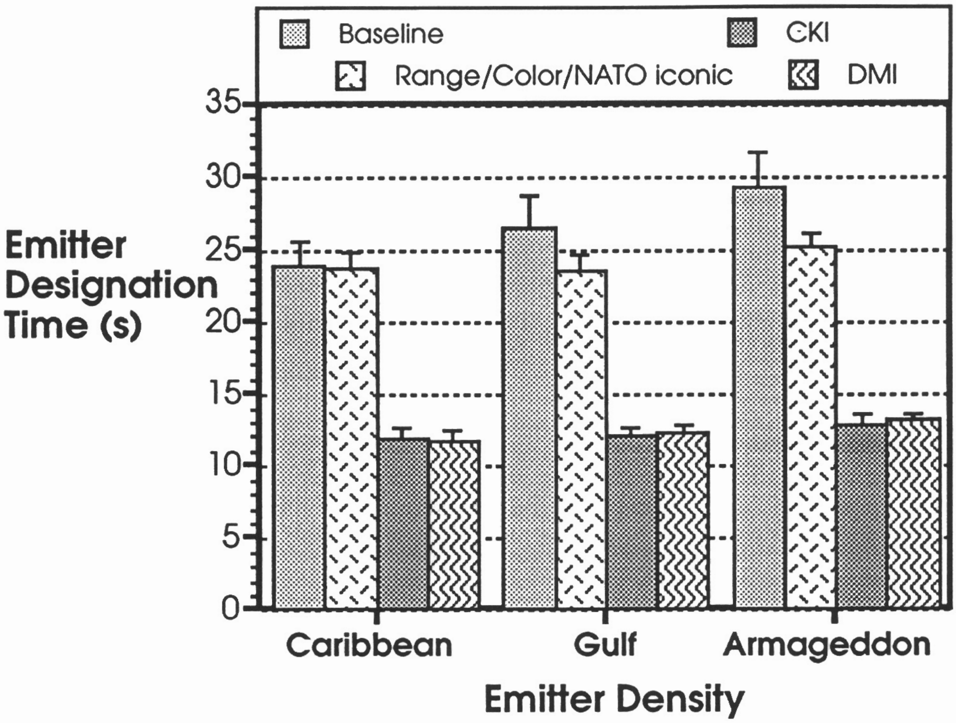

Figure 41. The effect of Display Format by Emitter Density on Emitter Designation Time (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 40
Simple-Effects F-test of Emitter Density within Display Format on Emitters Designation Time (Experiments 1 & 2 Comparisons)

Source	*df*	*e*	*MS*	*F*	*p*	*p adj.*
Baseline	2	0.985	81.05	16.15	< 0.001	< 0.001*
Range/Color/NATO Iconic	2	0.890	9.47	1.89	0.159	
Command-Key	2	0.668	3.30	0.66	0.520	
Direct-Manipulation	2	0.554	6.49	1.29	0.282	
Format x Density x Subject	66		5.02			

**p reflects F-tests that were adjusted with* the *Geisser-Greenhouse maximal correction* $F_{0.05}$ *[1,44].*

TABLE 41
Newman-Keuls Analysis of the Effect of Emitter Density within the Baseline Display Format on Emitter Designation Time (Experiments 1 & 2 Comparisons)

Emitter Density within Baseline Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Emitter Designation Time (s)*	
Caribbean	12	8.45	2.44	29.20	A
Gulf	12	7.42	2.14	26.51	B
Armageddon	12	5.15	1.49	24.00	C
Means with the same letter are not significantly different at $p < 0.05$					

Number of Emitters Designated

The results of an ANOVA on the number of emitters designated are presented in Table 42. The main effects of Display Format ($p < 0.001$) and Emitter Density ($p = 0.001$) is significant, as is the Display Format by Emitter Density ($p < 0.001$) interactive effect. Note that many operators completed processing all possible emitters in the Caribbean condition when using the CKI and DMI. Thus, a ceiling effect will conservatively bias the results in favor of the Baseline and Range/Color/NATO Iconic formats.

A graph of the main effect of Display Format is presented in Figure 42. A Newman-Keuls analysis shows that participants designated significantly more emitters when working with the CKI and DMI than with the Baseline or Range/Color/NATO Iconic interfaces ($p < 0.05$, Table 43).

A graph of the main effect of Emitter Density on mean number of emitters designated is presented in Figure 43. The associated Newman-Keuls comparison across Emitter Density shows that participants designated significantly fewer emitters for the Caribbean density level than for the Gulf and Armageddon density levels ($p < 0.05$, Table 44).

The graph of the effect of Display Format by Emitter Density on the number of emitters designated is shown in Figure 44. The results of the simple-effects F-tests of Display Format and Emitter Density are shown in Table 45. The effect of the CKI ($p < 0.001$), and DMI ($p < 0.001$) format by Emitter Density are significantly larger than for the Baseline and Range/Color/NATO Iconic display formats.

A Newman-Keuls analysis of the effect of Emitter Density for the CKI and DMI Display Formats shows that operators designate fewer emitters in the Caribbean level (Tables 46 and 47, respectively). Due to the increase in the number of emitters designated by operators, a ceiling effect occurred. There are only 28 possible emitters in the Caribbean condition.

TABLE 42
ANOVA Summary Table for Number of Emitters Designated (Experiments 1 & 2 Comparisons)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	1243.91	113.08		
Format	3	11460.91	3820.30	164.72	< 0.001
Format x Subject	33	765.34	23.19		
Density	2	446.06	223.03	11.92	0.001
Density x Subject	22	411.78	18.72		
Format x Density	6	669.28	111.55	11.12	< 0.001
Format x Density x Subject	66	662.22	10.03		
Total degrees of freedom	143				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Display Format ($\varepsilon = 0.80$), Density ($\varepsilon = 0.76$), and Display Format x Density ($\varepsilon = 0.37$).

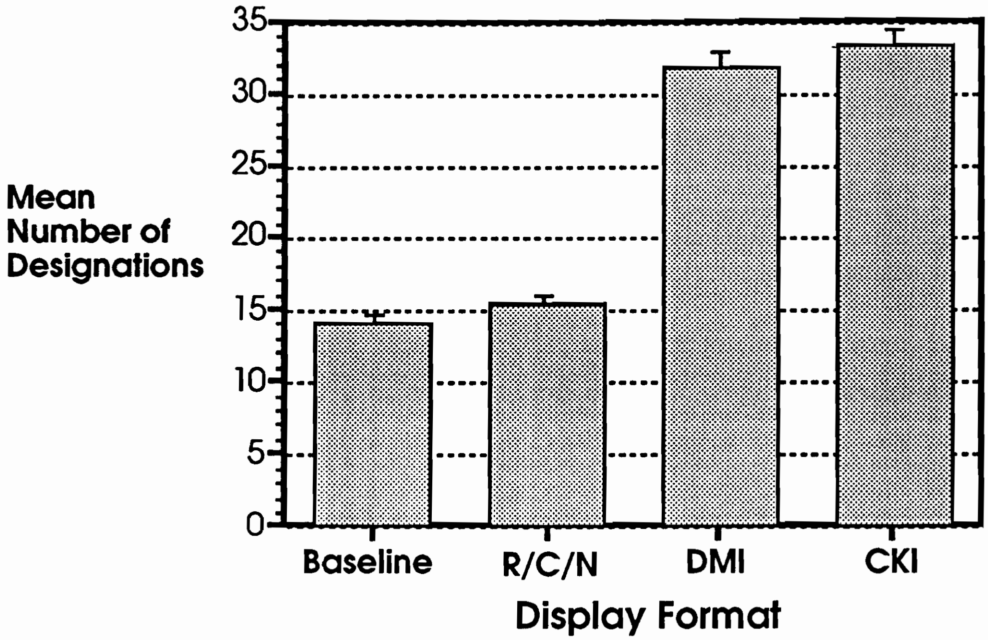

Figure 42. Main effect of Display Format on Number Emitters Designated (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 43
Newman-Keuls Analysis of the Main Effect of Display Format on Emitters Designated (Experiments 1 & 2 Comparisons)

Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Emitter Designations*	
Baseline	36	3.82	0.64	14.06	A
Range/Color/NATO Iconic	36	3.09	0.52	15.42	A
Direct-Manipulation	36	6.23	1.04	31.86	B
Command-Key	36	7.54	1.26	33.19	B
Means with the same letter are not significantly different at $p < 0.05$					

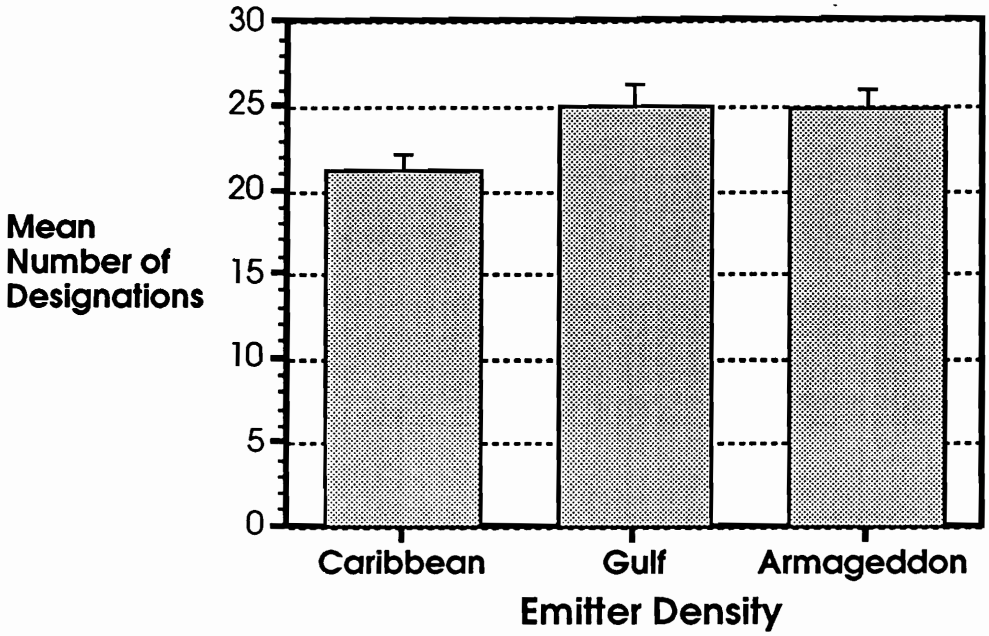

Figure 43. Main effect of Emitter Density on Number of Emitters Designated (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 44
Newman-Keuls Analysis of the Main Effect of Emitter Density on Emitters Designated (Experiments 1 & 2 Comparisons)

Emitter Density	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Number of Designations*	
Caribbean	48	6.58	0.95	21.15	A
Armageddon	48	12.51	1.81	24.77	B
Gulf	48	11.13	1.61	24.98	B
Means with the same letter are not significantly different at $p < 0.05$					

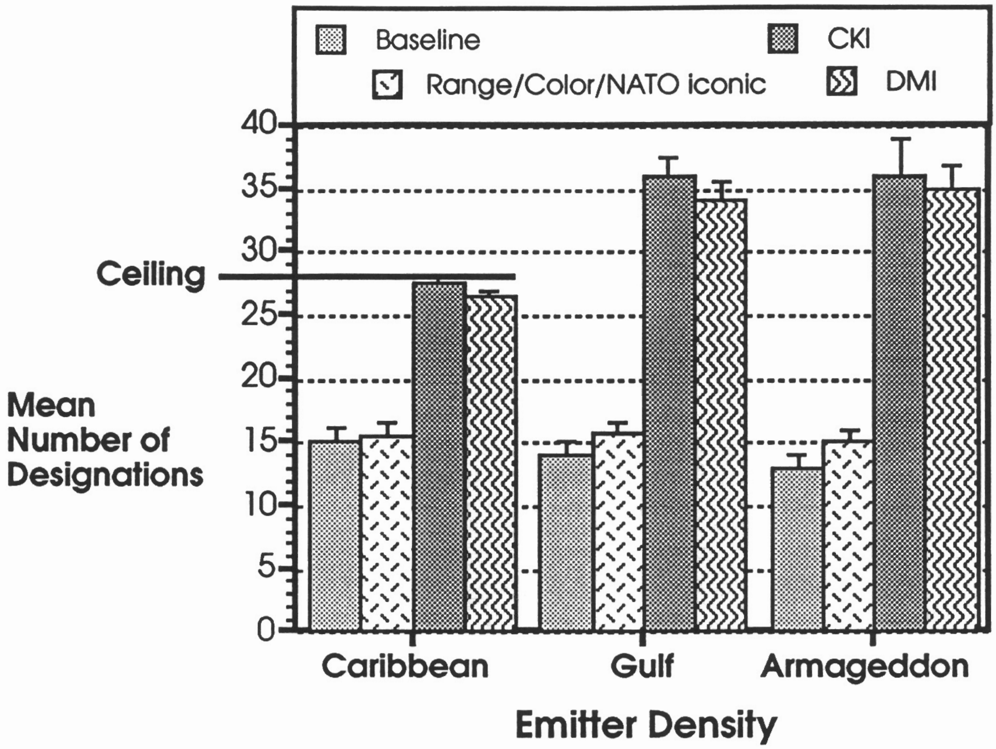

Figure 44. The effect of Display Format by Emitter Density on Emitters Designated (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean. The ceiling represents the maximum number of possible designations in the Caribbean condition.

TABLE 45
Simple-Effects F-test of Emitter Density within Display Format on Emitters Designated (Experiments 1 & 2 Comparisons)

Source	*df*	*ε*	*MS*	*F*	*p*	*p adj.*
Baseline	2	0.978	13.03	1.30	0.279	
Range/Color/NATO Iconic	2	0.942	0.75	0.07	0.933	
Command-Key	2	0.704	291.86	29.10	< 0.001	< 0.001*
Direct-Manipulation	2	0.759	252.03	25.13	< 0.001	< 0.001*
Display Format x Density x Subject	66		10.03			

****p* reflects *F*-tests that were adjusted with** the ***Geisser-Greenhouse maximal correction*** $F_{0.05}$ ***[1,33].***

TABLE 46
Newman-Keuls Analysis of the Effect of Emitter Density within the CKI Display Format on Emitters Designated (Experiments 1 & 2 Comparisons)

Emitter Density within CKI Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Emitter Designations*	
Caribbean	12	1.00	0.29	27.00	A
Gulf	12	5.41	1.56	36.00	B
Armageddon	12	9.89	2.85	36.08	B
Means with the same letter are not significantly different at $p < 0.05$					

TABLE 47
Newman-Keuls Analysis of the Effect of Emitter Density within the DMI Display Format on Emitters Designated (Experiments 1 & 2 Comparisons)

Emitter Density within DMI Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Emitter Designations*	
Caribbean	12	1.68	0.48	26.58	A
Gulf	12	5.06	1.46	34.17	B
Armageddon	12	7.03	2.03	34.83	B
Means with the same letter are not significantly different at $p < 0.05$					

Designation Errors

Designation errors for all 12 subjects and three density conditions (i.e., 36 trials per Display Format) for the Baseline, Range/Color/NATO Iconic, Command-Key, and Direct-Manipulation interfaces were 15, 15, 17, and 9, respectively. A Binomial analysis on the number of designation errors for each version is shown in Table 48. The CKI ($p < 0.001$) and DMI ($p < 0.001$) have significantly fewer errors than expected. Thus, operator errors are reduced by the CKI and DMIs.

Dummy Errors

The results of the ANOVA for the number of dummy errors committed during the IT sessions are presented in Table 49. The main effects of Display Format ($p < 0.001$) and Emitter Density ($p < 0.001$) are significant, as is the Display Format by Emitter Density ($p < 0.001$) interactive effect.

TABLE 48
Binomial Summary Table for Designation Errors (Combination of Experiment 1 & 2)

Source	*Total Number of Designations*	*Observed x (Total Number of Designation Errors)*	*Expected x †*	*NPQ ‡*	*Z*
Baseline	506	15	15		
Range/Color/NATO Iconic	555	15	16.46	15.97	- 0.49
CKI	1195	17	35.43	34.38	- 3.23*
DMI	1146	9	34.01	33.00	- 4.44*

* Significant at $p < 0.001$

† Expected frequency is based on the probability of a designation error in the Baseline multiplied by the number of observations in the Source (For Baseline: 15 errors per 506 observations, $P = 0.0297$).

‡ With an NPQ > 9, the sampling distribution of x is approximately normal and z is computed from $z = x - NP/\text{Sqrt}(NPQ)$. x is the number of Designation Errors, N is the number of observations, P is the probability of a Designation Error, $Q = 1 - P$.

TABLE 49
ANOVA Summary Table for Dummy Errors (Experiments 1 & 2 Comparisons)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	130.72	11.88		
Format	3	1778.22	592.74	60.44	< 0.001
Format x Subject	33	323.61	9.81		
Density	2	109.60	54.80	14.78	< 0.001
Density x Subject	22	81.57	3.71		
Format x Density	6	333.40	55.57	16.92	< 0.001
Format x Density x Subject	66	216.76	3.28		
Total degrees of freedom	143				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Display Format ($\varepsilon = 0.41$), Density ($\varepsilon = 0.62$), and Display Format x Density ($\varepsilon = 0.36$).

A graph of the main effect of Display Format is presented in Figure 45. A Newman-Keuls comparison across Display Format is presented in Table 50. The comparison of the number of dummy errors reveals each format is significantly different from all others. Dummy errors are virtually eliminated in the Direct-Manipulation interface.

A graph of main effect of Emitter Density is presented in Figure 46. The associated Newman-Keuls comparison across Emitter Density is presented in Table 51. The comparison of dummy errors reveals that participants make significantly more errors for each increase in density ($p < 0.05$).

The results of the simple-effects F-test of Emitter Density within Display Format is shown in Table 52. The effect of the Baseline Display Format is significant ($p < 0.001$). The graph of the interactive effect of Display Format and Emitter Density is presented in Figure 47. A Newman-Keuls analysis shows that each Emitter Density level is significantly different from every other level for the Baseline format ($p < 0.05$, Table 53).

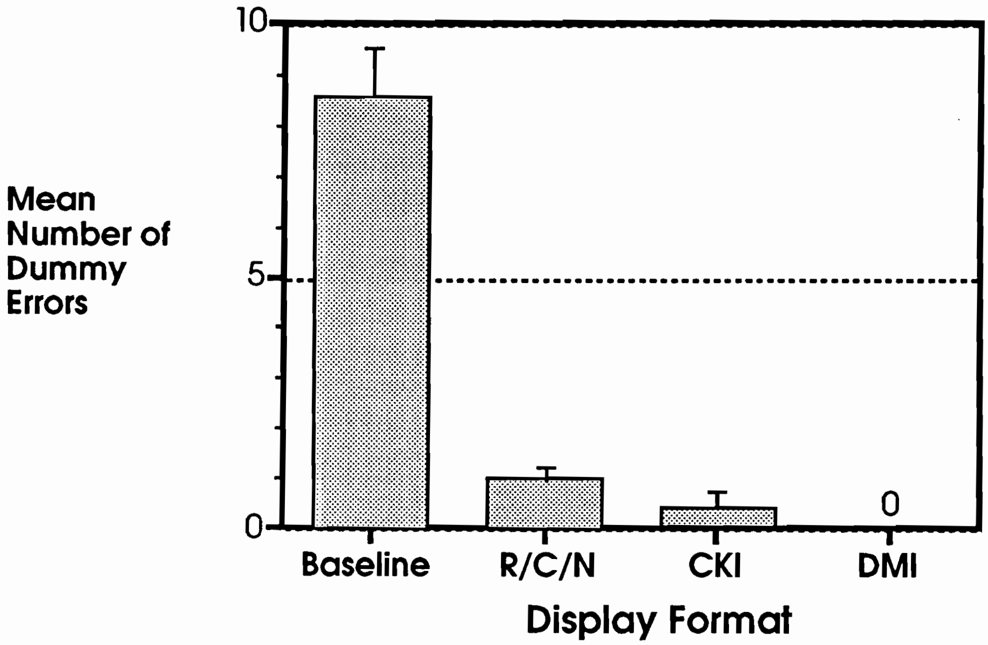

Figure 45. Main effect of Display Format on Dummy Errors (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 50
Newman-Keuls Analysis of the Main Effect of Display Format on Dummy Errors (Experiments 1 & 2 Comparisons)

Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Number Dummy Errors*	
Baseline	36	5.48	0.91	8.58	A
Range/Color/NATO Iconic	36	1.23	0.21	1.03	B
Command-Key	36	1.59	0.27	0.47	C
Direct-Manipulation	36	0.17	0.03	0.03	D
Means with the same letter are not significantly different at $p < 0.05$					

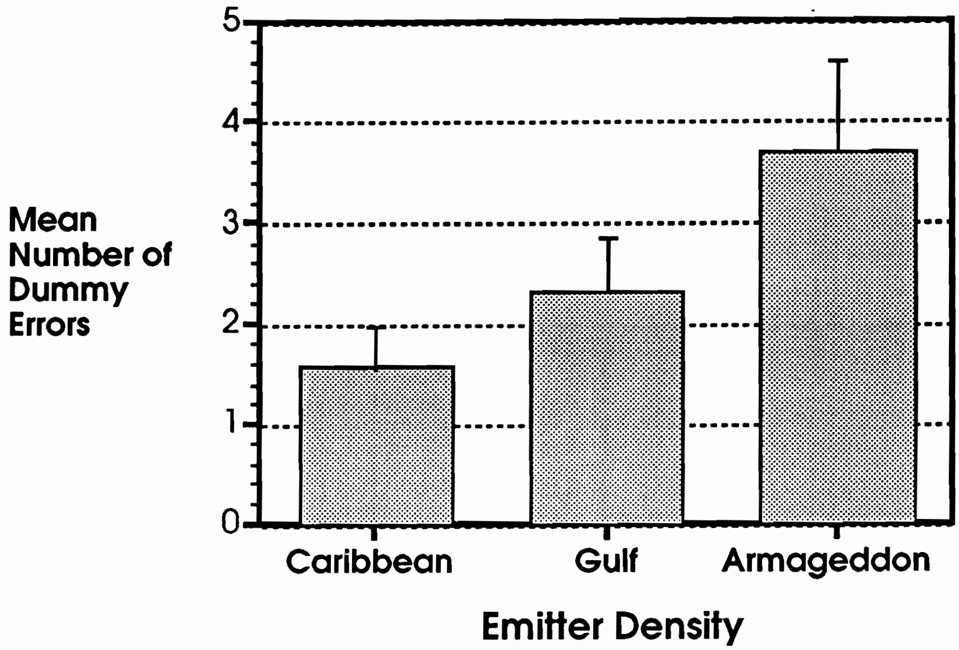

Figure 46. Main effect of Emitter Density on Dummy Errors (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 51
Newman-Keuls Analysis of the Main Effect of Emitter Density on Dummy Errors (Experiments 1 & 2 Comparisons)

Emitter Density	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Number Dummy Errors*	
Caribbean	48	2.70	0.39	1.58	A
Gulf	48	3.71	0.54	2.31	B
Armageddon	48	6.31	0.91	3.69	C
Means with the same letter are not significantly different at $p < 0.05$					

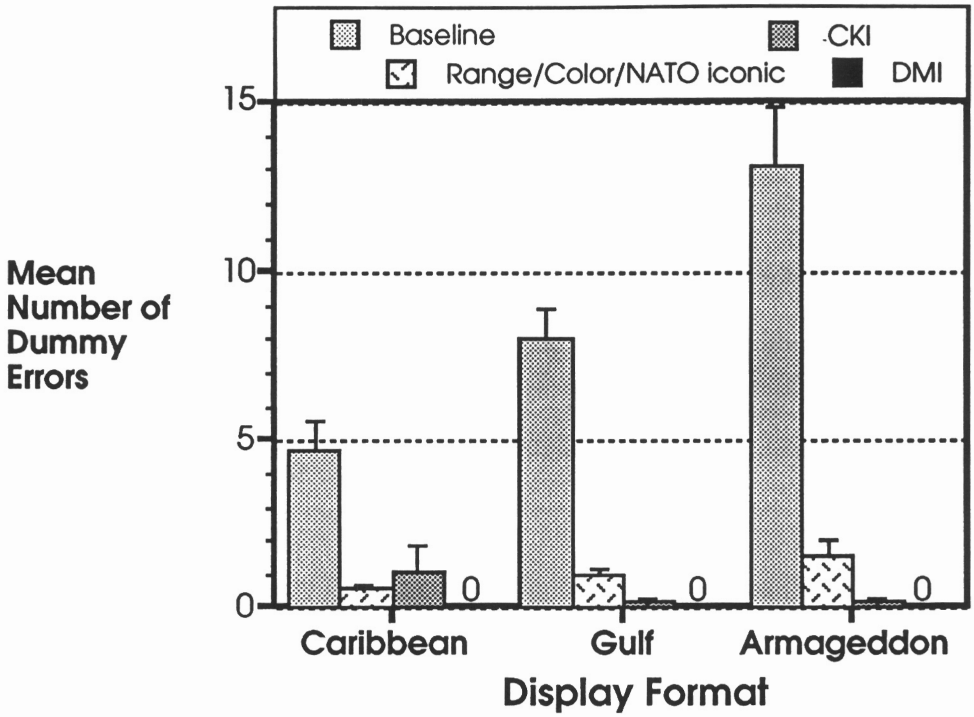

Figure 47. The effect of Emitter Density and Display Format on Dummy Errors (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 52
Simple-Effects F-test of the Effect of Display Format within Emitter Density on Dummy Errors (Experiments 1 & 2 Comparisons)

Display Format within Emitter Density	*df*	*ε*	*MS*	*F*	*p*	*p adj.*
Baseline	2	0.64	215.58	65.73	< 0.001	< 0.001*
Range/Color/NATO Iconic	2	0.67	2.53	0.77	0.467	
Command-Key	2	0.55	3.36	1.02	0.364	
Direct-Manipulation	2	0.50	0.03	0.01	0.992	
Format x Density x Subject	66		3.28			

****p* reflects F-tests that were adjusted with the Geisser-Greenhouse maximal correction $F_{0.05}$ [1,33].***

TABLE 53
Newman-Keuls Analysis of the Effect of Emitter Density Within the Baseline Display Format on Dummy Errors (Experiments 1 & 2 Comparisons)

Emitter Density within Baseline Level	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Dummy Errors*	
Caribbean	12	3.03	0.87	4.67	A
Gulf	12	3.22	0.93	8.00	B
Armageddon	12	6.08	1.76	13.08	C
Means with the same letter are not significantly different at $p < 0.05$					

Performance Measure

The results of an ANOVA conducted for the performance measure are presented in Table 54. The main effects of Display Format ($p < 0.001$) and Emitter Density ($p = 0.076$) are significant.

TABLE 54
ANOVA Summary Table for Performance (Experiments 1 & 2 Comparisons)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	172406.94	15673.36		
Format	3	3627752.23	1209250.74	117.86	< 0.001
Format x Subject	33	338593.48	10260.41		
Density	2	40259.92	20129.96	3.23	0.076
Density x Subject	22	137287.24	6240.33		
Format x Density	6	28960.69	4826.78	1.00	0.393
Format x Density x Subject	66	317503.45	4810.66		
Total degrees of freedom	143				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Display Format ($\varepsilon = 0.67$), Density ($\varepsilon = 0.76$), and Display Format x Density ($\varepsilon = 0.40$).

The graph of Display Format on the performance measure is presented in Figure 48. The associated Newman-Keuls comparison across Display Format is presented in Table 55. Performance is significantly lower for the Baseline interface ($p < 0.05$). Performance with the Range/Color/NATO Iconic interface is significantly higher than with the Baseline interface, but lower than with either the CKI or the DMI ($p < 0.05$).

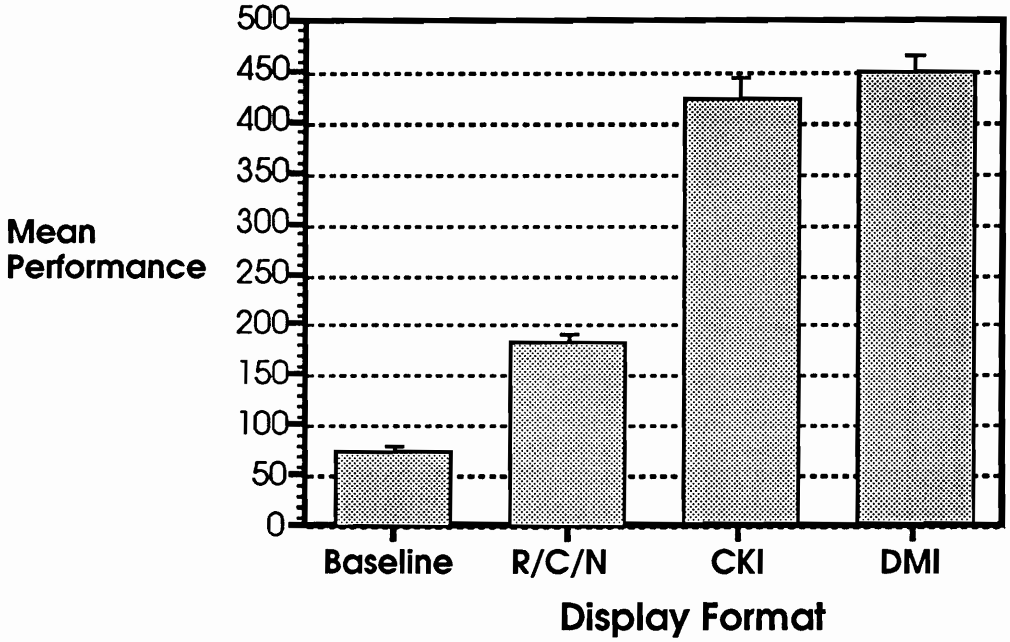

Figure 48. Main effect of Display Format on Performance (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 55
Newman-Keuls Analysis of the Main Effect of Display Format on Performance (Experiments 1 & 2 Comparisons)

Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Performance Score*	
Baseline	36	39.21	6.53	74.78	A
Range/Color/NATO Iconic	36	47.48	7.91	183.19	B
Command-Key	36	128.60	21.43	423.11	C
Direct-Manipulation	36	96.14	16.02	449.80	C
Means with the same letter are not significantly different at $p < 0.05$					

A graph of the main effect of Emitter Density on the performance measure is presented in Figure 49. The associated Newman-Keuls comparison across Emitter Density is presented in Table 56. Performance is higher in the Caribbean than in the Armageddon density condition ($p < 0.05$).

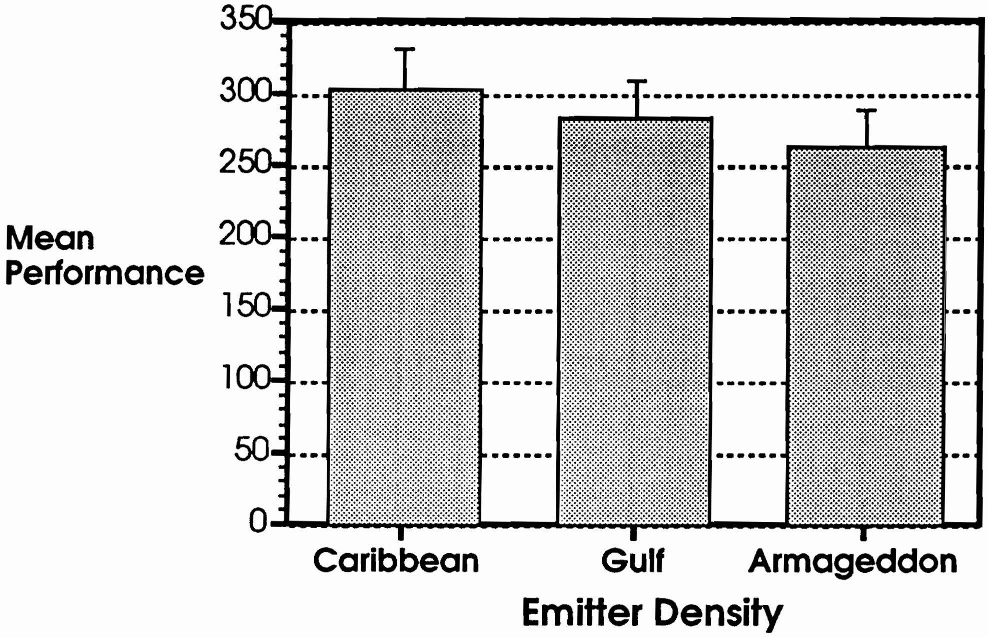

Figure 49. Main effect of Emitter Density on Performance (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 56
Newman-Keuls Analysis of the Main Effect of Emitter Density on Performance (Experiments 1 & 2 Comparisons)

Emitter Density	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Performance Score*	
Caribbean	48	185.40	26.76	303.09	A
Gulf	48	179.61	25.92	282.94	AB
Armageddon	48	178.10	25.71	262.13	B
Means with the same letter are not significantly different at $p < 0.05$					

Subjective Workload

The results of an ANOVA conducted for subjective workload are presented in Table 57. The main effect of Display Format ($p < 0.001$) and Emitter Density ($p < 0.001$) are significant, as is the Display Format by Emitter Density ($p = 0.002$) interactive effect.

TABLE 57
ANOVA Summary Table for Subjective Workload (Experiments 1 & 2 Comparisons)

Source	*df*	*Sums of Squares*	*MS*	*F*	*p*
Subject	11	35027.40	3184.31		
Format	3	17637.81	5879.27	16.83	< 0.001
Format x Subject	33	11528.37	349.34		
Density	2	21772.94	10886.47	17.27	< 0.001
Density x Subject	22	13867.51	630.34		
Format x Density	6	4030.69	671.78	4.65	0.002
Format x Density x Subject	66	9544.12	144.61		
Total degrees of freedom	143				

F-tests involving a df greater than 1 were corrected for sphericity using the Geisser and Greenhouse (1959) adjustment procedure. Tabulated probabilities reflect the adjusted F-tests. The correction was applied to Display Format ($\varepsilon = 0.89$), Density ($\varepsilon = 0.63$), and Display Format x Density ($\varepsilon = 0.74$).

A graph of the main effect of Display Format is presented in Figure 50. The associated Newman-Keuls comparison is presented in Table 58. The comparison of subjective workload reveals that participants experienced lower levels of workload ($p < 0.05$) for both the Command-Key and Direct-Manipulation interfaces than either the Baseline or Range/Color/NATO Iconic interfaces.

A graph of the main effect of Emitter Density is presented in Figure 51. The associated Newman-Keuls comparison is presented in Table 59. The comparison of subjective workload reveals that subjective workload increased ($p < 0.05$) for each increase in the density level.

The results of a simple-effects F-test for Display Format by Emitter Density are presented in Table 60. A graph of the effect of Display Format by Emitter Density is shown in Figure 52. The simple effects of Format for the Caribbean and Gulf densities is significant ($p < 0.01$). Newman-Keuls analysis for the Caribbean and Gulf Emitter densities show that both the Baseline and Range/Color/NATO Iconic formats are significantly different from both the CKI and DMI display formats ($p < 0.05$, Tables 61 and 62, respectively).

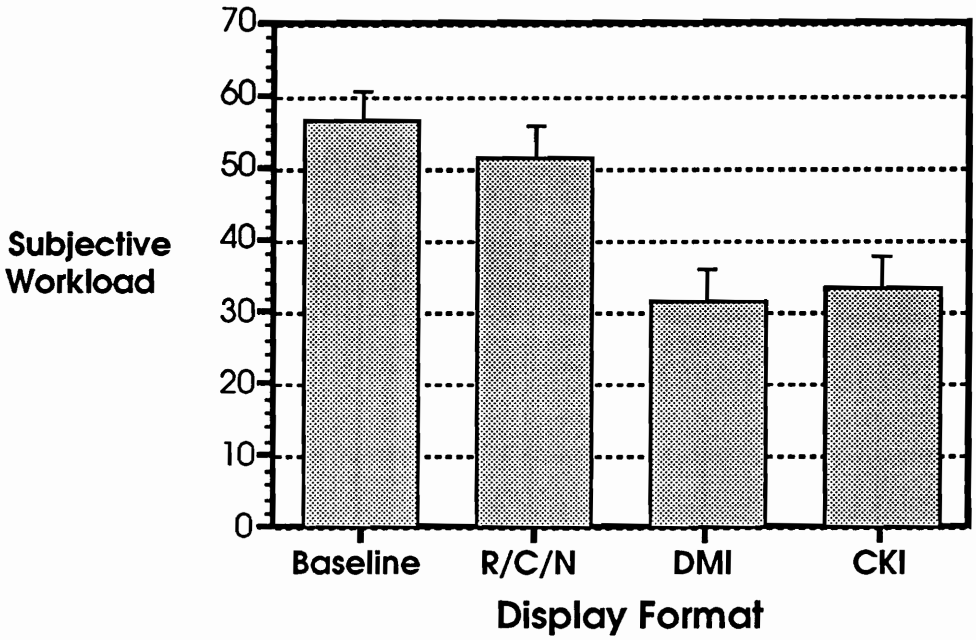

Figure 50. Main effect of Display Format on Subjective Workload (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 58
Newman-Keuls Analysis of the Main Effect of Display Format on Subjective Workload (Experiments 1 & 2 Comparisons)

Display Format	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Subjective Workload*	
Baseline	36	23.36	3.89	56.70	A
Range/Color/NATO Iconic	36	25.74	4.29	51.59	A
Command-Key	36	27.69	4.62	33.32	B
Direct-Manipulation	36	27.59	4.60	31.38	B
Means with the same letter are not significantly different at $p < 0.05$					

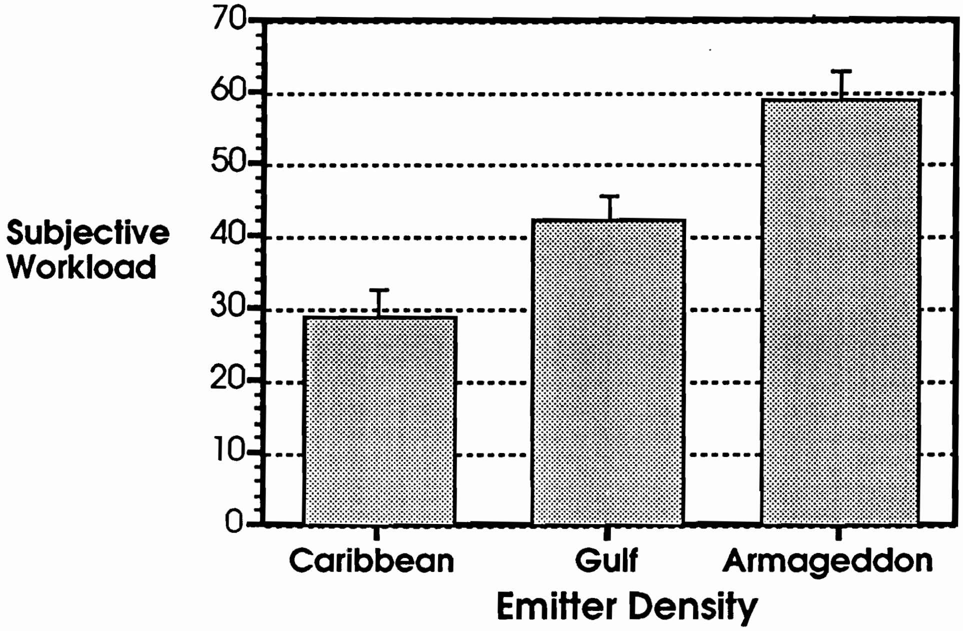

Figure 51. Main effect of Emitter Density on Subjective Workload (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 59
Newman-Keuls Analysis of the Main Effect of Emitter Density on Subjective Workload (Experiments 1 & 2 Comparisons)

Emitter Density	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Subjective Workload*	
Armageddon	48	26.48	3.82	58.90	A
Gulf	48	24.03	3.47	41.98	B
Caribbean	48	25.91	3.74	28.86	C
Means with the same letter are not significantly different at $p < 0.05$					

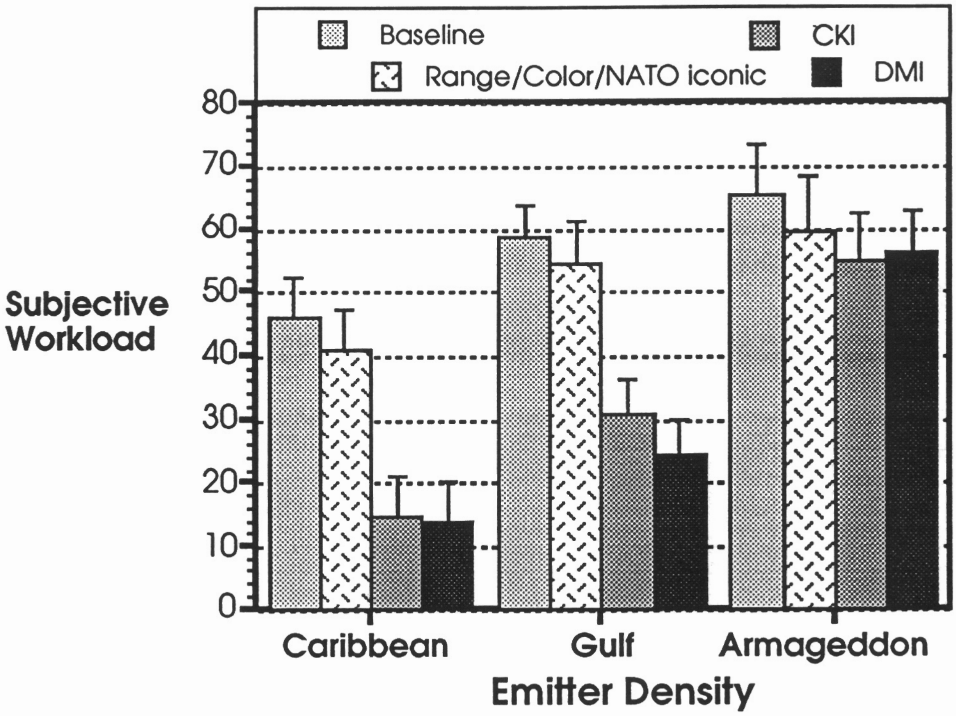

Figure 52. The effect of Display Format by Emitter Density on Subjective Workload (Experiments 1 & 2 Comparisons). Error bars represent +1 Standard Error of the Mean.

TABLE 60
Simple-Effects F-test of Display Format Within Emitter Density on Subjective Workload (Experiments 1 & 2 Comparisons)

Source	*df*	*e*	*MS*	*F*	*p*	*p adj.**
Caribbean	3	0.86	3450.01	23.86	< 0.010	< 0.010
Gulf	3	0.90	3491.18	21.14	< 0.010	< 0.010
Armageddon	3	0.89	281.64	1.95	> 0.750	
Display Format x Density x Subject	66		144.61			

**p reflects F-tests that were adjusted with the Geisser-Greenhouse maximal correction $F_{0.05}$ [1,44].*

TABLE 61
Newman-Keuls Analysis of the Effect of Display Format within the Caribbean Emitter Density on Subjective Workload (Experiments 1 & 2 Comparisons)

Display Format within Caribbean Emitter Density	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Subjective Workload*	
Baseline	12	22.36	6.46	45.91	A
Range/Color/NATO Iconic	12	22.16	6.40	40.97	A
Command-Key	12	21.43	6.19	14.72	B
Direct-Manipulation	12	21.83	6.30	13.86	B
Means with the same letter are not significantly different at $p < 0.05$					

TABLE 62
Newman-Keuls Analysis of the Effect of Display Format within the Gulf Emitter Density on Subjective Workload (Experiments 1 & 2 Comparisons)

Display Format within Gulf Emitter Density	*Count*	*Standard Deviation*	*Standard Error of the Mean*	*Mean Subjective Workload*	
Baseline	12	16.60	4.79	58.72	A
Range/Color/NATO Iconic	12	23.06	6.66	54.28	A
Command-Key	12	18.95	5.47	30.61	B
Direct-Manipulation	12	18.67	5.39	24.32	B
Means with the same letter are not significantly different at $p < 0.05$					

Discussion

Direct Selection of Emitters

The CKI and DMI display formats tested in Experiment 2 were more than twice as fast for designating emitters than were the Baseline and Range/Color/NATO Iconic display formats. The CKI and DMIs were more resilient to changes in density conditions. That is, performance in the Baseline interface slowed when density increased, but no significant change occurred in performance with increasing density with the CKI or the DMI. Thus, these results indicate that a robust method of emitter selection can be incorporated in the redesign of the AN/SLQ-32(V) to allow operators to make rapid selections without having to scan the sometimes cluttered range (or polar) display. The Sequence FAB on the AN/SLQ-32(V), although useful, does not allow operators to select any emitter in the sequence list with a single action (using the keyboard or mouse). Therefore, direct selection of emitters listed on the Sequence List is recommended.

The simultaneous presentation of the range display with the on-line library keeps the operator focused on the tactical environment, even without looking at the range display. When this situation arises, the operator may focus on selecting and identifying emitters from the range display without looking at the sequence list. When emitter density increases and in the unlikely event the operator cannot maintain a cognitive image of the tactical environment, direct selection from the sequence list (still ordered by threat) will allow operators to concentrate on the primary threats.

Use of Range Information and NTDS

Since the redesigns from Experiment 2 did not require the operator to scan the Range display, the portion of time spent comparing the Sequence List information to the emitter bearing on the AN/SLQ-32(V) polar display was eliminated. Clearly, many tasks do require the operator to search by bearing. Even so, the operator frequently must look to the NTDS range display to find the corresponding emitter on the NTDS range display. Then the operator has to manually compare the system's information to map the emitter to the correct range information. Given the redesigns presented in Experiment 2, the addition of range information on the Sequence List eliminates the time-consuming and error-prone step of searching on the polar display and comparing the information to that provided by the NTDS range display.

Designation Errors and the Reduction of Workload

The analysis of Designation errors revealed that the DMI had fewer errors than the CKI. The total number of designation errors for all display formats was small, as in the actual AN/SLQ-32(V). However, the criticality of making an incorrect designation is so high that to help in the redesign process it is important to understand the types of errors operators made.

During testing, designation error rates were less than 1 percent (0.0078) when using the DMI, whereas participants using the CKI were twice as likely to make a Designation error

(0.014), and four times as likely to make an error with the Baseline (0.030) or Range/Color/NATO Iconic (0.27) display formats. This disparity may be attributed to the visual feedback provided when moving the cursor to select an emitter, which is probably more useful than the feedback generated in the Baseline and Range/Color/NATO Iconic displays where the operator must type an arbitrary number that corresponds to the emitter's identification number. It is recommended that the designation process be conducted by direct manipulation. Of course, some form of direct selection via the keyboard is needed during high-sea conditions. Command-Key selection may be the only alternative. The intermediate error rates for the CKI (as the error rate falls in between the DMI and Baseline formats) may be attributed to the indirect link between the library number and the emitter. Compared to the link of direct selection using the mouse in the DMI, the CKI process is one step removed, as it requires a cognitive link from the item on the display to a number on the keyboard.

Inadvertent and Mistaken Activation Errors

Based on experimental observation, participants experienced two types of errors. The first type, inadvertent activations, occurred when operators accidentally selected the wrong emitter from the library. Participants generally knew immediately they made an incorrect choice (similar to a touch typist pressing an incorrect key and immediately pressing the delete key to re-key correctly). For data collection purposes, participants did not correct inadvertent activations. It was apparent from the remarks during the testing session that participants recognized when an inadvertent activation error was committed. The second type of errors are mistaken activations, in which the operators mistakenly chose an incorrect emitter (i.e., the participant selected what he or she thought to be the correct emitter although it was an incorrect emitter). When committing this type of error, operators incorrectly interpreted emitter parameters or misread the display. No data are available to determine the frequency of each error type. Furthermore, questionnaire data do not indicate a preference for input style (six participants preferred key selection and six preferred double clicking).

Although it is impossible to eliminate human errors, a good redesign allows one to revert or undo a given action so that the system can cancel the input, reset the system, and wait for another action. When combined with a usable interface design, an undo feature can reduce the magnitude of inadvertent activations. Therefore, it is recommended that an undo feature be incorporated into the AN/SLQ-32(V).

The computer can be used to compare the emitter parameters in the system to what the on-line library database contains for the specified emitter. Further processing by the computer might be able to uncover unusual discrepancies in the operator's choice for an emitter. Under certain conditions, this could be made apparent so the operator may re-examine the emitter profile to confirm or refute the emitter designation. Of course, a redesign must take into account that a sophisticated computer algorithm might not be able to convince an operator that a mistake was made. Making the AN/SLQ-32(V) library larger and more capable of discrimination among emitters would allow an operator to choose an emitter from a list rather than key in an identification number. This method would reduce the total number of errors and at the same time change the type of operator error from a keying error (high probability of error) to a visual selection error (low probability of error). It is recommend that the use of the publications and existing on-line library be eliminated in favor of a new CAIS capable of holding, searching, and presenting all possible emitters in an area of the main screen. It should be emphasized that the current library system should not be redesigned. Instead, a completely new design should be created.

Dummy Errors and Range Information

Dummy errors, although less critical, are still important. Incorrect selections can slow performance, annoy the user, and distract the operator from the task. Both the CKI and DMI effectively reduced operator's dummy errors to zero. This is due to the emitter-selection process in the sequence list. Not having to search the range display eliminated the need to scan the cluttered tactical environment and avoided the possibility of selecting the wrong emitters from the few that were overlapping. The use of the Range/Color/NATO Iconic display also reduced the number of dummy errors. Participants used the range information to reduce their selection choices (maintained in their mental representation of the tactical environment). In the Baseline version, operators quickly selected a few emitters in error before selecting the correct emitter. The number of errors was reduced when using the Range/Color/NATO Iconic display by increasing the time required to make a single correct selection. More time is required to make multiple incorrect selections than to make one correct selection. Figure 53 presents the comparison of errors and time. Note that whereas errors are reduced with the addition of either the NATO Iconic or Color variable, they are dramatically reduced by the addition of a Range display. With a Range display, reductions in Dummy errors are achieved by the addition of the Color and NATO Iconic attributes. Thus, range information must be provided to the operator to reduce dummy errors. The addition of the NATO icons is also justified.

Performance

The performance metric was based on the percentage contribution of each score to the total of all scores, so that when comparing the results of Experiment 1 to Experiment 2, one must combine the raw measures of performance to determine a new measure relating both sets of results. To make a valid interpretation of the differences among display formats, the values from each set of data must have common points of reference. This is resolved by combining the raw data and recalculating a new performance measure. With the other dependent measures, one can directly compare one value to any other (the mean time to designate an emitter in the baseline format compared to the CKI format) without re-scaling the measures.

Performance results, a combination of dummy errors and mean times, reflect the elimination of errors made by operators in the CKI and DMI sessions. Since errors were weighted equally with time in the overall performance metric, the differences in performance are greater than either measure analyzed individually. Thus, performance improved 500 to 600 percent with the formats tested in Experiment 2 compared to the Baseline interface, and

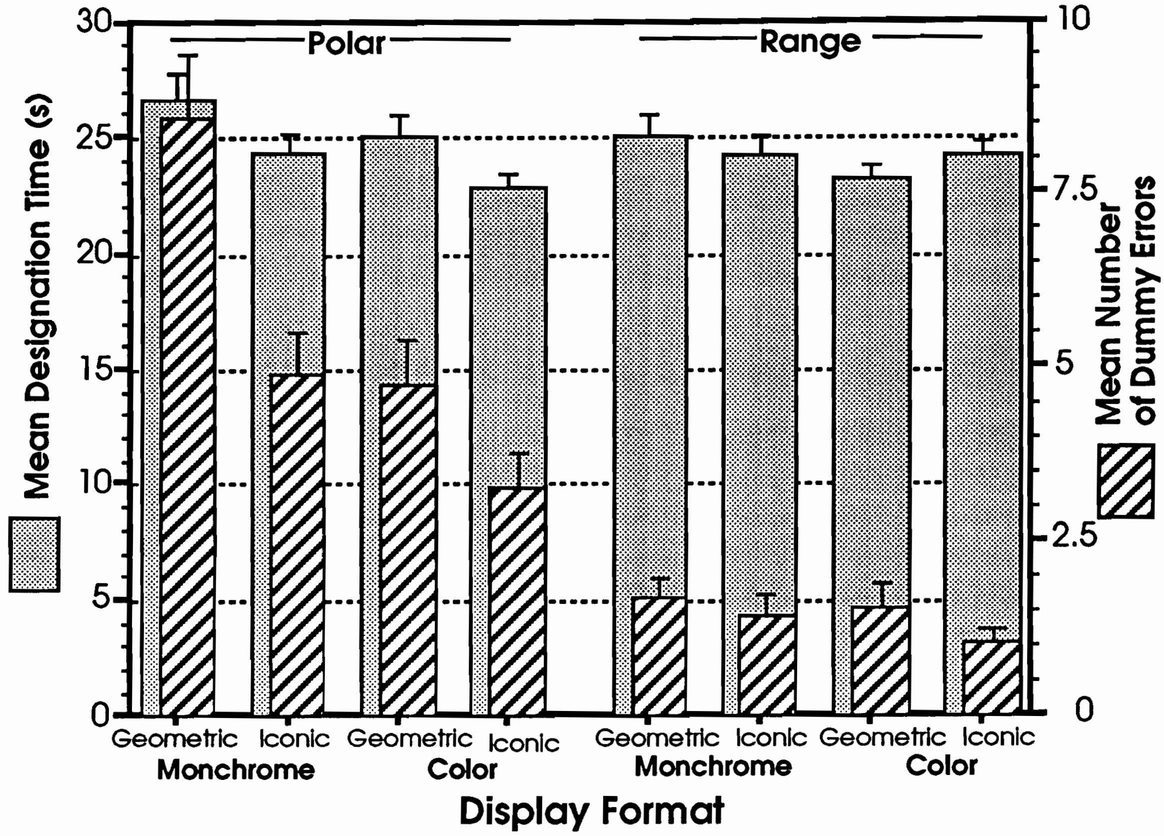

Figure 53. Comparison of dummy errors and mean designation times in Experiment 1.

about 250 percent when compared to the Range/Color/NATO Iconic interface (see Table 55, page 101). The significant difference (statistically and practically) justifies the complete redesign of the AN/SLQ-32(V). The use of modern information display technology (hardware and user-interface design) makes for large improvements in performance.

Interface Ratings

When comparing the interface formats in Experiment 2, participants assigned a rating to each interface of about 6 on a 1 (Worse) to 7 (Better) scale. Participants rated both formats of the interfaces used during Experiment 2 as being faster than the versions tested in Experiment 1 (mean ratings of 6.0 and 6.4 for the CKI and DMI, respectively). This is interesting since the CKI and DMI were slower in responding to user requests, but the number of emitters processed per unit time was much higher. Thus, participants' perception of speed was based on productivity and not on actual system response. Of course, given two systems that appear exactly the same (except for response time), preference would favor the faster system when differences exceed user expectations. Mayhew (1991) explained that user strategy changes as a function of response time and the ease of error recovery. In a situation such as operating the AN/SLQ-32(V), once chaff is launched or AECM is established, it is difficult to stop the process. Where error recovery at the system level is unlikely, users will: (1) think more before making a decision (Designation Time), (2) have a low number of errors (Dummy and Designation Errors), (3) express low user satisfaction (Preference), and (4) have higher Subjective Workload. The results of this experiment are consistent with these generalizations, favoring the tradeoff of designing a more usable interface in exchange for system response time. Adding an Undo feature for intermediate steps, giving users feedback on tasks that require more than a few seconds, and presenting updated status reports on complex processes could help to reduce further the level of operator workload expectations.

Idle Time

The Display Format by Emitter Density interaction shows no difference in workload for the Armageddon scenario. Figure 54 shows that the inverse of idle time was almost identical to the subjective workload when idle time was above zero. When idle time was zero (as in all the Baseline and Range/Color/NATO Iconic and the DMI Armageddon conditions), the value is not shown on the graph, as it is infinite. Thus, an effective redesign should minimize the operator's task load to allow for rest time. This rest period reduces perceived workload.

Accommodating Individual Differences

Table 38 (page 87) shows the variability in Designation Time. The reduction in variability suggests that the redesigns are more robust to variance in operator skill. Egan (1988) wrote that a user interface is robust when it can accommodate a wide range of users while the operator maintains high performance. If an interface design takes into account individual differences and isolates those differences, it is possible to create a redesign that accommodates the users. Egan reported numerous studies that showed differences in time to locate computer files and find text in hierarchical database structures ranging from 7:1 to 10:1. Decreasing variability in operator performance is useful for creating Measures-of-Efficiency (MOE) for tasks. This allows the Navy to better understand the task and to create training systems that create consistency in operator performance.

Visual Scanning in the CKI

When using the CKI, the task required operators to work top-down then left-right (Figure 55), moving from the Sequence List to the ULQ and down and across the Library list. Once at the right end of the library list, operators were forced to look back to the left side of the library list to determine the command-key number for the library entry (Table 63). If the number was positioned on the right side of the library list (maybe on both sides), then the operator would not have the additional scanning time associated with looking back to the left side of the library list. Adding the command numbers to the right side of the library would eliminate operators having to scan back to the left side of the Library. This could reduce the selection process to a recognition task rather than a counting task, that is, not requiring the operator to count the rows of emitters to determine the command number.

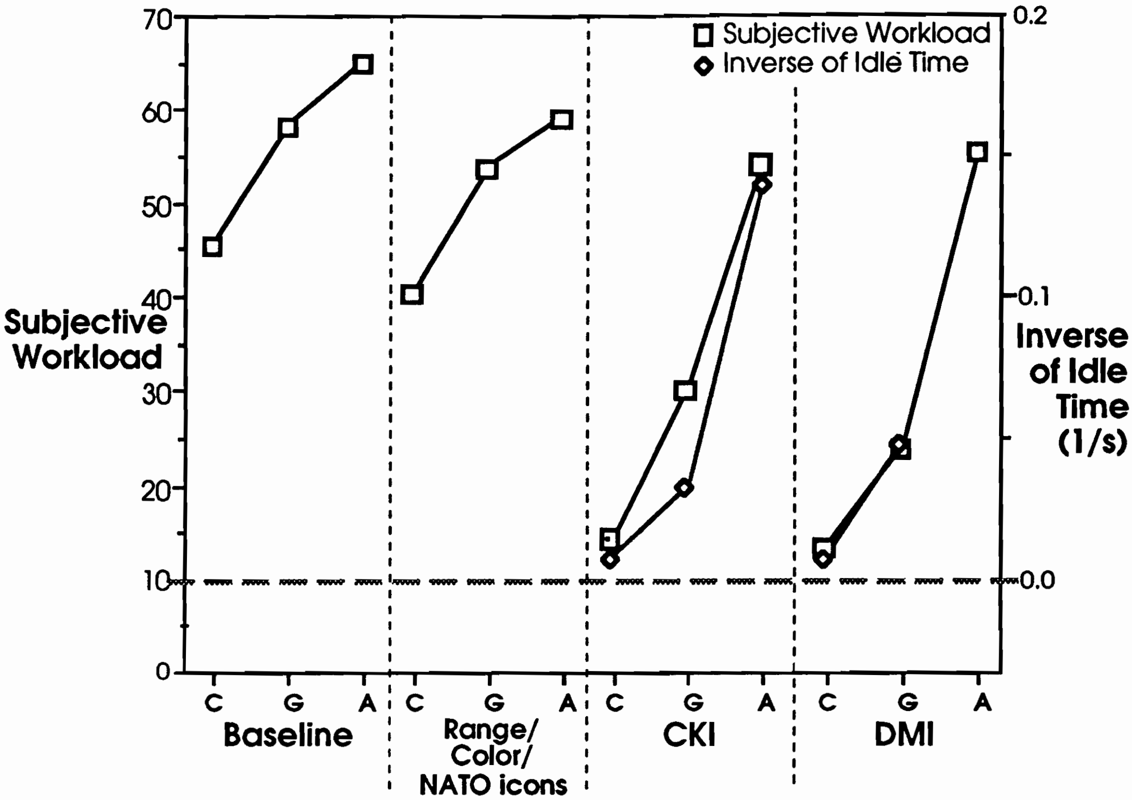

Figure 54. Comparison of subjective workload and the inverse of idle time between the Baseline, Range/Color/NATO Iconic, Command-Key, and Direct-Manipulation interfaces for all three density conditions.

Overall Data Analysis

The significant reduction in time to designate emitters, the number of errors, and level of subjective workload all indicate that the original AN/SLQ-32(V) interface needs improvement. A redesign of the AN/SLQ-32(V) will improve operator performance if human factors engineering principles and design guidelines are applied properly. In this series of experiments, the results indicate that some types of errors can be virtually eliminated. Reducing errors in the system helps operators gain confidence in the system's ability, while reducing the operator's need to check, double check, and verify information.

All of the dependent measures substantiate the conclusion that use of the CMI and DMI are independent of Emitter Density. The reason is clear—operators did not use the cluttered emitter display to make selections. Operators were also able to concentrate on selecting emitters with either the CKI or DMI from the Sequence List and did not have to spend time searching the wagonwheel. Some form of direct selection from the Sequence List is warranted.

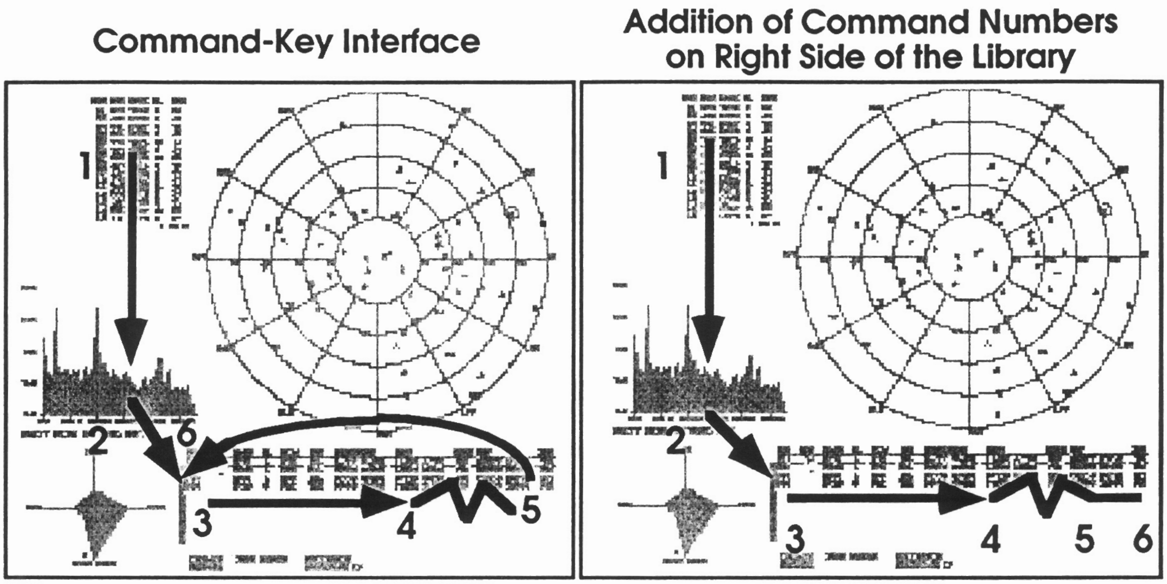

Figure 55. Searching for the command numbers to the left side of the Library in the Command-Key Interface.

TABLE 63
Key to Figure 55

Step	Action
1	Choose Emitter from Sequence List
2	Listen to Emitter and view PRF
3	Start to Scan Library for Correct Entry (this is location of command numbers; if only one library entry appears in Library then they know to select "1" for the command number)
4	Scan across information in Library entry, zigzaging to compare emitter parameters.
5	Make final determination of the correct choice using the EFX, listed last on the Library Entry
6	Return to list of Library numbers to select command number (If only a few entries are listed in the library the operator may just count down the list ("1", "2", "3") to determine the command number)

IMPACT FOR DESIGN AND FUTURE RESEARCH

Based on the results of Experiments 1 and 2, the present findings can be applied to future system design efforts. The application and implications of this research to a redesign of the AN/SLQ-32(V) and perhaps to other complex command and control systems are discussed.

Symbology

Symbol sets based on real-world metaphors and analogies provide information which reduces the level of intermediate processing of the operator. In this way, intuitive and common icons, rather than cryptic symbols, serve to improve the interface design. In these experiments, emitters on the Sequence List, Range Display, and CAIS all share common icons to aid linking the various information sources. With the support of modern display technology, military systems need not be synonymous with interfaces that are cryptic and difficult to use.

Color

The use of color in a wide variety of tasks is well documented in the literature. In this experiment, the use of color was extended outside the bounds of laboratory search and selection tasks. Color linked not only threat level with emitters, but also linked the Range display with the Sequence List, and the polygon display with the CAIS. Thus, color coding provided a method for increasing consistency between organized textual information and the pseudo-random pattern of emitters on the Range display. Designers of complex information displays should consider extending the use of color to enhance the perception of connections between a primary visual link (in this case, the Range display and the threat of the emitter) and other system information sources (such as the Sequence List, CAIS, and polygon display).

Range

Range information allows operators to narrow their focus on a range display in order to select an emitter. Bearing gives only one dimension on a two-dimensional display. Range information gives the second dimension. Without range information, operators had to scan the entire bearing line, making numerous errors, before making the correct selection. Thus, providing enough information to pinpoint the coordinates of a target is a significant advantage for any operator. The application of range information in emitter-type displays (airport radars, military tracking and designation systems, tactical maps) is limited, but the concept of providing feedback and coordinates for making selections on information displays is applicable.

Command-Key and Direct-Manipulation Interfaces

The CKI and DMI provided an improved design for emitter designation. However, the CKI had twice as many designation errors as the DMI. The DMI did not use the intermediate step of menus found on most direct manipulation interfaces. That is, the operator acted directly on the object rather than through a menu selection. Although the system as a whole is too complex for all actions to be provided by a single or double click, direct selection can be applied to common functions. Menus, commands, and icons are capable of handling hundreds of functions, but the feedback from direct selection and activation reduces errors and increases usability.

To appreciate the scope of the AN/SLQ-32(V) effort, a list of some of the existing menu functions on the DCC is presented (Table 64). They are organized by functional analysis (Beaton et al., 1991). All of these features are important to the current version of the AN/SLQ-32(V). Re-engineering the system would eliminate, consolidate, and reorganize the existing information hierarchy. The incorporation of direct manipulation and command selection provides the AN/SLQ-32(V) or any complex system a basis for logically organizing and effectively accessing the information system

TABLE 64
Menu Functions of Existing AN/SLQ-32(V)

	1. Library	
1.1. Update data from outside source	1.2. Emitter(s) search	1.3. Add emitter to library
1.4. New manual emitter entry	1.5. Edit entry	1.6.Copy entry
1.7. Delete entry	1.8. Platform correlation	1.9. ID research
1.10. Designate ID		
	2. Chaff	
2.1. Quick launch	2.2 Modify configuration	2.3.Calculate launch parameters
2.4. Distraction		
2.4.a. Initiate	2.4.b. Reseed	2.4.c. Interlock
	3. Electronic Measures	
3.1. ESM	3.1.a. Tactical specs	3.1.b. Create sector
3.1.c. Modify sector	3.1.d. Delete sector	3.1.e. Drop current emitter
3.1.f. Delete current emitter	3.1.g. Reinstate inhibited emitters	3.2.ECM inhibit sector (IS)
3.2.a. Create ECM IS	3.2.b.Modify ECM IS	3.2.c. Delete ECM IS
	4. Counter Targeting [AECM and preemptive jamming(PJ)]	
4.1. Create PJ parameters	4.2. Modify PJ parameters	4.3. Delete PJ parameters
4.4. Modify PJ frequency	4.6. Modify PJ bearing	4.7. Modify PJ technique

TABLE 64
Menu Functions of Existing AN/SLQ-32(V) (Continued)

5. Communications		
5.1. Electronic		
5.1.a. CDS send - operator sends track manually	5.1.b. or - track is sent automatically to CDS	5.1.c. Lamps search control
5.2. Voice	*5.2.a. Radio*	
1) EWC (fleet)	2) Other EWs via EWC	3) LAMPS operator
5.2.b. Intercom	1) CDS operator in EW module (may also be the EW supervisor)	
2) Outboard	3) Weapons officer	4) Bridge & lookouts
5) TAO	6) EW maintenance	7) EW supervisor
6. Alert inhibits		
6.1. Friendly	6.2. Non-missile	6.3. All
7. Configuration review/control		
7.1. RR doctrine		
7.1.a. Create RR doctrine	7.2.b. Modify RR doctrine	7.3.c. Delete RR doctrine
7.2. Band control (boxed)	7.2.a. Create standard band 1 control	
7.2.b. Modify standard B1C	7.2.d. Set upgraded B3 sensors	7.2.d. Delete standard B1C
7.3. Synchro data input source		
7.3.a. CDS	7.3.b. Own-ship	7.3.c. Manual
7.3.d. Fault	7.3.e. Clear fault	7.4. Status display
Toggles		
1. True relative bearing	2. Lamps to polar	3. Signal select
4. Three "on-off's" for each band		
SOTs (Toggles with their own special input)		
1. Band 1 on/off	2. Bands 2/3 on/off	3. Background on/off
4. Bit monitor reset/no change	5. Lamps bit request	

Command Keys and Menus

This experiment tested only a small portion of the features found on an AN/SLQ-32(V). As the navigation and selection methods tested had large associated increases in performance, adding complexity and functionality will create an additional burden on the operator. It is important to consider the overall information selection and presentation for the complete system. Adding command keys for frequent functions, a menu system for all functions, and icons for tools or tasks should be addressed. Gestures provide operators a direct manipulation method for selecting emitters. If important functions placed many levels below the main menus in the AN/SLQ-32(V) information system had representative icons on the display, it may be possible to drag-and-drop emitter icons over the icons or click on the icons to initiate identification, countermeasure, or a correlation process.

In addition, the use of type-ahead and menu-skipping features to navigate through a menuing system has been shown to help users find the correct path (Cohen and Schirmer, 1989; Kreigh, Pesot, and Halcomb, 1990). Navigation with type-ahead or menu skipping should be allowed only to decision points. The system should still require the operator to initiate a hardware selection sequence to actually perform some operations. Thus, the menuing system makes function setup easy, but does not allow the completion of the action (starting electronic countermeasures, which is considered an act of war). The entire AN/SLQ-32(V) should be redesigned to take into account the frequency of function usage to optimize the use of icons, command-keys, and menus.

CAIS–A Redesign for the Publications

The basic computer architecture of the AN/SLQ-32(V) is over 20 years old. Designers need to take advantage of advances in computing technology specifically in the areas of storage and presentation of visual information. Even if it is not possible to redesign the AN/SLQ-32(V) to choose the correct emitter in the library, the computer can provide a better estimation from the possible correct emitters in its database and input from the operator. The CAIS in Experiment 2 is an example of redesigning the AN/SLQ-32(V) to take advantage of a computer as a mass-storage and retrieval device. The Publications, as a source of information, take too long to search visually. This large database of cross-referenced information should be available on-line for quick and accurate retrieval.

Object Display

Since objective measures of the effect of the object display is confounded by the display format, only subjective results can be analyzed. The results of this study do not support the use of an object display. This result is attributed to the limited number of emitter parameters analyzed and to the exacting nature of the task. Since only four emitter parameters are used and each parameter has hundreds of levels, participants found it easier to compare information using the textual display rather than the object display. As information load in the system increases (up to 8 or 9 parameters), the potential benefits of an object display may warrant its usage. Laboratory research comparing the object display to other presentation styles did not address complex information, such as the emitter information found on the AN/SLQ-32(V). It appears that research into more advanced on-line emitter classification systems may eliminate the need for operators to compare many emitters (or any emitters) to determine emitter identification (S. A. Moscovic, personal communication, April 1992). These expert systems, if validated, will provide interpretation and identification for emitters, thus dramatically altering the task of the AN/SLQ-32(V) operator.

Rotation of Emitter Symbols

As discussed previously (see "Symbology," page 15), the NATO icons are not transitive around the vertical or horizontal axis. Thus, the NATO icons could be rotated to show the direction of travel for the emitter (the track). The track for an emitter is different from the bearing, which is the position of the emitter relative to the ship. Tracing dots used on the AN/SLQ-32(V) are incorrectly interpreted to represent emitter's track (Navy Briefing, personal communication, December 6, 1991). The orientation of the icons to show track may be more beneficial to the operator than the loss in recognition time due to an oblique icon orientation. However, the symbols need to be designed with sufficient pixel density to overcome shape distortions due to rotation. In addition, an analysis should be performed on the NATO icons to determine the number of orientations necessary (e.g., one per degree?) as a function of the operator's ability to accurately discriminate orientation without additional aid (i.e., numeric presentation of track). The solution may be to allow the operator to display numeric or graphic track information (an arrow or following dots) under certain conditions (e.g., all missiles, all new emitters, or by specific emitters).

Dimming Emitters During High Workload

The redesigns presented in Experiment 2 did not eliminate the density effect on subjective workload. The time constraint and the number of emitters in the Armageddon condition had operators working constantly. If, in the real system, operators used a Range display, one would expect workload to be an issue for operators. As the density of emitter increases the operator will tend to concentrate on the missiles and hostile threats. A redesign of the AN/SLQ-32(V) may include a dimming feature that would reduce the relative intensity of the friendly emitters (in the Sequence List and on the Range display) to make the display look less cluttered.

A Zoom Function and Windows

A zoom function that would narrow the focus of the display into a specific quadrant is recommended by NOSC (1991) for the AN/SLQ-32(V). Zooming is expected to be a useful feature because as emitter density increases, discrimination between emitters on the Range display decreases. The use of direct selection in the Sequence List helps to eliminate hooking errors due to close spacing between emitters on the display. This may be sufficient to overcome the problem of not being able to select a single emitter from the display, but other circumstances may require the operator to select directly from the tactical display area. Whether the windows should overlay or be separate, the size of the window, and the functionality of the window should be investigated.

Research does exist on the effect of tiled and overlapping windows in information displays (Bly and Rosenberg, 1986; Chen and Greenstein, 1986). Bly and Rosenberg suggests allowing overlapping windows when the displays are unpredictable, the display is small and users are experienced. As Billingsley (1988) points out, overlapping windows provide user control to open up many windows but then can increase confusion, create window management problems, and hide the Range display. A tiled system where each panel provides a specific area for a function or class of functions may provide the flexibility needed to display information from subsystems while keeping the primary display areas visible.

Statistical and Practical Significance

In Experiments 1 and 2, the ANOVA procedure used a level of significance (α) of 0.10. Interpreting actual significance, of course, is a task for the reader. The cost of errors in any military system is high since starting wars and shooting down airplanes are critical mistakes that must be avoided at all costs. Statistical significance helps to support design recommendations, but it is not always necessary or sufficient. One must balance the possibility of making an improvement against the cost of making an error. In these experiments it was considered more important to increase the probability of Type I error (an increase in α, thus accepting that differences exist between display formats when there might not be a meaningful difference) in exchange for Type II error (β). Increasing the number of subjects can decrease the probability of Type II error, but the cost of running subjects can become prohibitive. It is always possible to find a difference with enough subjects, but the practicality of that difference must be considered.

Redesign and Innovation

The results from Experiment 2 suggest that to make significant increases in usability as defined by all the dependent measures, the AN/SLQ-32(V) would need to be completely re-engineered. The potential incremental changes tested in Experiment 1 pale in comparison to the complete redesign solutions proposed in Experiment 2. Foster (1986) explained that incremental changes in a system can be beneficial to a point, then a discontinuity appears when a new technology appears to replace the old system. At that point, radical change brings the system to a higher level of performance. Without innovation, the cost of incremental changes will continue to increase with a decreasing rate of return. Experiment 1 tested incremental changes and Experiment 2 tested innovative changes to the system. The difference in how we view these changes is shown in Figure 56. Note how the changes tested in Experiment 1 fall on curve A. Curve A represents the evolution of the AN/SLQ-32(V). To get greater gains in performance, a jump to curve B is necessary. Curve B represents a completely new design for emitter detection and classification. Thus, the designs tested in Experiment 2 reflect the leap in design needed to make corresponding leaps in performance. In the AN/SLQ-32(V) system, the operator, and the hardware are too complex to apply iterative design changes with the expectation of usability increases on the order of magnitude generated from a systems redesign of the user interface.

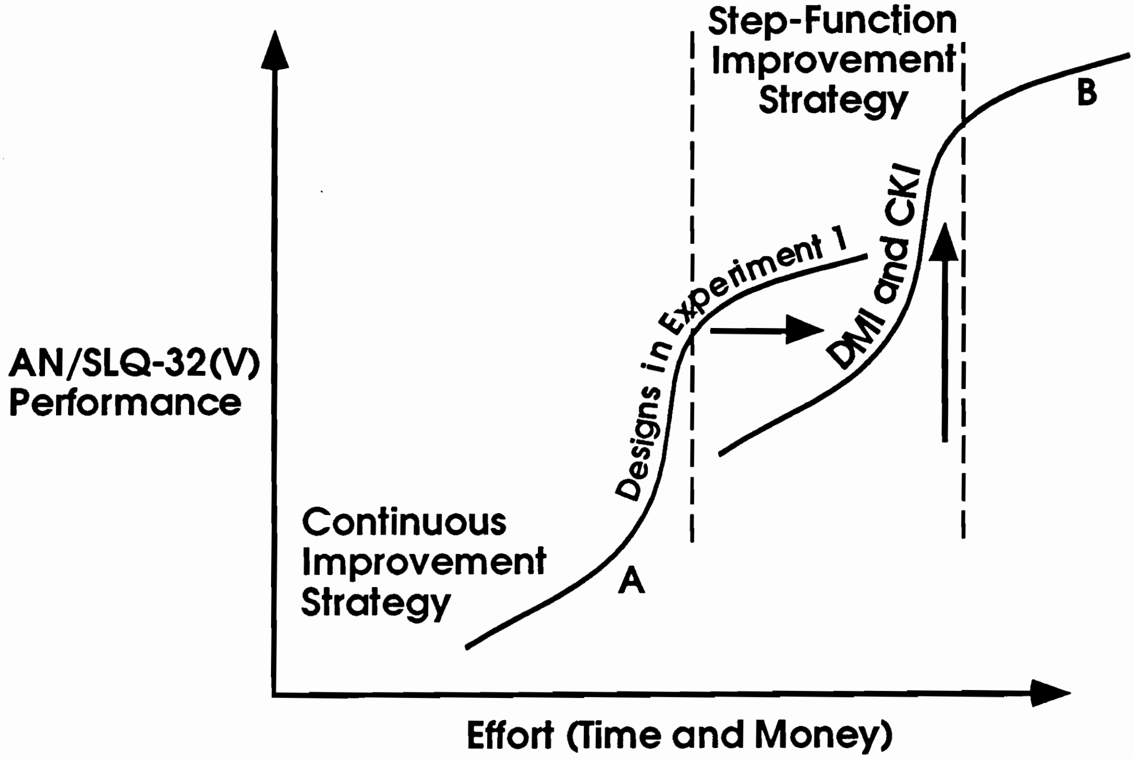

Figure 56. Step-function improvement needed for the AN/SLQ-32(V) (Adapted from Foster, 1986).

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APPENDIX A: SCREEN DISPLAYS

Graphics in this appendix are shown with black and white reversed to improve printer output. In the simulation, as on the actual AN/SLQ-32(V2), the background of the display is black. Note the various levels of emitters shown on some of the displays. Figure 61 on page 132 shows what the operator would see when the session is just underway in the Caribbean condition. On the other hand, Figure 63 on page 134 shows a condition towards the end of an Armageddon trial.

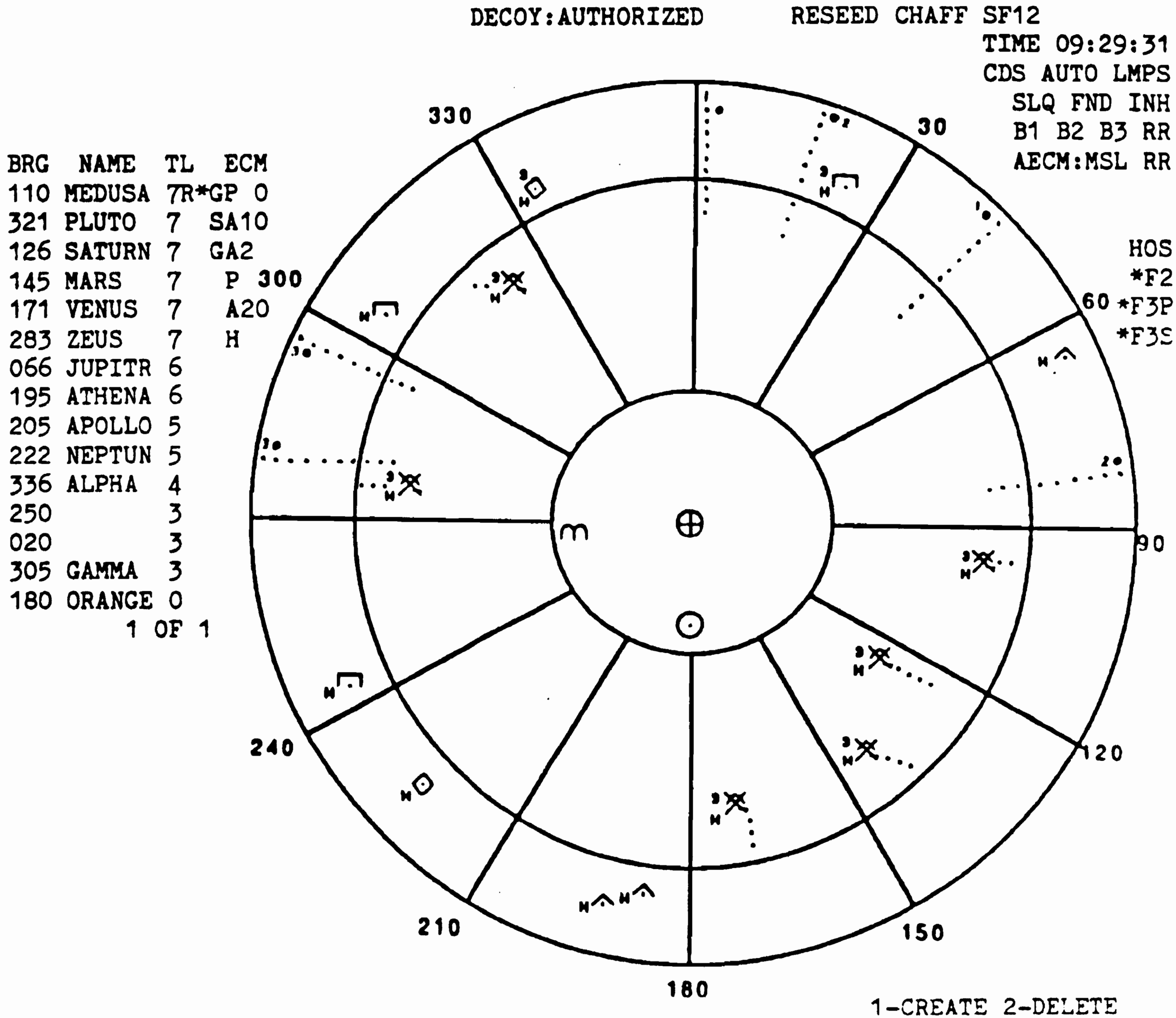


Figure 57. A screen image of the actual AN/SLQ-32(V2) simulator (Actual size).

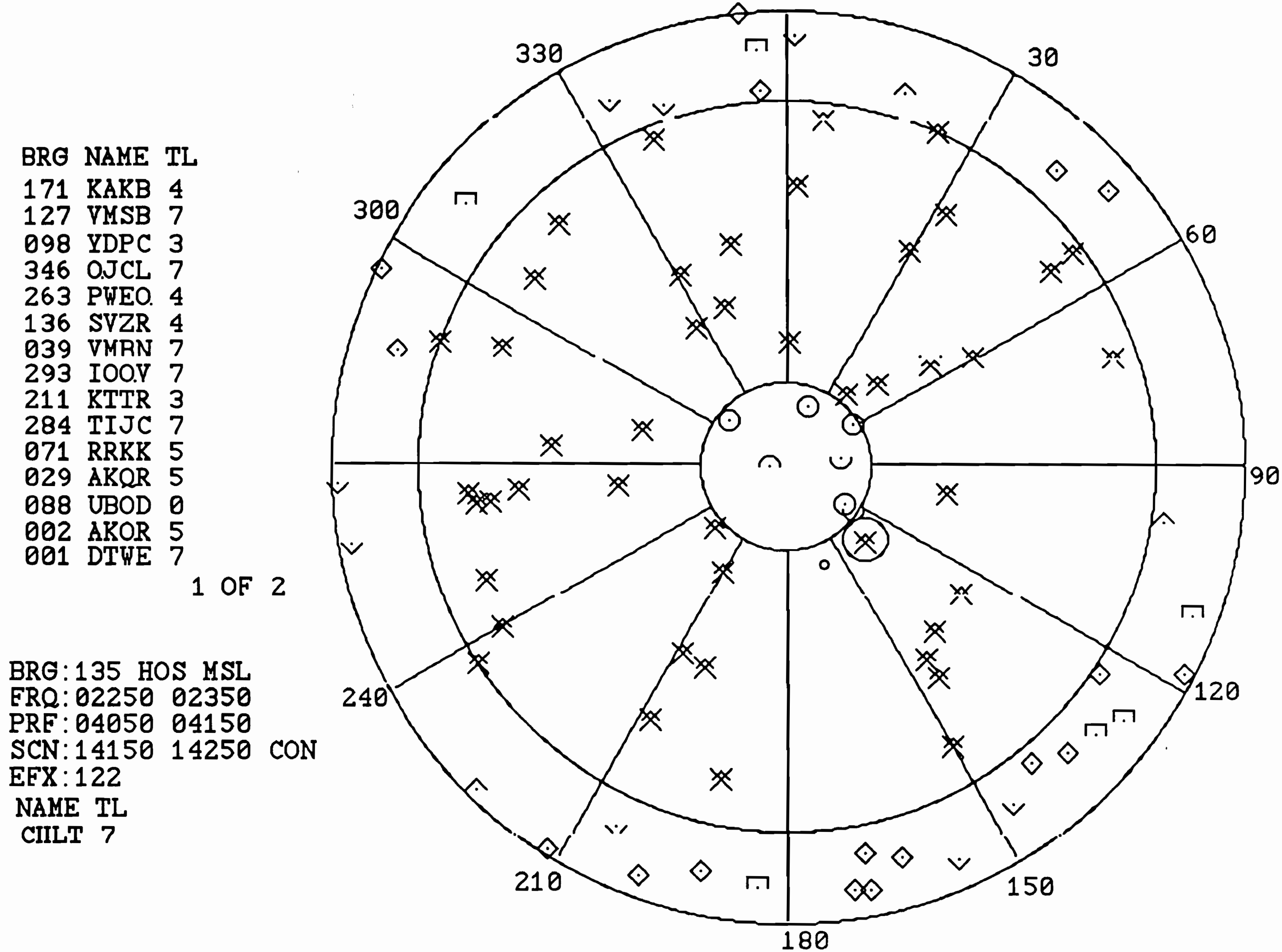


Figure 58. A simulation of the Polar/Monochrome/Geometric symbol (Baseline) display.

BRG	NAME	TL	RNG
350	VWNV	6	42
163	WFUX	7	17
204	FHOF	7	48
100	HTMX	3	13
238	KTTR	3	19
030	KTTR	3	11
046	RGUM	4	27
224	BMIX	7	25

1 OF 1

BRG:345 RNG:25
EFX:285 HOS MSL
FRQ:16250 16350
PRF:09450 09550
SCN:00350 00450 SEC
NAME TL
KZJD 7

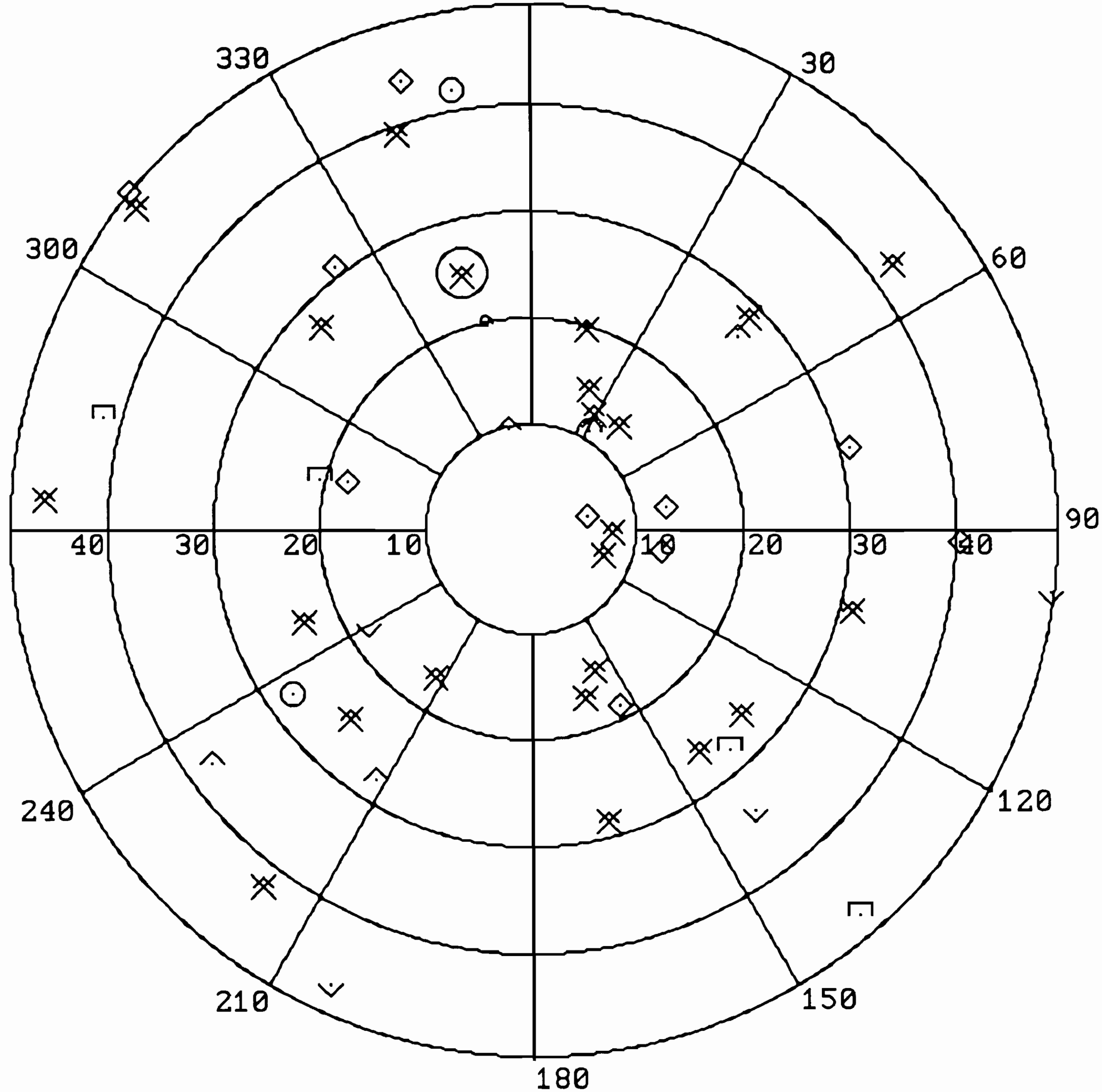


Figure 59. A simulation of the Range/Monochrome/Geometric symbol display.

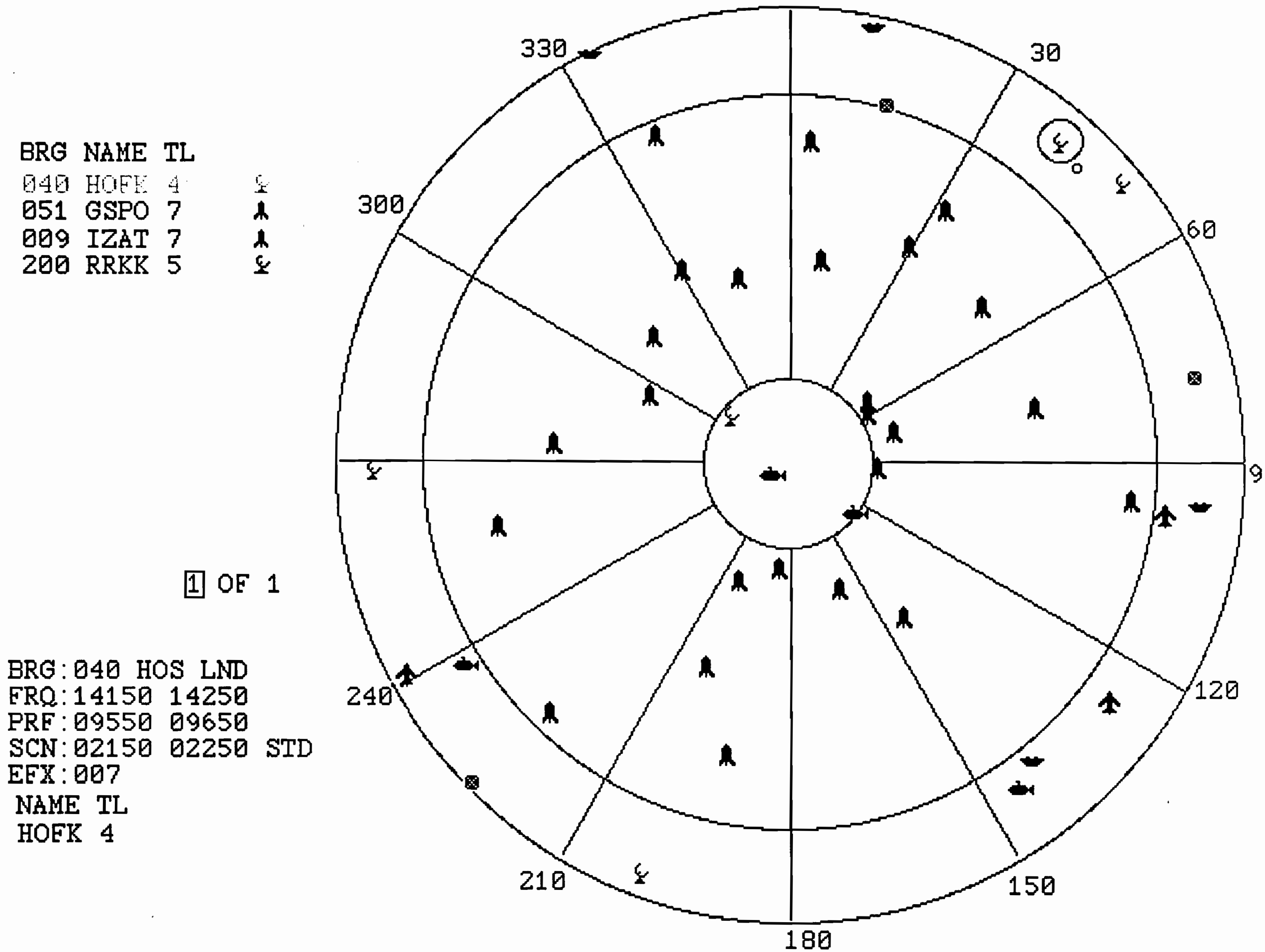


Figure 60. A simulation of the Polar/Monochrome/NATO Iconic display.

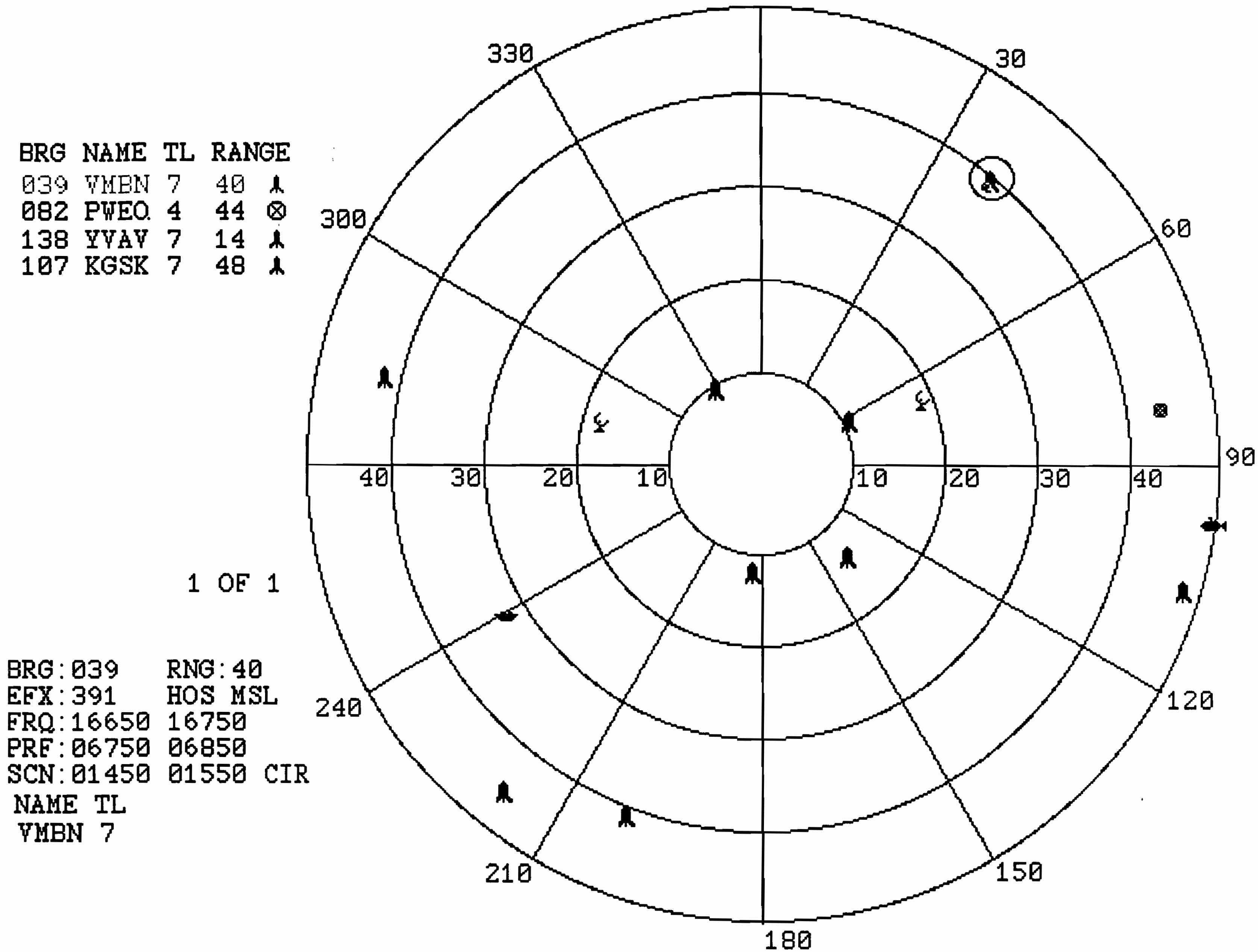


Figure 61. A simulation of the Range/Monochrome/NATO Iconic display.

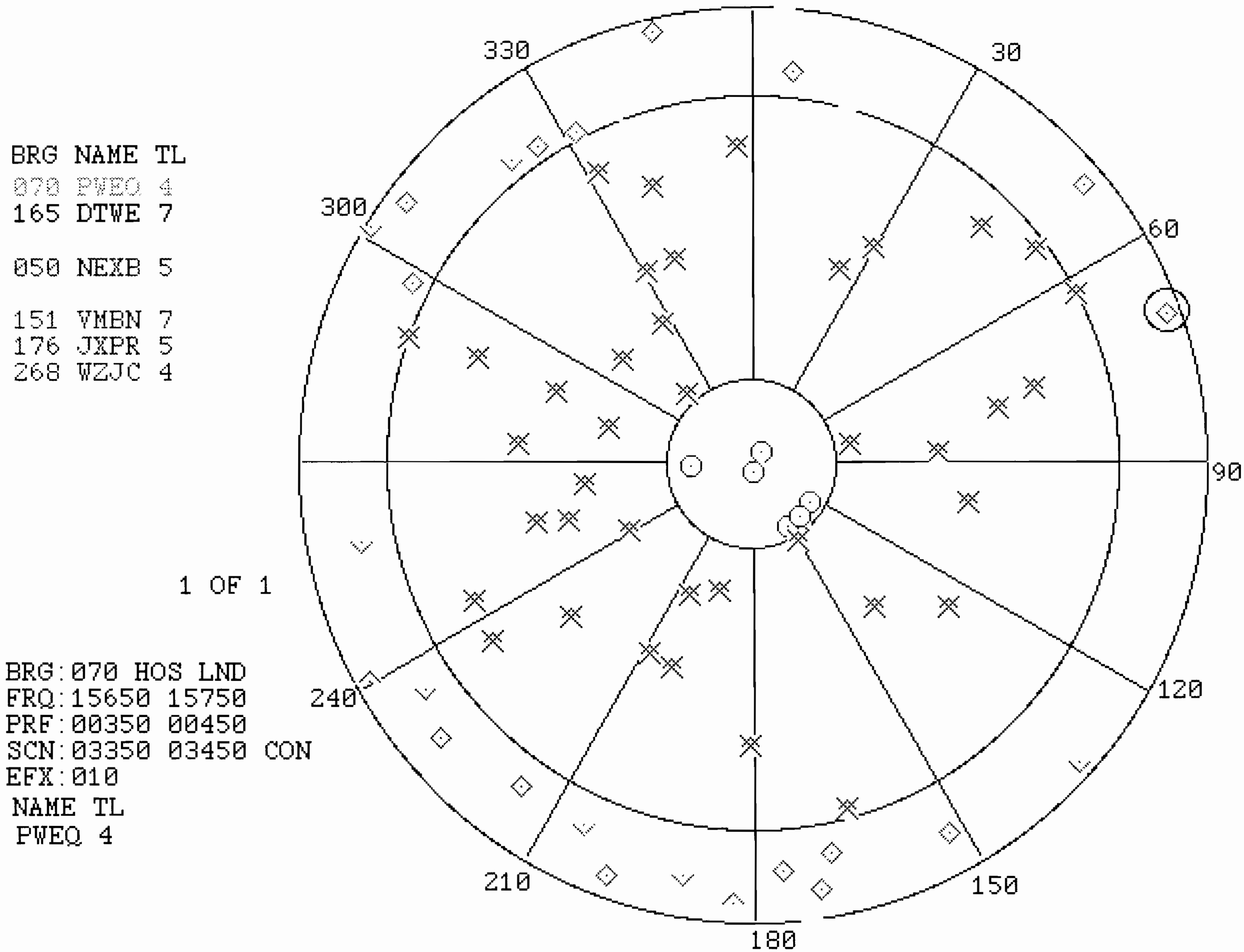


Figure 62. A simulation of the Polar/Color/Geometric symbol display.

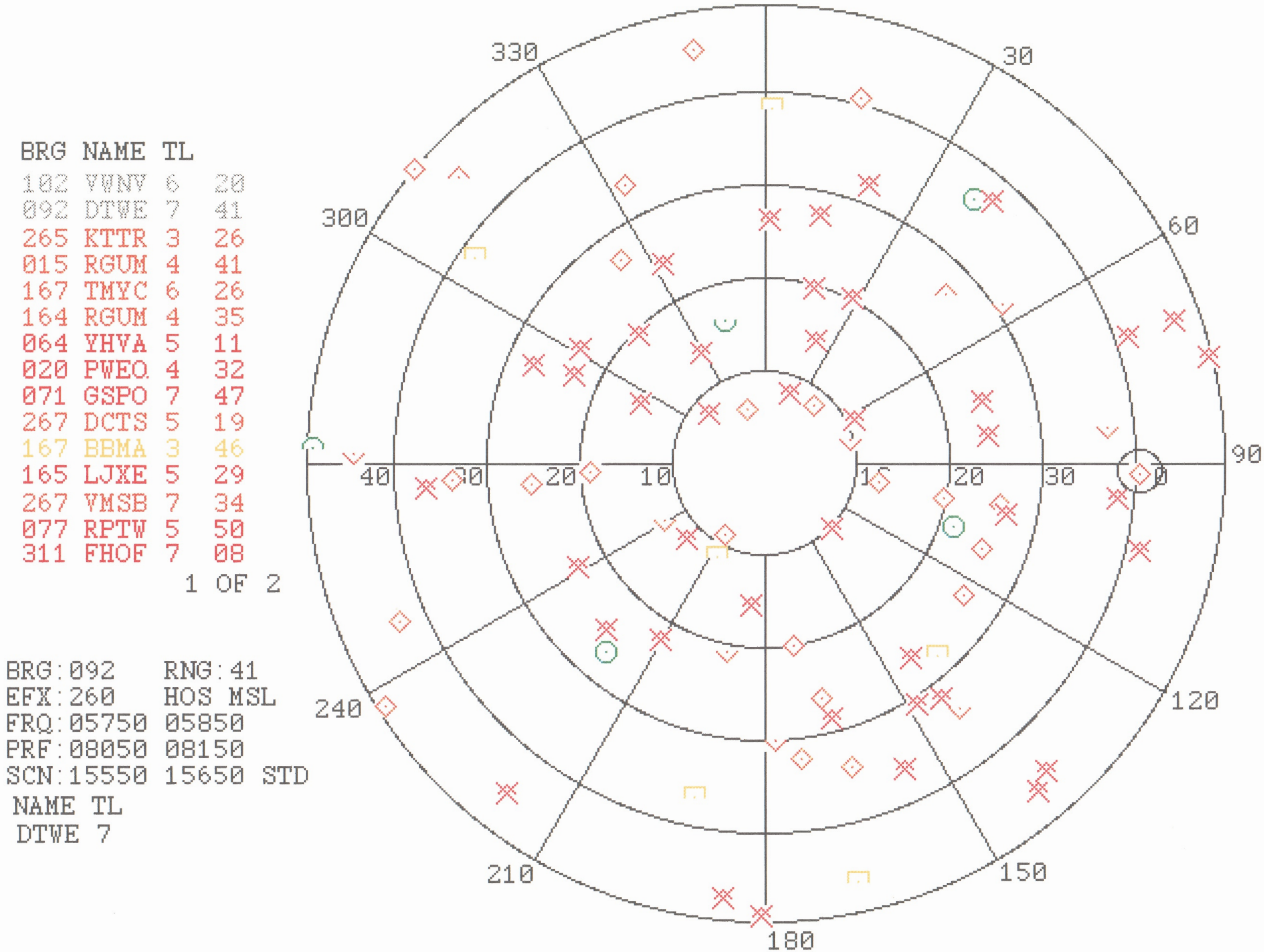


Figure 63. A simulation of the Range/Color/Geometric symbol display.

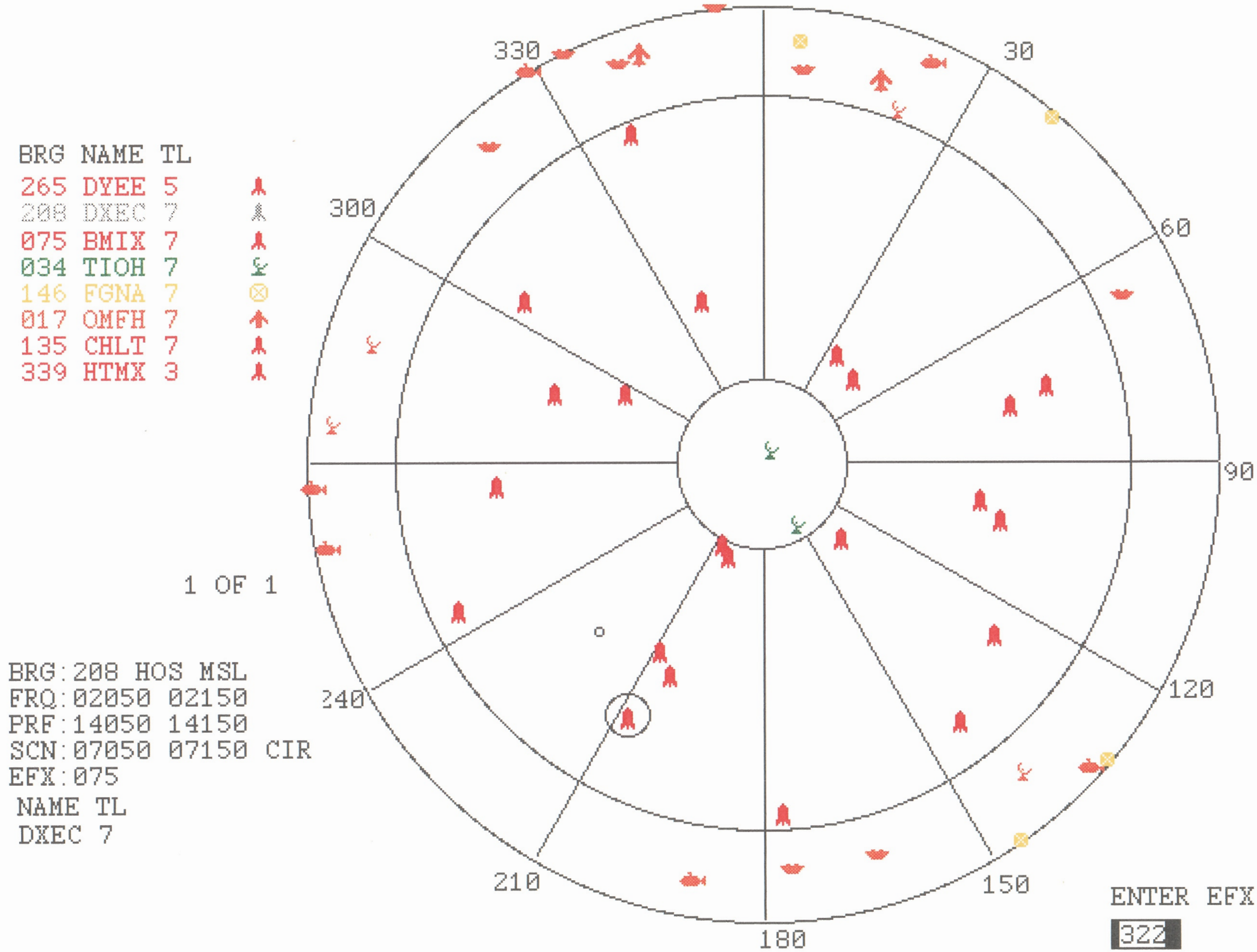


Figure 64. A simulation of the Polar/Color/NATO Iconic display.

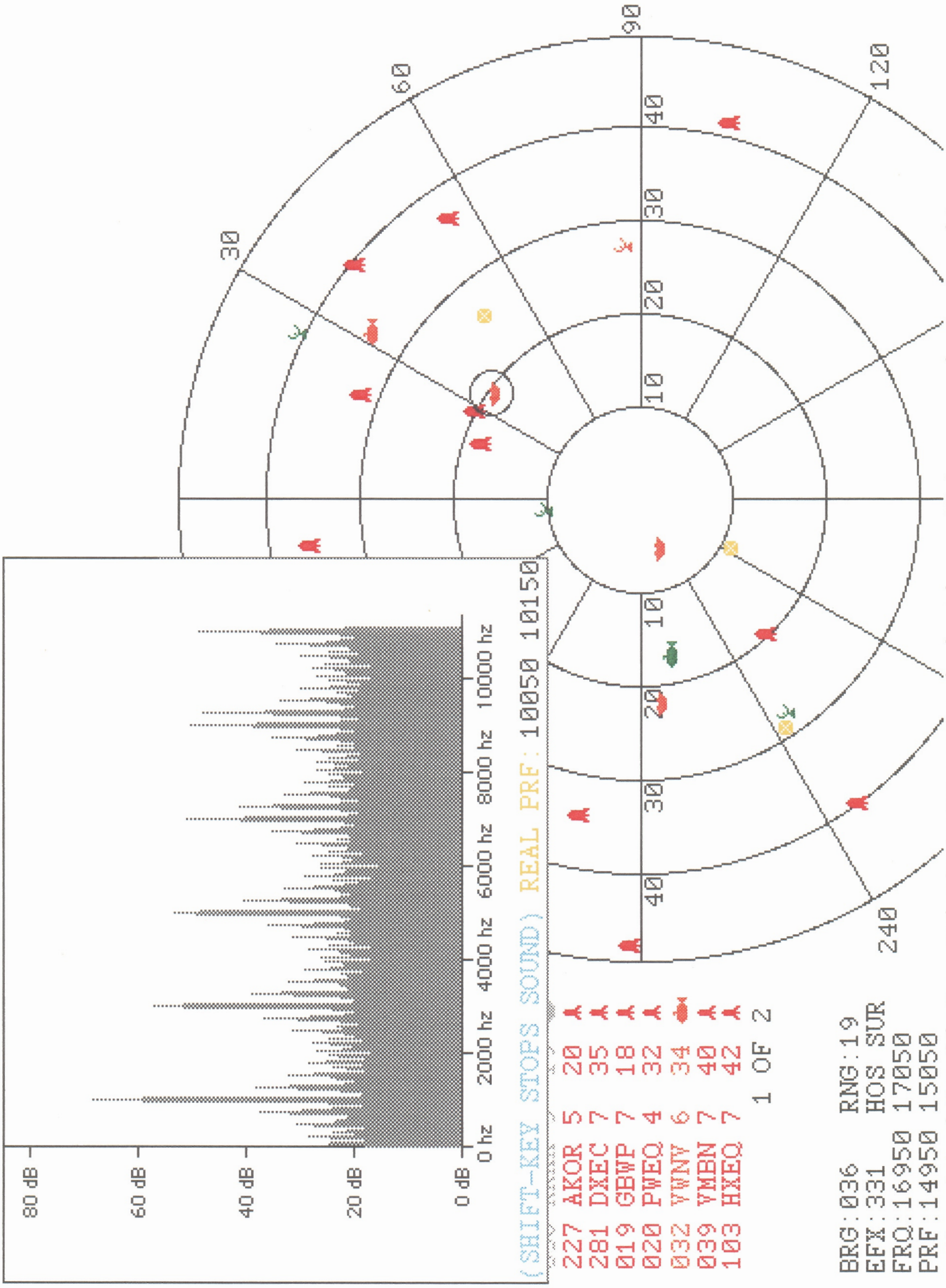


Figure 65. A simulation of the Range/Color display/NATO Iconic display (Showing ULQ-16, cropped maintain scale).

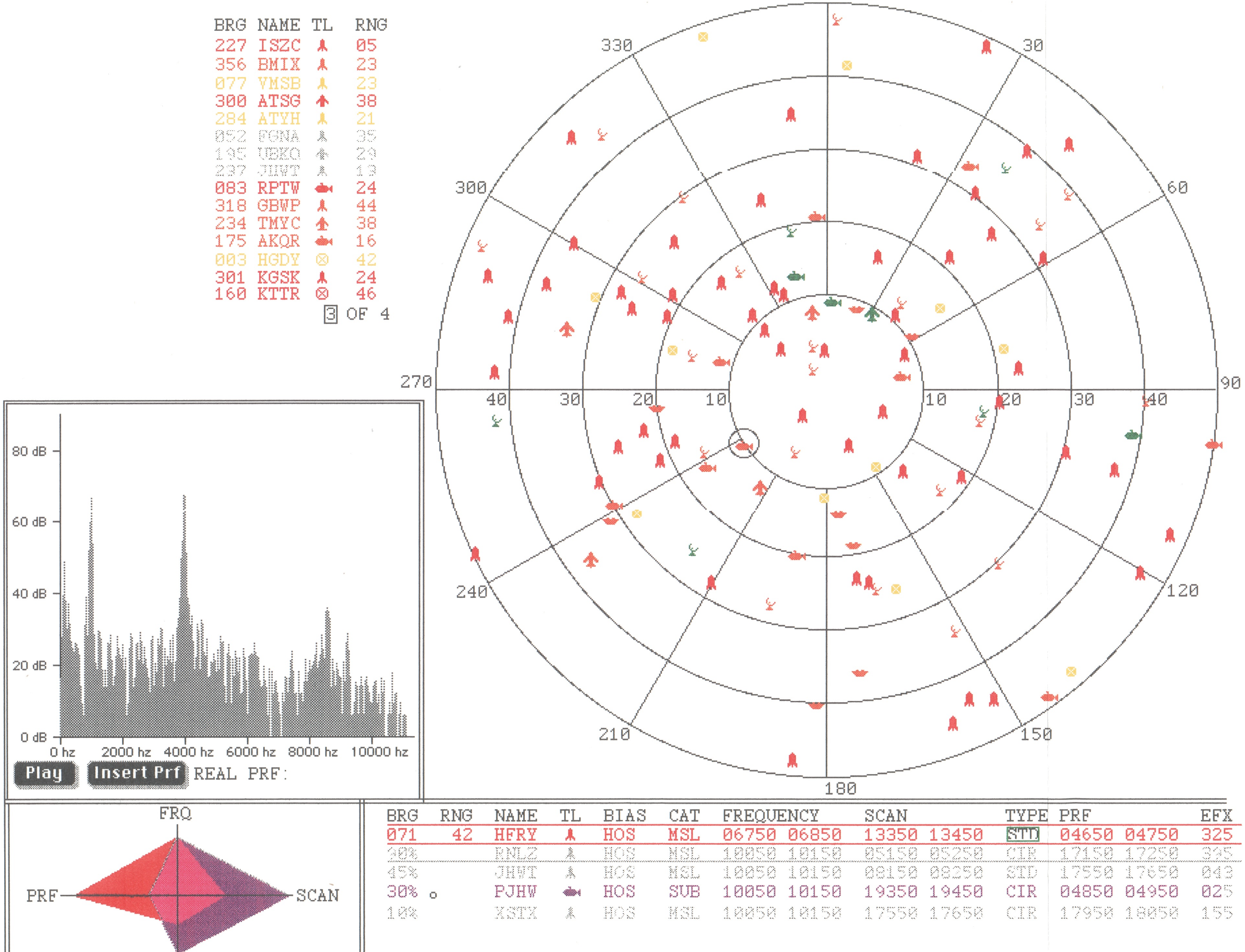


Figure 66. A simulation of the Direct-Manipulation Interface (Cropped to maintain scale).

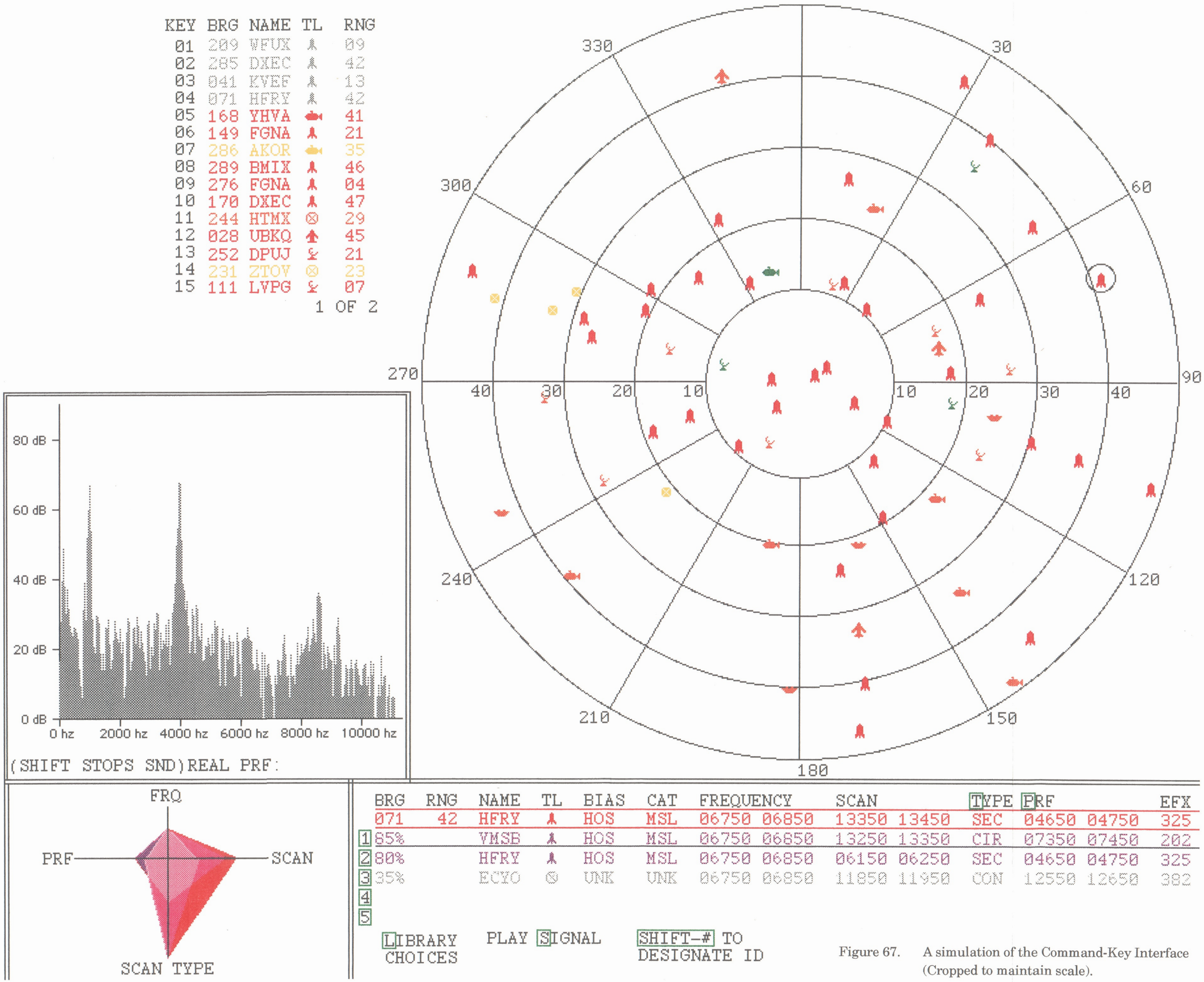


Figure 67. A simulation of the Command-Key Interface (Cropped to maintain scale).

APPENDIX B: GROUP SCALING

TABLE 65
Group Scaling for Subjective Workload Assesment Technique

TIME LOAD	EFFORT LOAD	STRESS LOAD	WORKLOAD SCORE
1	1	1	00.0
1	1	2	20.4
1	1	3	40.8
1	2	1	12.4
1	2	2	32.8
1	2	3	53.2
1	3	1	26.4
1	3	2	46.8
1	3	3	67.2
2	1	1	10.3
2	1	2	30.7
2	1	3	51.1
2	2	1	22.7
2	2	2	43.1
2	2	3	63.5
2	3	1	36.7
2	3	2	57.1
2	3	3	77.5
3	1	1	32.8
3	1	2	53.2
3	1	3	73.6
3	2	1	45.2
3	2	2	65.6
3	2	3	86.0
3	3	1	59.2
3	3	2	79.6
3	3	3	100.0

APPENDIX C: INFORMED CONSENT FORM

You are being asked to participate in a research project. The purpose of the study is to determine performance differences given various computer prototypes. You will be asked to complete 30 separate trials. It is anticipated that the entire experiment will take approximately 34 hours total of your time, spread over 10 days. This research is being conducted by the Human Factors Laboratory of the Department of Industrial and Systems Engineering. ISE research team members on this project include:

Richard Miller, Doctoral Student (231-3323)
Dr. Robert J. Beaton, Faculty Member (231-5936)

The study consists of two parts: introduction/screening, and training/ experimental sessions.
Screening tests: You will be required to complete a screening procedure. This screening procedure includes testing with Dvorine Color Plates to ensure that you do not have color-deficient sight. This procedure takes approximately one minute.
After the screening, you will be asked to perform a card sort for the Subjective Workload Assessment Technique. This card sort entails rank ordering 27 different cards based on your judgment of the cognitive workload.

Introduction/ consent form/ SWAT 90 minutes

Experimental sessions: The experimental sessions require training you on a task using the computer. The task will be taught first by components then in whole. You much reach a specified level of proficiency at the task prior to testing.
There will be eight different experimental testing conditions. Since you must learn the task prior to the first of these, the first training session will take the longest. The approximate length of the first training session is expected to be about three and a half hours.

Training on scan types15 minutes
Training on symbol set15 minutes
Training on threat level15 minutes
Training on hooking targets60 minutes
Training on the task 60 minutes
Testing30 minutes
Total Time195 minutes
(about 3 hours 15 min.)

Each of the seven subsequent test trials will last approximately 3 hours:
Review of scan types 5 minutes
Training on symbol set15 minutes
Training on threat level15 minutes
Training on hooking targets60 minutes
Training on the task45 minutes
Testing30 minutes
Total Time170 minutes
(about 2 hours 50 min.)

These 8 test trials will occur in consecutive days according to your schedule. YOU MUST BE ON-TIME FOR ALL YOUR SCHEDULED SESSIONS due to the necessity to run participants back to back.
If you decide to participate, you will be paid approximately $3.50 per hour ($10.00 per day) for the actual time you participate. If you complete all trials, you will be paid an additional bonus of $50.00.
Your participation will require you to be available for the following days;

Day 1 SWAT Training 90 minutes

at some point, within a few days of your first session you will need to return for 8 consecutive days;

Day 2	1st configuration	3.5 hours	$10.00
Day 3	2nd configuration	3 hours	$10.00
Day 4	3rd configuration	3 hours	$10.00
Day 5	4th configuration	3 hours	$10.00
Day 6	5th configuration	3 hours	$10.00
Day 7	6th configuration	3 hours	$10.00
Day 8	7th configuration	3 hours	$10.00
Day 9	8th configuration	3 hours	$10.00

In a few weeks you will be asked to participate in the three final sessions;

Day 10	9th-11th configuration	7 hours	$70.00

After each day you will be paid $10.00 the time you have completed on the experiment. After completing the sessions on Day 10 you will be paid $20.00 for that day, and a the bonus of $50.00.

It is important that once you commit to the schedule accepted by the research team and you, and that you keep to that schedule. You can not miss any of the Day 2 to 9 sessions. **If you miss even one day, you will NOT be eligible for the $50 bonus.**

The first 9 days could start on any day of the week, depending on what day you start you will have to have sessions on at least one Saturday and Sunday. There is some flexibility within a few-day window to help you with scheduling, but you need to attempt to run days 2-9 consecutively. There will be several days (and as much as a few weeks) between Day 9 and Day 10.

Risks and Rights: There are no known risks associated with this research. The only known discomfort to which you will be exposed is possible fatigue resulting from the length of the study. However, you will be permitted to take rest breaks. Sandwiches, fruit and drinks will be provided between configurations. As a research participant, you have certain rights:

1. It is your right to withdraw from the study at any time for any reason.

2. Members of the research team will answer any questions you may have concerning this research. You should not sign this consent form until you are satisfied that you understand all the terms involved.

3. You have a right to see your data and withdraw it from the study if you so desire. If you desire to withdraw your data, please inform the site monitor immediately. Otherwise, identification of your data will not be possible since it is separated from the participant in order to ensure anonymity.

4. If you wish to receive a summary of the results of this research, please include your address (where you expect to be living three months from now) with your signature below. Please do so only if you are truly interested in seeing the results. If you desire more detailed information after receiving the synopsis, please contact the Human Factors Laboratory and a full report will be made available to you.

5. Should any further questions or problems arise, you may contact any of the research team members. If you have any concerns about the way the research is being conducted or the way you are being treated, you may contact Dr. E.R. Stout, Chairman of the Institutional Review Board (231-5281).

Your participation is greatly appreciated and we hope that will find the study to be an interesting experience. Your signature below indicates that you have read this document in its entirety, that your questions have been answered, and that you will not discuss participation in this study with anyone until April, 1992 when the study is to be completed.

Print Name　　　　Signature　　　　Date

APPENDIX D: INSTRUCTIONS TO PARTICIPANTS

Explanation of AN/SLQ–32(V) System

You are being trained to do one of the primary duties of a naval Electronic Warfare officer, or EW operator. In this scenario, you are on a ship and your responsibility is to observe the environment around the ship through the use of a radar-type scope to detect, identify and classify the emitters (such as missiles, planes, ships and subs) that you encounter. The reason that you do this task is that although the computer is very good at detecting signals from other vessels, it is poor at making correct identifications. However, you are able to take several pieces of information and make the correct identification.

In general, you will have a primary display that shows where the emitters are in relation to your ship. You must process each and every one quickly and accurately using the functions available to you to evaluate certain parameters associated with each emitter. Those parameters include:

-the emitter's frequency (a number ranging from 100 to 20,000)

-the threat level (a number ranging from 0 to 7)

-the PRF, or pulse repetition frequency (another number from 100 to 20,000)

-the scan type of the emitter

-and the bias factor (the type of emitter; Hostile or Friendly)

The role you play in performing this task is critical to the protection of you, the ship, and everyone on board. For instance, if a missile has been launched at your ship, you may have as few as thirty seconds to identify the emitter as hostile. Clearly, the consequence of not making a correct identification is great. Therefore, in the performance of this task, SPEED AND ACCURACY are of the essence.

In the upcoming sessions, we will train you on the components of the task and subsequently, the whole task. Once you have learned the task and can perform it as quickly and accurately as possible, we will test you on your performance.

(Show DCC) Do you have any questions at this time?

Sound Training

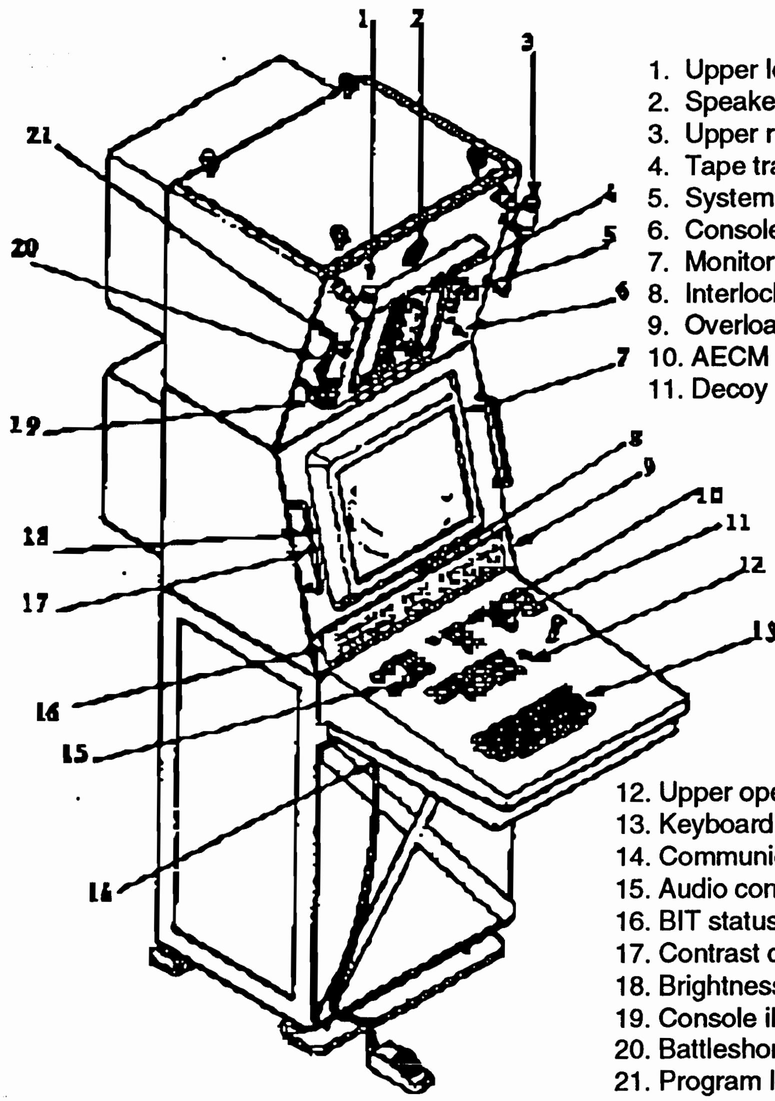
[Use the computer trial sessions.]

The emitters each have a sound that identify the scan type of that emitter. Put differently, the way an emitter emits "radar" waves is called a scan type, and helps to identify what the purpose of that emitter is. For our purposes, there are four scan types that you will need to identify.

Those types are standard (STD)*, Circular (CIR)*, Conical (CON)*, and Sector (SEC)*.

[Run the trials, and explain each sound as you get to it.)

See how standard (STD) signal sounds like a constant tone, with a regularly appearing signal. Notice how the picture represents these signal spikes appearing out of the constant tone.



1. Upper left floodlight
2. Speaker
3. Upper right floodlight
4. Tape transfer assembly
5. System power control
6. Console breaker
7. Monitor Assembly
8. Interlock status indicator
9. Overload status indicator
10. AECM control group
11. Decoy launcher control group
12. Upper operator panel control
13. Keyboard control group
14. Communications connectors
15. Audio control group
16. BIT status group
17. Contrast control
18. Brightness control
19. Console illumination control
20. Battleshort control
21. Program load control

This is a circular (CIR) scan type. It sounds like an object is putting out a signal and rotating it around it's entire body, so that the sound seems to get louder as it comes near you, fades as it moves away, then gets louder as it comes back around. The picture looks like this.*

This scan type is a Conical (CON) type. The sound sounds like an emitter is continuously pointing a beam at you, and moving that beam around in small circles (but still pointing at you). This would be illustrated by a cone coming out of the front of an emitter. Listen to what a conical sound sounds like. Not the illustration of the scan type.

This scan type is a Sector or SEC type. The sound represents a beam pointing out at you scanning back and forth is a small sector over you. The signal sounds like it is going back and forth over you...it has a "tinny" quality to it. Notice how that scan type looks when graphed.

We'll just run through the first session of these sounds together to get you familiar with the scan types, then I will let you repeat sessions on your own to practice. In order to participate in the study you must maintain the highest level of accuracy. Sounds will be presented in sets of 25. You will have to go though (5 - pretest or 1-session) set(s) of these sounds. Try not to make any mistakes. Do you have any questions?

Emitter Symbol Training

Configurations 1 & 5: Old NATO/B&W

(*-Denotes pointing to the object.)

Here (show card) are the eight different types of symbols that you will need to work with. Note that there are hostile types, which are designated with "v" shapes* around a dot; and there are friendly types, which are designated with half circles* around a dot. In the AN/SLQ–32(V), hostile is abbreviated "hos" and friendlies are "fnd".

A half-square* over a dot represents an unknown ("unk") bias factor. A bias factor is the classification, such as a hostile aircraft, a friendly sub, etc.

The two overlapped "x's"* represents a missile---which is always considered hostile. The abbreviation for missile is "msl"

For aircraft (or "air"), the dot is always represented with a "hat" over it*, the shape of which depends on whether the emitter is hostile or friendly.

For surface ships ("sur") or land-based emitters (simply, "land"), the dot is surrounded by the corresponding shape: one on top and one underneath*.

For submarines ("subs"), the friendly half circle or hostile v-shape is underneath the dot*.

You may have as much time as you would like to study these emitters. Let me know when you would like to practice identifying these emitters. Take as much time as you like.

Do you have any questions?

Configurations 2 and 6: Old NATO/Color

Here (show card) are the eight different types of symbols that you will need to work with. Note that there are hostile types, which are designated with "v" shapes* around a dot; and there are friendly types, which are designated with half circles* around a dot.

A half-square* over a dot represents an unknown ("unk") bias factor. A bias factor is the classification, such as a hostile aircraft, a friendly sub, etc.

The two overlapping "x's" * represents a missile---which is always considered hostile (Missile is abbreviated as "MSL" by the AN/SLQ–32(V).).

For aircraft ("air"), the dot is always represented with a "hat" over it*, the shape of which depends on whether the emitter is hostile or friendly.

For surface ships ("sur") or land-based emitters (simply, "land"), the dot is surrounded by the corresponding shape: one on top and one underneath*.

For submarines ("sub"), the friendly half circle or hostile v-shape is underneath the dot*.

In addition to the shape of the emitter, the emitters are coded with color. All missiles are red.* All other hostiles (air, subs, sur/land) are an orange or amber color.* All friendlies are coded green *.

Unknown emitters are yellow*.

You may have as much time as you would like to study these emitters. Let me know when you would like to practice identifying these emitters. Take as much time as you like.

Do you have any questions?

Configurations 3 and 7: NEW NATO/B&W

Here (show card) are the six different types of symbols that you will need to work with. The shape of the emitter depicts what kind of an emitter is being depicted:*

-missiles look like missiles ("msl")

-aircraft ("air")

-surface ships ("sur")

-submarines ("subs)

-land-based emitters, or "land" (look like satellite dishes)

-and unknowns ("unk") are boxes with an "x" inside

Note that missiles are always "hostile" ("hos"). The remainder of the symbols may be either hostile or friendly (fnd)--which you will have to determine by reading the "bias factor". We will train you on those threat levels in the next session.

For now, just memorize the symbols. You may have as much time as you would like to study these emitters. Let me know when you would like to practice identifying these emitters. Take as much time as you like. Do you have any questions?

Configurations 4 and 8: NEW NATO/Color

Here (show card) are the ten different types of symbols that you will need to work with. The shape of the emitter depicts what kind of an emitter is being depicted:*

-missiles look like missiles ("msl")

-aircraft ("air")

-surface ships ("sur")

-submarines ("subs")

-land-based emitters, or "land" (look like satellite dishes)

-and unknowns ("unk") (boxes with an x inside)

Note that missiles are always "hostile" and red. The remainder of the symbols may be either hostile or friendly ("fnd")---which you will have to determine by the color. All hostile emitters that are not missile will be coded orange or amber in color*.

All friendlies are green*. Unknown emitters are yellow.

For now, just memorize the symbols. You may have as much time as you would like to study these emitters. Let me know when you would like to practice identifying these emitters. Take as much time as you like. Do you have any questions?

Threat Level Training

(This session follows training of emitter types except for NEW operator NATO/Color)

(Show appropriate configuration-specific card.)

Now that you know and can recognize the emitter symbols, you need to be learn the threat level, often abbreviated "TL" for each type.

Threat levels range from zero to seven, with zero being no threat, and seven the highest level of threat.

All friendlies, regardless of type, are considered "zero"*.

There is no "1" or "2" level.

All unknowns are considered intermediate levels of threat---a "3"*.

All hostile land based threats are "4"*.

All hostile surface ships or hostile submarines are a threat level of "5"*.

All hostile aircraft are a threat level "6"*.

Finally, all missiles are hostile, and are a threat level of "7".

You may now study the TLs for as long as you like, and when you are ready we will practice identifying them. Do you have any questions?

Hooking

Now we are going to practice the first part of the task, which means that you are sitting at your console and encounter new emitters.

An alert will sound when new emitters appear. The AN/SLQ–32(V) will try to identify the new emitters, and will present what it believes to be the correct identification on the Polar display* AND will list them here* in a "Threat Summary List". You must try to locate and identify each of the emitters that appears in the threat summary list. Each new emitter is registered on this summary, and you will try to process them in the order they appear – or more simply, top to bottom.

Polar Configurations

In this type of display, you have what is called a Polar display. Each of the bearing lines represents a location or bearing in degrees around you (your ship is in the center*). Zero or 360 is ahead of you, or the top of the display. 90 degrees is to the right of you, 180 behind you (or at the bottom of the screen), and 270 is to the left of you. To help you, the three regions of the display are used by the computer to portray what kind of emitter is on that bearing.

These rings on the Polar display* do NOT portray distance from your ship. Instead, they are meant to assist you by displaying the emitters according to threat. Because you are mostly concerned with threats, the largest section is this * intermediate section, which is where all missiles (TL of 7) will appear. In the center of the display, all friendlies (TL of 0) will appear. Do not be confused because the innermost circle does not have bearing lines---you simply must imagine the bearing lines to extend into the center. In the very outermost ring, all unknowns and non-missile hostiles will appear (TLs 3-6).

The way to find the emitter is to read the information in the threat summary list, correlate it with what you've been taught about symbols and threat levels, and then go out and "hook" the emitter. Hooking means you place the cursor over the emitter you think is the right one, then you "click" the mouse button.

When any emitter has been selected by you in this manner, the computer does what is called "placing the emitter in close control", which means that it displays here * all the parameters of the emitter that you have selected. You may determine by reading those parameters whether you have or have not "hooked" the emitter you intended to identify. There are two things that happen when you hook the correct emitter:

(1) the emitter is "grayed out" on the threat summary list

(2) the close control parameters match* the threat summary description of that emitter.

Only 15 new emitters can be listed in the threat summary* list at a time. If there are more than 15 new emitters, the emitters are located on subsequent "pages". The number of pages of emitters is given here*. If you want to go to other pages, you use the "up" arrow* to go to the next page and the "down" arrow to go to a previous page.

Remember, you must process the emitters from top to bottom of the list. Also remember that SPEED and ACCURACY are essential! Be sure to use all the relevant information to help you---such as which ring on the primary display contains what emitters, etc. Your mean time will appear on the screen after each trial.

Do you have any questions?

I will now ask you to practice hooking emitters to the best of your ability. Remember, you must work as quickly and accurately as possible. As you go through these practices, try to think of strategies that will enable you to go as quickly as possible.

Range Configurations

Now we are going to practice the first part of the task called hooking. You are sitting at your console and encounter new emitters.

An alert will sound, and new emitters will appear on the Range display and will be listed here in the Threat Summary List*. You must try to identify each of the emitters that appears in the threat summary list*. Each new emitter is registered on this summary, and you will try to process them in the order they appear---or more simply, top to bottom.

In this type of display, you have bearing lines* which represents a location of an emitter with respect to degrees around you (your ship is in the center). Zero or 360 is ahead of you, or the top of the display. 90 degrees is to the right of you, 180 behind you (or at the bottom of the screen), and 270 is to the left of you. To help you, there are concentric rings which mark distance or range away from you*.

The way to find the emitter is to read the information in the threat summary list, and then go out and "hook" the emitter like you did in the previous training session.

When any emitter has been selected by you in this manner, the computer does what is called "placing the emitter in close control", which means that it displays here * all the parameters of the emitter that you have selected. You may determine by reading those parameters whether you have or have not "hooked" the emitter you intended to identify. There are two things that happen when you hook the correct emitter:

(1) the emitter is "grayed out" on the threat summary list

(2) the close control parameters match the threat summary description of that emitter.

Only 15 new emitters can be listed in the threat summary list at a time. If there are more than 15 new emitters, the emitters are located on subsequent "pages". The number of pages of emitters is given here*. If you want to go to other pages, you use the "up" arrow* to go to the next page and the "down" arrow to go to a previous page.

Remember, you must process the emitters from top to bottom of the list. Also remember that SPEED and ACCURACY are essential! Your mean times will be displayed on the screen after each of the trials.

Do you have any questions?

I will now ask you to practice hooking emitters to the best of your ability. Remember, you must work as quickly and accurately as possible. As you go through these practices, try to think of strategies that will enable you to go as quickly as possible.

Integrated Task Training: Configuration Task Stabilization

Now we are going to work on the entire task.

One of your "tools" you have to help you in this identification and classification task is a set of Publications or pubs*. [Show pubs.] The pubs are a reference that list all the existing emitters. Emitters are listed by order of their Cross-reference number in the front of the pubs and by frequency in the back.

Each emitter has a unique 3-digit number associated with it which is used to identify that emitter. The number is referred to as an EFX (emitter file index) and is located on the first few pages in the pubs*.

I will come back to how to use the pubs in a bit.

You know that on the Polar/Range display, when the AN/SLQ–32(V) detects new emitters, an alert sounds, the new emitters appear, and the emitters are listed on the threat summary list. These emitters on the Polar/Range display represent the AN/SLQ–32(V) (computer's) guess at the correct identification.

When your AN/SLQ–32(V) detects new emitters you will hear an auditory alert. Starting at the top of the list, you will need to locate the corresponding emitter on polar/range display. Once you have hooked the correct emitter, you will need to evaluate the emitter on each of the following parameters to see whether or not the computer has correctly identified and classified the emitter:

• Threat level, • Bias Factor, • Frequency

• Pulse Repetition Frequency (PRF), • Scan Type, and • Scan

The computer can always be relied on to give you the correct location and frequency of an emitter, but it is not always accurate with any of the other parameters.

Sometimes you will notice that there are inconsistencies between the symbol threat level or type in the threat summary list and symbol displayed on the Polar/range display.

Sometimes you will see that after you have hooked an emitter, the parameters that show up in the close control box* are inconsistent with the parameters listed in the threat summary list.

Or perhaps there are inconsistencies between the threat summary list, polar/range display, and the close control information.

Any inconsistency is a clue that the computer (AN/SLQ–32(V)) has made an incorrect designation. In fact, everything could be correct in the list but the Scan number. Unfortunately there is no way to check to see if the Scan number is correct, so you must go to the pubs to figure out the correct EFX.

On a real ship, the EW operator can check the scan type, the pulse repetition frequency (PRF) and scan of an emitter by using another piece of equipment located on the ship. This other piece of equipment is MORE ACCURATE than the AN/SLQ–32(V) at identifying scan type and PRF. It presents an audio display of the scan type so the EW operator can listen to and determine scan type; it provides a readout of the PRF.

In this scenario, we give you this "other piece of equipment" on this same MACINTOSH screen with the press of a button located here*. The button is labeled "Sig Sel" for Signal Select. When you wish to check the accuracy of the AN/SLQ–32(V) classification of PRF and scan type, you "use" this other piece of equipment. To turn off this other piece of equipment, you hit the Shift Key. Before you do any further function, you must hit the Shift Key which stops the SIGNAL SELECT actions. (* Demonstrate the ULQ-Sig Sel.)

During the session you might find the information on the ULQ and the close control area to match, even so you need to figure out the correct sound in order to designate the correct EFX number. Since the first few pages of the publications contain the correct EFX numbers you need to figure out the correct cross-reference number. The correct cross-reference number is found by looking up the Frequency and PRF listed in the main part of the publications finding the correct entry in the back of the publications* (demo). Then use the X-REF number to search the listing in the front of the publications. Each X-REF number will have two entries, you must use your knowledge of the emitters sound type to determine which of the two entries is correct* (demo). Once you have picked what you think is the correct entry find the EFX listed. Enter the EFX number in the close control box by hitting the DesigID button, and entering the 3-digit EFX and then hit the Return Key. Note how the Design ID will bring up a box for the EFX entry here* (demo). The DesigID button will not function with the ULQ window open, as shown here* (demo).

So, after you have hooked the correct emitter, there are several things that you will want to check (these items are not in any order---you will need to adopt your own strategies):

- TL, emitter symbol, name, and bias factor are consistent across all displays (threat summary list, close control, and main display)

- Scan Type and PRF

You must consult the pubs for the correct EFX #.

If you need to use the pubs pick up the book, and search for the correct emitter.

After you have found the correct EFX (by searching for the correct designation), you must hit the DESIG key, enter the three-digit EFX, then the Return Key.

Remember after processing each emitter, you must Designate the EFX, even if it is already correct.

Also note that after you have hooked the emitter at the top of the list, it is "greyed" out of the emitter summary list (just like in the hooking practice trials).

As you process emitters from top to bottom of the threat summary list, you may occasionally hook an emitter out of order and see it grey out further down the list. In this case, it is up to you to either continue to identify the emitter you've accidentally hooked, and then resume with the top of the list–OR– you may simply continue to try and hook the emitter at the top of the list.

The order and strategy you use to go through this process is entirely up to you. You must remember that the critical factors are SPEED AND ACCURACY. The white box above the display is to provide you with feedback by displaying a mean time for each correctly identified emitter that you have processed.

The feedback is for you to use to decrease your times and to increase your accuracy. If you realized that you have not correctly identified an emitter because a time did not appear in the window, do not try to re-identify the emitter. Simply continue to the next emitter and do the best you can. Do you have any questions?

(Answer all questions---without telling them a specific strategy. Run trials.)

Task Session

Before Going into Description of IT TASK

This session will be very similar to the training session you just completed. You will now be given three seven minute sessions. Each one will have a different number of emitters on the screen, and a different number of emitters in the threat summary list. Remember that if you complete the emitters on the first page use the arrow keys to go to the second page of emitters. The session will time out, so go as FAST as possible and designate as many emitters that you can ---and as ACCURATELY as you can. At the end of the session you will need to answer three questions relating to the level of workload that you experienced during the session.

Take a minute or two to read this event scoring information for the SWAT workload measure.

Again, at the end of the session, you will be prompted by the computer to give a time load (1, 2, or 3), a mental effort rating (1, 2, or 3), and a psychological stress load rating (1, 2, or 3). Simply click the mouse over the appropriate number and then click "Return".

Interface Ranking

You used eight different versions of the AN/SLQ–32(V). This is a set of pictures that represent each of the versions. You will be shown two pictures at a time. Please select the picture that represents the version of the AN/SLQ–32(V) that you found to be easiest to use.

You used eight different versions of the AN/SLQ–32(V). You will be shown every possible combination. There will be a total of 27 comparisons, this will take about 5 minutes.

Experiment 2 Sound and Icon Training

Thank-you for returning for the second part of our study. Today we will train and let you use two versions of the SLQ. The training sessions will be similar, but much shorter than previously. You will be able to take breaks between each of the training sessions. Today's session will take about 3 1/2 hours.

If you would like to review the informed consent form, you may do so now.

Sound Training

The sound training is identical to the training you received in previous sessions.

[OPEN SOUND TRAINING MODULE]

As in the previous experiments, there are four scan types that you will need to identify.

Those types are standard (STD)*, Circular (CIR)*, Conical (CON)*, and Sector (SEC)*.

[Run participant with 10 sounds, and explain each sound as you get to it, if needed)

We'll just run through a few sounds (10) together to get you familiar with the scan types, then I will let you repeat sessions on your own to practice. Sounds will be presented in a set of 25. You will have to go though one set with 2 or less mistakes. Otherwise you will have to repeat the training. Do you have any questions?

[IF NEEDED]

See how standard (STD) signal sounds like a constant tone, with a regularly appearing signal. Notice how the picture represents these signal spikes appearing out of the constant tone.

This is a circular (CIR) scan type. It sounds like an object is putting out a signal and rotating it around it's entire body, so that the sound seems to get louder as it comes near you, fades as it moves away, then gets louder as it comes back around. The picture looks like this.*

This scan type is a Conical (CON) type. The sound sounds like an emitter is continuously pointing a beam at you, and moving that beam around in small circles (but still pointing at you). This would be illustrated by a cone coming out of the front of an emitter. Listen to what a conical sound sounds like. Not the illustration of the scan type.

This scan type is a Sector or SEC type. The sound represents a beam pointing out at you scanning back and forth is a small sector over you. The signal sounds like it is going back and forth over you...it has a "tinny" quality to it. Notice how that scan type looks when graphed.

2nd Session: Please complete one set of 25 sounds. The same passing criteria applies.

Icon Training

The icon training is identical to the training you received in previous sessions. Here (show card) are the ten different types of symbols that you will need to work with. Here are the symbols we will use for this study:*

For now, just memorize the symbols. Let me know when you would like to practice identifying these emitters. Icons will be presented in a set of 25. You will have to go though one set with 2 or less mistakes. Otherwise you will have to repeat the training. Do you have any questions?

2nd Session: Please complete one set of 25 sounds. The same passing criteria applies.

Experiment 2 IT Training

Direct Manipulation Interface - Training

In this scenario there are no publications, all the information is available on the computer screen. The pubs are now called the on-line library. It contains all the information about emitters that was contained in the paper publications.

You will use the threat list located here* (demo) to hook emitters. You do not need to search the range display. A single click will place the emitters information here* (demo). The information that was presented in the corner is now horizontal here* (demo). A double click will initiate a library search.

You will always use a double click on the Threat Summary list. Practice double clicking, if you do not double click correctly the system will not process your double click! Try clicking the icons they provide the best target for doing double clicks. (Example of how double clicks need to be completed) You know you double clicked successfully because library information will appear under the close control information located here* (demo). The same information was located in a block here* in the previous sessions. It is better to slow down and double click accurately than having to go back later and try double clicking again. If the library information does not appear in a second or two, you will have to double click again.

As in the previous experiments, the PRF in the Signal Select window is ALWAYS correct. Once you select an emitter you an insert the PRF into the close control parameters by clicking the Insert PRF button. You must press the "Play" button here* (demo) to hear the Scan Type. Use the pop-up menu located here* (demo) to set the Scan Type. By changing the Scan type the graphic representation will also change* (demo). This might help you compare the hooked graphic to the library graphics. You must choose a scan type in order to see the rest of the emitter information, but you must close the Signal Select before doing anything else. A click anywhere will close the Signal Select. If you try to double click an emitter while the Signal Select is open, it will not work; the first click will close the Signal Select and the second click will be like a single click to the emitter. To double click on something while the Signal Select is open you need to triple click. Once to close the Signal Select and twice for the double click* (demo).

The object display is shown here on the screen* (demo). It represents the most important parameters for determining the EFX of the emitter. Each vertex represents one parameter. For example, the computer thinks the PRF is XXX (use information on screen). This number is about X (fill-in from screen) percent of 20,000, so it appears about X percent of the way from the center to the perimeter. By clicking on one of the selections in the library the information for that emitter is shown over the hooked emitters information. By looking at each corner you can compare how close each of the four parameters match on the object display. By comparing each of the library entries listed to the information presented by the computer you can then determine the correct emitter identification. You can select on any emitter listed in the Library field to make the corresponding graphic appear on the polygon display. If you wish to remove a graphic, click on the graphic again. Two clicks in rapid succession are considered a double click by the computer. Do not double click on an emitter unless you wish to designate that emitter as the correct choice.

Double click on the library choice to designate it* (demo). Note the tone, the graphic overlays match exactly and any information in the Close control parameters are identical. This means a designation has been made, it does not mean that it was correct. Once you hear a tone, even if you know you have made a mistake go to the next emitter. If you try to fix your error by designating other choices it will add to your time and will not help your performance.

As you process emitters from top to bottom of the threat summary list, you may occasionally select an emitter out of order., go ahead and process that emitter. Order is not important. Remember, you will get more than one page of emitters, do not stop once you have completed one page. Use the pop-up menu, located on the page identifier, to change pages* (demo). If the page identifier displays "1 of 1" then there are no more pages of emitters.

One suggested strategy for processing emitters would be to select an emitter, in the order that it appears on the list, Insert the PRF, (if only one emitter listed designate it immediately), select the "Signal Select", adjust the Scan Type and start to compare the emitters by clicking on them or scanning the text until you find a match. Occasionally, you will see only one emitter listed in the library. Since the correct emitter will always be listed in the on-line library, it must be the correct emitter., so try to designate it immediately* (demo how information comes up and you can just go over to library and designate emitter without Signal Select, or after Signal Select, but without setting the Scan Type). You can use the graphics, the library list (just using the textual information), or both (the text and graphics) to compare emitters and select the emitter to designate. You will only need to compare the Scan Type and PRF to determine the correct emitter.

You will have 3 minutes to process as many emitters as possible. This is a practice session. Be concerned with making an accurate analysis of the emitter parameters. You will have 9 sessions to practice. We will review your scores at the end of each practice session to confirm that you are designating emitters properly. Let's try some together. [Do a training session, do the first 3, and then let the subject do 3, with you commenting on how to do it]

Direct Manipulation Interface Only - IT

This session will be very similar to the training session you just completed. You will now be given three seven minute sessions. Each one will have a different number of emitters on the screen, and a different number of emitters in the threat summary list. Remember, if you complete a page of emitters use the pop-up menu to go to the next page of emitters. If you have processed all the emitters on all pages, just wait more emitters will appear in a few seconds. If you process all the emitters, the time you wait improves your performance, but making errors just to beat the computer is not productive. It is possible to do from 2 to 4 pages of emitters, depending on the conditions of the trial. The session will time out, so go as FAST and as ACCURATELY as you can.

If you attempt to designate an emitter (double clicking) while new emitters are appearing on screen you might have to try designating it again. Listen for the designation tone.

Take a minute or two to read the event scoring information for the SWAT workload measure. At the end of the sessions, you will be prompted by the computer to give a time load (1, 2, or 3), a mental effort rating (1, 2, or 3), and a psychological stress load rating (1, 2, or 3). Simply click the mouse over the appropriate number and then click "Return".

Command-key Interface - Training

In this scenario there are no publications, all the information is available on the computer screen. The pubs are now called the on-line library. It contains all the information about emitters that was contained in the paper publications.

You will use the threat list located here* (demo) to hook emitters. You do not need to search the range display. There can be up to 15 emitters listed in the Sequence List. Use the corresponding function keys to select an emitter on the list and place the emitters information here* (demo). The information that was presented in the corner is now horizontal here* (demo). Holding the shift-key down while Pressing the function key will do a library search on that emitter.

You will always use shift-function key # to select from the Threat Summary list. Practice the shift-function key #, if you do not hold the shift key down properly the system will not process your request! Try holding the shift key down before during and after pressing the function key* (Demo how to shift select). You will know you shift-selected successfully because library information will appear under the close control information located here* (demo). This is the same information that was located in a block here* in previous sessions. It is better to slow down and shift select accurately than to go back later and try again. If the library information does not appear in a second or two, you can also use the "L" key to perform the library search. Shift selecting and using the "L" key are identical in function.

You must press the "S" key* (demo) to hear the Signal. Use the "T" located here* (demo) to set the Scan Type. Pressing the SHIFT key will close the Signal Select. You must press the SHIFT key to proceed. So, you must remember the Scan type and PRF. You can always go back to the Signal window if you forget the PRF.

Repeatedly selecting the "T" will toggle through the list of possible scan type choices* (demo). Sometimes the Scan type is correct the first time you press the "T" key. By changing the Scan type the graphic representation will also change* (demo). This might help you compare the hooked graphic to the library graphics. You must choose a scan type in order to see the rest of the emitter information, but you must close the Signal Select before doing anything else.

As in the previous experiments, the PRF in the Signal Select window is ALWAYS correct. Once you select an emitter you an insert the PRF into the close control parameters by pressing "P", and typing in the PRF value. Since you cannot type and have the signal select on screen, you must remember the PRF value. You do not have to set the PRF, but it makes comparing the library information easier* (demo). All PRF's end in 50, if you enter a PRF that does not end in 50 the system will not accept your input. If you enter a PRF incorrectly, but it ends in 50, the system WILL accept your input* (demo).

The object display is shown here on the screen* (demo). It represents the most important parameters for determining the EFX of the emitter. Each vertex represents one parameter. For example, the computer thinks the PRF is XXX (use information on screen). Since PRF can range from 0 to 20,000 it scales the PRF to fit onto the axis about here* (demo). This number is about X (fill-in from screen) percent of 20,000, so it appears about X percent of the way from the center to the perimeter. By selecting a library entry, the graphic for that emitter will be shown over the hooked emitters information. By looking at each corner you can compare how close each of the four parameters match on the object display. By comparing each of the library entries listed to the information presented by the computer you can then determine the correct emitter identification. You can select n any emitter listed in the Library field y pressing it's number to make the corresponding graphic appear on the polygon display. If you wish to remove a graphic, select the corresponding number on the keyboard again. Shift-clicking a number will designate the corresponding library choice.

To designate the emitter choose the shift-key and select the library number* (demo). NOT THE FUNCTION KEYS. You must hold down the shift-key while the number is being pressed. You will hear a tone if you have designated the emitter. The tone means that a designation has been made, it does not mean that it was correct. Once you hear a tone, even if you know you have made a mistake go to the next emitter. If you try to fix your error by designating the correct emitter it will add to your time and will not help your performance.

As you process emitters from top to bottom of the threat summary list, you may occasionally select an emitter out of order., go ahead and process that emitter. Order is not important. Remember, you will get more than one page of emitters, do not stop once you have completed one page. Once you have completed a page of emitters you can go to the next page of emitters by using the up arrow key* (demo). If the page identifier displays "1 of 1" then there are no more pages of emitters. The down arrow goes down to the next page, the up arrow goes to the previous page* (demo).

One suggested strategy for processing emitters would be to select an emitter, in the order that it appears on the list, select the "Signal Select", remember the PRF, and insert it, if necessary, adjust the Scan Type and start to compare the emitters by clicking on them or scanning the text until you find a match. Occasionally, you will see only one emitter listed in the library. Since the correct emitter will always be listed in the on-line library, it must be the correct emitter., so try to designate it immediately* (demo how information comes up and you can just go over to library and designate emitter without Signal Select, or after Signal Select, but without setting the Scan Type). You can use the graphics, the library list (just using the textual information), or both (the text and graphics) to compare emitters and select the emitter to designate. You will only need to compare the Scan Type and PRF to determine the correct emitter.

You will have 3 minutes to process as many emitters as possible. This is a practice session. Be concerned with making an accurate analysis of the emitter parameters. You will have 9 sessions to practice. We will review your scores at the end of each practice session to confirm that you are designating emitters properly. Let's try some together. [Do a training session, do the first 3, and then let the subject do 3, with you commenting on how to do it]

Command-key Interface Only - IT

This session will be very similar to the training session you just completed. You will now be given three seven minute sessions. Each one will have a different number of emitters on the screen, and a different number of emitters in the threat summary list. Remember, if you complete a page of emitters use the arrow keys to go to the next page of emitters. If you have processed all the emitters on all pages, just wait more emitters will appear in a few seconds. If you process all the emitters, the time you wait improves your performance, but making errors just to beat the computer is not productive. It is possible to do from 2 to 4 pages of emitters, depending on the conditions of the trial. The session will time out, so go as FAST as possible and designate as many emitters that you can ---and as ACCURATELY as you can. You will have 7 minutes to process as many emitters as possible. Be concerned with making an accurate analysis of the emitter parameters.

Take a minute or two to read the event scoring information for the SWAT workload measure. At the end of the sessions, you will be prompted by the computer to give a time load (1, 2, or 3), a mental effort rating (1, 2, or 3), and a psychological stress load rating (1, 2, or 3). Simply click the mouse over the appropriate number and then click "Return".

APPENDIX E: POST SESSION QUESTIONNAIRE

Please answer the following questions and give us your opinion of the interfaces. The more you tell us about the interface the better our results. Anything, even the smallest problems, or suggestions would be appreciated. We are concerned with making the system easier to use.

Notes: The questionnaire was administered to participants in a larger font. Free response areas are denoted with the "______", additional lines were provided on the actual questionnaire. [Numbers in brackets correspond to participant responses found in APPENDIX F: QUESTIONNAIRE RESPONSES on page 160.

How do you rate the command (button pressing) interface and the mouse interfaces? (Circle a score on a scale from 1 to 7). Please comment on why you scored each item.

The Command-Key Interface

[1] Command-Interface	Poor						Excellent
	1	2	3	4	5	6	7

[5] Why? ______

[2] Command-Interface	Slow						Fast
	1	2	3	4	5	6	7

[6] What about it made working with it slow (not the speed of the computer), but the interfaces ability to help you work quickly? ______

[3] Command-Interface	Inconsistent						Consistent
	1	2	3	4	5	6	7

[7] What about it was consistent or inconsistent? ______

[4] Command-Interface	Confusing						Makes Sense
	1	2	3	4	5	6	7

[8] Why?______

The Mouse Based Interface

[9] Mouse-based Interface	Poor						Excellent
	1	2	3	4	5	6	7

[13] Why? ______

[10] Mouse-based Interface	Slow						Fast
	1	2	3	4	5	6	7

[14] What about it made working with it slow (not the speed of the computer), but the interfaces ability to help you work quickly? ______

[11] Mouse-based Interface Inconsistent Consistent
1 2 3 4 5 6 7

[15] What about it was consistent or inconsistent? _____

[12] Mouse-based Interface Confusing Makes Sense
1 2 3 4 5 6 7

[16] Why? _____

[17] Which interface did you like better (circle one)? Command based -or- Mouse-based

[18] When using the Command interface did you get
the Function keys and the Library number keys confused? Yes No

[19] Which was easier; Double clicking or
shift-selecting emitters and library choices? Double-Clicking -or- Shift-Selecting

[20] Which made you make more mistakes? Double-Clicking -or- Shift-Selecting

What percentage of the time would you say you used each of these parts of the interface? Please make the columns total 100 percent.

	Command-based	Mouse-based
Range Display (Large Rings)	[21] ________	[22] ________
Threat Summary List	[23] ________	[24] ________
Library Area	[25] ________	[26] ________
Object Display (Diamonds)	[27] ________	[28] ________
Signal Select (Sound and Graphic)	[29] ________	[30] ________
Other?[33 and 34] ______________	[31] ________	[32] ________
Totals	(100%?)	(100%?)

[35] What about the Colors used on the display. Did they help you in any way? Why? _____
[36] Were the colors helpful on the versions you used in the last series of experiment? Why? __

How would you rate the interface compared to the previous version?

[37] Mouse-based Interface Worse Better
vs. Old Versions 1 2 3 4 5 6 7

[38] Command-based InterfaceWorse Better
vs. Old Versions 1 2 3 4 5 6 7

[39] Mouse-based Interface Slower Faster
vs. Old Versions 1 2 3 4 5 6 7

[40] Command-based InterfaceSlower Faster
vs. Old Versions 1 2 3 4 5 6 7

What suggestions do you have to improve the system and make the SLQ easier-to-use? Circle Mouse, Command, or Both types of interfaces for each comment.

[41] In the Threat Summary List? (M, C, B) _____

[42] In the Library? (M, C, B)_____

[43] In the Close Control Area (the hooked emitters information bar (in red)? (M, C, B) _____

[44] On the Object Display? (M, C, B) _____

[45] Did you like the pop-up buttons? Yes No

[46] Why? _____

[47] Did you like the PRF field, when you had to type in the PRF? Yes No

[48]Why? _____

[49] Which did you like better? Pressing the Insert PRF button -or- Typing the PRF

[50] Did the Labels and Prompts (like "Library Search") help? Yes No

[51]Why? _____

[52] What is your Age? _____

[53] Male or Female? _____

[54] What is your Major? _____

[55] Grad or Undergrad? _____

[56—Scored as a value from 1 to 8]
About how many hours a week do you use computers (circle one)?

0 to 4	4 to 8	8 to 12	12 to 16
16 to 20	20 to 24	24 to 28	More than 28

[57—Scored as a value from 1 to 4] About how fast do you type (circle one)?
Hunt and Peck H & P, but fast Touch Type, slow Touch type, fast

[58] Any other comments or suggestions for improving these or any of the other versions of the SLQ. We can load up and run any version if you would like to review something on one of the interface designs? _____

APPENDIX F: QUESTIONNAIRE RESPONSES

Participants answered the questionnaire with a pencil and paper. The results shown in this appendix are presented as written by the participants. Please refer to the column numbers to locate the corresponding questions shown in Appendix G. Column captions are shown in a footnote when sufficient room is not available in the title area.

The following words may be shown abbreviated: Double Click (DC), Shift-Select (SS) [Refers to the selection/activation procedure in the command interface], Mouse (M), Command-Key (C), Both (B) [Refers to both the Command-Key and Direct-Manipulation interfaces], Did not use or not applicable (n/a).

TABLE 66
Participant's Responses From Questions 1 to 5

Ss	1	2	3	4	5—Command-Key Interface (Poor & Excellent Comments)
A	5	6	6	3	Was probably a little faster to process emitters, no long mouse dragging to get to where you wanted to go.
B	5	4	4	4	It's better than looking things up in Pubs, but a pain to type in #'s, keep track of when to press 'shift', & also pressed # instead of F# (or revised) on occasion. I didn't like having to look from screen to keyboard, or back - it slowed me down.
C	2	2	3	3	Use a "next" button instead specific number (PR- keys), delete unnecessary "keys" - use a smaller keyboard, don't use shift key access- use other keys for this
D	6	6	6	6	Very easy to use - easy to access what you want when you want -- But, I would change either the function keys (emitter # in Threat summary list) or library number choices to alphabet characters.)
E	5	5	6	5	It was pretty good, I liked the keyboard over mouse for most projects
F	4	6	7	6	Seems to work well but some button presses do not take well. it does not place the corrected number into the emitter box unless you type it. This should be easier in the library the id # was too far from the numbers used for identification
G	5	6	6	3	I did not make mistakes as easily, but there were more buttons to push than w/ the mouse
H	6	5	7	7	The mouse requires too much movement the command keeps everything close together
I	5	5	6	4	Though the shift key was hard to register at times, it was easier to locate emitters and to press buttons (cause all those buttons were close together)
J	4	5	7	6	Needs more getting used to than the mouse - further it required a lot more concentration
K	7	7	6	7	Easier to push buttons than double click
L	5	5	5	5	Because there is less chance of error using a keyboard

1-4 —Command-Key Interface (Scale 1 to 7) Poor to Excellent, Slow to Fast, Inconsistent to Consistent, and Confusing to Makes Sense, respectively

TABLE 67
Participant's Responses From Questions 6 to 8

Ss	6— Command-Key Interface (Slow& Fast Comments)	7— Command-Key Interface (Inconsistent& Consistent Comments)	8—Command-Key Interface (Confusing& Makes Sense Comments)
A	Same as previous comment	Consistent from keypad to function keys (i.e., emitter #).	If you are really rushed, you can get number & key-pad & function keys messed up
B	Slow- shifting focus from screen to keyboard, pressing button combination, keying #'s & selecting scan type, Fast - not using Pubs!!!! Having all the info I needed on the screen. Seeing all my options at once.	Inconsistent - why press 'shift' to stop 'Play' - why not press 'S' again?	had 'Shift' key for too many different, sometimes unrelated things got F# & regular #'s confused sometimes made it hard to figure out where I was (did I need to start over on that emitters?)
C	Same as previous comment— too much key selecting time (keys not distinct)	Why use page up when I want to go back in list, press S twice for function on-off - why S key anyway.	After training "alright"
D	Confusion b/w function key #'s & library #'s, having to hold shift - liked using arrows for pages in threat summary list	Key identifications (first letters of words)	Easy to go exactly where you wanted, except for problem stated above
E	The shift idea really a; sucked b: didn't work well	The shift key seemed to be inconsistent everything else was fine. I mean I started using 'F1' 'L' instead of 'Shift' 'F1'	Directions seemed to have: a varying ways to do job, b: unnecessary data
F	Did not have to move mouse around. Seemed faster than mouse but keys were difficult to find.	All keys presses seemed very consistent	I had no problem with confusion
G	I was more sure of myself than w/ the mouse - w/ the mouse I had to be careful where I placed the cursor & I had to spend time getting it precisely in position	As stated above - the buttons didn't move- I knew where they were all the times & could hit them consistently	Hit the function keys & shift keys didn't necessarily make sense. I just had to memorize when to us them
H	The shift button procedure is a little too sensitive	Very consistent	Straight forward & easy to use.
I	Didn't have to worry about running out of mouse pad or getting cord tangled which add time and frustration to the user	Always seemed to work consistently- no fowl ups or errors	Hard to get to at 1st since all we've used before was the mouse
J	Same as previous comment	Unlike the mouse this was more??? - sometimes the mouse doesn't 'hook' right	After you get used to it
K	Easier to do	Most of the time, buttons activated properly	Intuitive
L	More familiar w/ a keyboard so I could react quicker	Didn't have to worry about whether a key was hit once or twice	Keyboards are used for many functions so again it was familiar

TABLE 68
Participant's Responses From Questions 9 to 14

Ss	9	10	11	12	13—Mouse-Based Interface (Poor & Excellent Comments)	14— Mouse-Based Interface (Slow& Fast Comments)
A	4	4	3	3	A lot of arm movement required especially over the 19" diagonal screen	Small target areas (pop-up window) compared to distance to travel across the screen. I did like the insert PRF key (button).
B	6	7	5	7	I liked this a lot! Much quicker, didn't have to look at keyboard or key in anything.	Didn't take much effort to move cursor to select items. However, I got slowed down when I didn't DC properly - maybe give more room around emitter icons, or make the whole line work for that? Slow-going to next page-maybe put [^ &v) to click on instead
C	5	5	6	6	Instant feedback but speed depends on moving hand	Moving hand
D	5	5	6	7	Primarily due to system constraints.... double clicks were hindered by processing speed of computer	Having to move the mouse from top of screen to bottom (Threat summary list & library) and vice versa.
E	6	6	7	6	More of a visual interfacing which eliminated keeping track of what icon you were on (for max speed you could remember 7 is next with the keypad, whereas the mouse just meant you go these)	When the double click either didn't register or only registered once
F	6	4	6	6	I liked the ability to directly effect the emitters. I.e., point and click. However I found it very fatiguing (physically)	It took a long time to move the mouse to different portions of the screen
G	5	6	4	6	With enough practice I became more efficient, there are less operations to perform, but getting the cursor in the right positions & getting the double click right required more coordination	As I said-the clicking of the mouse took time to get right-I often thought I'd clicked twice & in the right spot on symbol & moved on to the preset-& sound- before I realized there was no lib choice & I had to back & 2 click- w/ time I got better & faster
H	5	3	6	7	I didn't like having to track around the screen, it works but no quite as fast	It's easier when the buttons are at your fingertips instead of hunting down the icons
I	5	4	5	6	Sometimes computer does not register double clicks. Also w/ mouse it is hard to locate emitters on the grid	Cord got tangled; ran out of pad & had to start at top again; when clicks didn't register had to go back & reclick
J	6	7	5	7	A lot more user-friendly less time to get used to - less concentration demand	Same as previous comment
K	4	3	2	7	Not bad, but hard to double click	Had trouble double- clicking at times
L	1	?	2	2	I was very unfamiliar to with a mouse and kept messing up	The mouse had to be maneuvered to direct locations in order to be on the correct location,hard to maneuver.

9-12 —Mouse-based Interface (Scale 1 to 7) Poor to Excellent, Slow to Fast, Inconsistent to Consistent, and Confusing to Makes Sense, respectively

TABLE 69
Participant's Responses From Questions 15 to 20

Ss	15— Mouse-Based Interface (Inconsistent& Consistent Comments)	16—Mouse-Based Interface (Confusing& Makes Sense Comments)	17	18	19	20
A	Double clicking activation was a real pain. Very small area to double click in w/ no feedback that activation had been accepted.	same as previous comment, if double click was not activated there was no "feedback", had to double click again	CKI	Yes	SS	DC
B	Although thee were several different ways to complete each little part of the task (DC on icon, single click on 'Play', pop-up menus...), they were not confusing.	Nothing	DMI	Yes	DC	**
C	Why click to make sound disappear- why not leave on	Nothing	DMI	Yes	DC	SS
D	Double-clicking activation, single-click selection was consistent	Easy to "point" to what you want	CKI	Yes	*	DC
E	Self-explanatory	I didn't like all of the competing information; it seemed useless & therefore slowed down the computer speed, slowing me down	DMI	No	DC	***
F	No problems. DC was sometimes difficult but it was consistent	I do not have any real problem with this.	CKI	Yes	SS	SS
G	Even when I'd had more experience, I still messed up double clicking or designating the wrong line	If you can get the uncoordinated workers (like me) to be experts at DC, this would be the ideal interface- it makes perfect sense& requires less memorized (like when to hit function key over shift key	CKI	No	SS	DC
H	Double clicking too picky, too sensitive to minute movements, other than that it's fine	Straight forward & easy to use	CKI	No	SS	SS
I	Seemed to work consistently throughout- no noticeable inconsistencies	Because we used this much more, it was more natural & automatic to use	DMI	No	DC	SS
J	Sometime (I don't know why) it doesn't 'hook' right and requires multiple attempts	Takes very little time to get used to the system	DMI	No	DC	DC
K	If you didn't DC right, it wouldn't work	It was intuitive also	CKI	No	SS	DC
L	The double clicks were confusing and when you hit it a third time it would shut off	I kept messing up because I could not get the hang of the mouse	CKI	No	SS	DC

* DC for selection, SS for designation, **Don't know but w/ DC it was easier to tell if I made a mistake or not. *** DC, mistakes for clicking thus losing speed; not mistakes for info thus being wrong

17—Which did you like (Command based or Mouse based, CKI or DMI, respectively)
18—Did you confuse the function and library keys?, 19—Which was easier double clicking (DC) or shift-selecting (SS)
20— Which (DC or SS) made you make more mistakes?

TABLE 70
Participant's Responses From Questions 21 to 34

Ss	21	22	23	24	25	26	27	28	29	30	31	32	33	34
A	0	0	5	10	50	55	5	5	30	30	10	0	Keyboard	nothing
B	0	0	10	20	75	55	0	0	15	25	0	0	nothing	nothing
C	0	20	40	5	35	0	0	25	40	5	30	0	nothing	nothing
D	0	0	48.5	48.5	46.5	46.5	0	0	5	0	0	2	—	*
E	0	0	10	10	40	40	0	0	40	40	10	10	mistakes	mistakes
F	0	0	10	15	25	25	0	0	65	60	none	none	none	none
G	0	0	15	15	75	65	0	0	10	20	none	none	none	none
H	1	1	8	10	70	70	1	1	20	18	none	none	none	none
I	5	5	10	10	40	35	10	20	35	30	none	none	none	none
J	0	0	10	20	60	40	0	0	30	40	none	none	none	none
K	0	0	45	45	45	45	0	0	10	10	none	none	none	none
L	0	50	25	10	25	10	0	10	25	10	25	10	keys	mouse

* PRF assign, Threat summary list includes 2% for page #'s

21-22 Percent of time using the range display for the command and mouse interfaces, respectively
23-24 Percent of time using the threat summary list for the command and mouse interfaces, respectively
25-26 Percent of time using the library areafor the command and mouse interfaces, respectively
27-28 Percent of time using the object display area for the command and mouse interfaces, respectively
29-30 Percent of time using the signal select area for the command and mouse interfaces, respectively
31-32 Percent of time using other parts of the command and mouse interfaces, respectively
33-34 Names of "other" areas of the command and mouse interfaces, respectively

TABLE 71
Participant's Responses From Questions 35 and 36

Ss	35—Use of color	36—Were colors helpful in previous versions?
A	Color on the graphic display helped on the overlay. Also the highlighted line which indicated "designation" gave good feedback	Colors were good last time because they helped me pick out the emitter that I wanted to hook
B	Hiliting in library helped to distinguish what I had selected. Grey-out on summary list helped.	On finding emitters on Range display, yes. But I didn't even look at Range display in this experiment, so colors didn't matter.
C	Yes, active - passive action - might use more contrast between selected text and unselect	Yes, distinct between friendly/ non friendly
D	Helped in command key interface to distinguish "command-key" to use (a bit confusing when the text colors in threat summary did not match text listing in library)	Yes! Helped decrease search time on polar/range display
E	Not particularly because all I needed was a sound type 7 a #	Yes, because icons were necessary for my calculations & color helped classify them better, thus giving better RT's (I thought so anyhow)
F	Yes, It was easy to determine that the read hading at top of the threat summary list was the standard and to indicate that items were selected	Yes, it made it easier to determine/find icons in the range display
G	The only way the colors helped me today (since I didn't look at the target or "range display") was to see which emitter I had hooked already verses which I had to hook next (grey to orange, etc...)	Yes, very much! The colors helped me locate the emitters faster because I could distinguish them easier Ex: if 2 emitters were close to each other in the uncolored display I had to look closely at its shape where as w/ the color display I could quickly pick the right one
H	NO, WITH THE EXCEPTION OF THE TRAT SUMMARY LIST, that only showed me where I was on the list quickly	A little, they would keep monotony from setting in as badly
I	Didn't really notice them since errors are being corrected & one could be an error	More helpful here because we had to go out & select emitters from the grid
J	No- They would matter only if user actually had to hook item in large display. on further thought, maybe- they removed the monotony of the screen	Yes- for the same reason as above
K	Yes - easy to tell where you were in threat summary list	Yes - easy you could hook icons on range display and the pervious reason
L	Yes, colors helped identify different pieces of equipment	No because you didn't have to hook the objects to do in the library & id the objects

TABLE 72
Participant's Responses From Questions 37 to 42

Ss	37	38	39	40	41—Threat Summary List Suggestions	42—Library Suggestions
A	6	7	6	7	M- Bigger area to double click in. Feedback to let you know double click activated	B - Line #'s on both sides of the data the 2 important items in this task were on the left side of the data. If there were 8 or 9 choices & the emitter needed is in the middle, you have to follow line over to left or count line.
B	6	7	6	7	Nothing	B - Why doesn't library come up immediately even if there is no double click (M) or Shift F# (C) used? This would be helpful to avoid having to re-do one or the other
C	7	4	7	5	B- better highlighting C select "next" key alphabetical order sound select	highlight sound text- color code individual sound indictors
D	6	7	6	7	M- Mouse, but have the emitter under the cursor highlighted in some way to facilitate selection (Like a pull down menu), - change the page manipulation to arrow-key functions	C- (or possibly both)
E	6	6	7	7	B-Eliminate the unnecessary info get rid of the Radar picture, the object display, ability to enter in a PRF, when you hit 'T' you don't need the correct choice in the box to make a choice—so why even have a T choice—just automatically pick a random one so as together the signal PRF up	B - same as previous comment
F	6	6	7	7	C - mouse requires too much movement, it is easy to press the F key	M - it is less likely to make mistakes
G	6	6	4	5	M - open upon the area that the cursor can click into to select an emitter - Ex: it's now very hard to double click exactly on the symbol to get the library	M - sometimes when new emitters were coming on to fill the page & I had clicked to get the menu of emitters [scan types] - it wouldn't work I had to hit the button & scan menu
H	7	7	7	7	No complaints	No complaints
I	7	5	7	6	M - makes selecting emitters much easier; command registered the shift button too slowly	M - Again, with the command, the computer did not always pick up the shift key with added frustration
J	7	6	7	6	B- you could prioritize the items depending on the threat levels and order them on the list	B - if only one option appears it could be selected automatically
K	4	7	4	7	M - easier to double click (C) make a button to go to next item on list [Liked command better, if button hit return would select next one 9emitter) w/ library]	B - exclude any information that won't help distinguish
L	5	6	5	6	B - mouse is easier because less chance of losing time- faster but accuracy with the keyboard is better	B - mouse is easier but the keyboard is quicker

37 and 39 —Rate the Mouse-based Interface to the versions from Experiment 1 (Scale 1 to 7) Worse to Better, Slower to Faster, respectively
38 and 40 —Rate the Command-based Interface to the versions from Experiment 1 (Scale 1 to 7) Worse to Better, Slower to Faster, respectively

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TABLE 73
articipant's Responses From Questions 43 to 46

Ss	43—Close Control Suggestions	44—Object Display Suggestions	45	46—Why? (Like/Dislikee the Pop-up)
A	Nothing	B - small scale perhaps? on the vertices	Yes	Hides info til you're ready to use it.
B	Nothing	Nothing	Yes/No	Yes, for signal type, no for page #
C	Better highlighting	Nothing	Yes	don't have too many choices, scrolling down 2 or 4 is ok
D	M- mouse to select parameters, keys to change the parameters (e.g. - mouse to select icon type, S= STD, C= circular, CO (?) for conical, etc...)	n/a	No	Seemed to take too long, especially when using scan types and I wanted to select one at the end of the menu
E	That is fine	Who needs it why bother	Yes	For page number yes, but again I thought the Con, SEC, STD, CIR was a waste of time for the user
F	M - It was easier to just select the correct type of sound & no typing	B - did not work here	Yes	Better than moving through an invisible list with a key
G	This was fine	This was fine although I found it quicker to not use this	No	I'm not as precise (coordinated) w/ the mouse
H	No complaints	No complaints	Yes	But the keyboard is easier to use
I	B - Didn't see much of a difference here because I never made any real changes except from scan type (which was easier with the keys)	M - used it more here just because with the mouse it was easier to look at the screen while using a CMD whereas when using keys you had to look at the key-board	Yes	Buttons are easier to click an when the mouse is on the screen - didn't have to think about what key to press to make a command work
J	Since the PRF is the primary comparison parameter it could be highlighted	B - n/a	No	It could have been quicker had all choices been displayed together
K	Same as previous comment	n/a	Yes	Yes, but sometimes it was hard to get it to go to the next page
L	C- command is easier & more accurate	C - command was easier by being faster and more accurate	No	Beacuse I sometimes couldn't get the mouse to keep it held down to change the column

45 — Did you like the Pop-up buttons?

TABLE 74
Participant's Responses From Questions 47 to 51

Ss	47	48—Why? (Like/Dislike the PRF field)	49	50	51—Why (Did labels and prompts help)
A	No	Because the "indent-PRF" was so much nicer	Insert	No	Frequently used buttons - Training had made the buttons rote. - If buttons were infrequently used, the prompts would probably be more useful.
B	No	Took too much time to look down at keyboard and to type in #.	Insert	Y/N	Helped at very beginning, but since there weren't too many things to memorize, I didn't really use them after the first couple training trials.
C	n/a	Never did type in	Insert	Yes	Didn't go through damn book
D	n/A	Did not do any PRFS --- worked from memory	Insert	Yes	Double-clicking had too many delays and problems due to the system time
E	n/a	n/a	n/a	No	Not after the first couple of run throughout because there were so few things I memorized them quickly & forgot about them. I would leave them on for people who just start out
F	No	Nothing	Insert	No	Did not notice them
G	Yes	I believe it's convenient, but I didn't use it very much because I thought I could scan the list fast enough & keep the PRF #'s in my head	Insert	Yes	Beacuase when I didn't hit the function key shift simultaneously., I could still access the library quickly (again it's a matter of coordination- when I failed to hit the F& shift together)
H	No	This is the one exception in which the mouse is easier, if you designates a button on the keyboard it would be even easier	Insert	No	After the first five minutes your eyes automatically go to the area needed
I	No	Never used it because it seemed like to much of a hassle to have to type in the numbers (it was also time consuming)	insert	No	Didn't really look at them, but probably in high stress situations they would be helpful because sometimes people forget what to do
J	n/a	n/a	Insert	Y/N	In the beginning - not after I got used to screen layout
K	Yes	Lots of room to type	Insert	Yes	Helped to remember needed commands
L	No	Didn't really use it much at all or rather should not have to	Insert	Yes	Because I forget things easily and even though I didn't ever use them it was nice to have them there

47 — Did you like the PRF field
49 — Which did you like better (Insert PRF button or typing the PRF)?
50 — Did the labels and prompts help?

TABLE 75
Participant's Responses From Questions 52 to 58

Ss	52	53	54	55	56	57	58—Comments
A	32	M	SYSE	G	8 to 12	Hunk & Peck	Nothing
B	25	F	Hopefully	G	12 to 16	Touch Type, slow	Also, it was much quicker to do the Insert PRF than to type it in (I would sometimes forget to remember the PRF # on the command interface & have to go back to it)
C	31	M	ISE	G	> 28	H&P, but fast	Once you decide on sound type it should highlight those types, trash the other (eliminate)
D	28	F	ISE	G	> 28	Touch Type, fast	Combine CMD key & mouse, put lib # at both ends of library entry, since mouse was used mostly to go from end-to-end of the display maybe look at D'ing C-D ratio import ULQ info (real) into SLQ system so the 2 are integ.,and you can "believe" the SLQ's PRF Strategy - (always have library choice displayed): (1) compare scans to lib., (2) if match - select for design, (3) if no match—CMD key- listen to scan and memorize PRF or with Mouse- designate any scan type & select "insert PRF" choose correctly matching PRF - designate
E	22	M	Eng/Psy	U	0 to 4	H&P, but fast	Single clicks for selection of icon Put T key next to sound [between sound and start of Library list] not away from list
F	27	M	ISE	G	> 28	Touch Type, fast	Library key in command format was helpful especially when you go to the next screen or screen is updated
G	22	F	ISE	U	4 to 8	Touch Type, slow	Nothing
H	21	M	Geology	U	8 to 12	H&P, but fast	The command type would be perfect with the addition of a button to designate the PRF and if the shift key method were not as picky
I	21	F	CPE	U	4 to 8	H&P, but fast	Not having to locate emitters on the grid with the mouse was very nice- sometimes it used to be hard to hook emitters.
J	28	M	ISE	G	> 28	Touch Type, fast	
K	24	F	ISE	G	8 to 12	Touch Type, fast	Nothing
L	22	F	Exercise	U	24 to 28	H&P, but fast	I think the program should be designed to run as accurately as possible with the most efficient means of command interface

52—Age
53—Male or Female?
54—Major Field
55—Graduate (G) or Undergraduate (U) student,
56—# hours of computer usage a week
57—Typing skill

VITA

Richard H. Miller was born in Milwaukee, Wisconsin, on June 12, 1965. He received his Bachelor of Science degree in Applied Psychology with a minor in Drama and Film from the Georgia Institute of Technology in June of 1987. While at Georgia Tech, he led the human factors effort on an award winning design of a Formula One style sports car for a Society of Automotive Engineer's competition. He also was active in community projects, a Dean's List student, played intercollegiate lacrosse, and was a member of Alpha Epsilon Pi.

In 1990, Richard received a Master of Science degree from the Virginia Polytechnic Institute and State University in Industrial and Systems Engineering with an option in Human Factors Engineering. He spent a summer working for the FMC Corporation, where he designed the computer interface for an air-defense tank, as well the user interface guidelines for FMC's subcontractors. Richard then investigated the usability and functionality of rapid prototyping software in the Vehicle and Simulation Laboratory at VPI&SU. Interest in rapid prototyping led to research in graphical user interface design. As one of VPI&SU's technical coordinators for Apple Computer, Inc., Richard designs computer software and hardware solutions for local projects. He helped to install and maintain parts of a state-of-the-art computer network while serving as an intern at the Design Resource Center of Eastman Kodak Company and continues to do network administration duties for the Displays and Controls Laboratory and the Virginia Productivity Center at VPI&SU. He also works with other university organization as owner of a local computer consulting group. Richard teaches training classes for computer-based applications, and has been an invited speaker at VPI&SU for sessions on multimedia in the classroom, networking, writing HyperCard applications, and interface design.

Richard enjoys the theater, designing gadgets, traveling with his family and friends, playing sports, and reading the hundreds of novels that he has accumulated since starting graduate school. Richard plans on pursuing a career in human factors and the management of engineering projects.