

THE EFFECTS OF DISPLAY FAILURES, POLARITY, AND CLUTTER
ON VISUAL SEARCH FOR SYMBOLS ON
CARTOGRAPHIC IMAGES

by
Craig J. Dye

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APPROVED:

H.L. Snyder, Chairman

P.T. Kemmerling

R.J. Beaton

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INTRODUCTION

Cartographic/symbolic displays refer to non-alphanumeric information displays in the form of maps, graphs, or other pictorial material. To date, almost all cartographic research has been conducted using paper maps. With the increase in viability of matrix-addressable and cathode ray tube (CRT)-based navigation aids in vehicles, as well as real-time monitoring of situational attributes in the military field on CRT and matrix-addressable displays, it is most important to discover the display parameters which affect the operator's performance while using such systems.

The human-performance research to date dealing with cartographic information has centered around symbol resolution and symbol size (Erickson, 1978; Florence and Geiselman, 1986; Geiselman, Landee, and Christen, 1982). Although these considerations are of some importance to cartographic image quality, variables at least as meaningful as symbol characteristics have gone unresearched.

With matrix-addressable displays, it is possible that cells or even whole lines on the display may fail, where a pixel or pixels may remain on or off irrespective of the intended state. In order to adequately define a failure situation on a matrix-addressable display, one must consider the type of failure (individual cell or line failure), the

mode of the failure ("on" or "off"), and the amount of failure present (typically quantified as the percent of pixels failed).

There are three failures that arise most often with matrix-addressable displays. A cell failure exists when individual elements or pixels turn "on" or "off" depending upon the mode of the failure. This failure is often described as producing a "salt and pepper" effect. A cell failure may result from a variety of causes depending upon the type of flat-panel technology being considered. Regardless of the technology, however, all such displays are susceptible to a cell failure.

The other two types of display failures are horizontal and vertical line failures. In most instances, a line failure of either type is the result of a faulty electrode or driver. In this case, an entire line on the display fails either "on" or "off."

For any failure type, the pixels comprising the failure may fail in "on" or "off" mode. Consider that on any given display, the luminance of the information will be higher or lower than the luminance of the background, depending upon the display's polarity. "On" mode refers to the case where a failure more nearly resembles the luminance of the information on a display (see Figures 1 and 2). "Off" mode conversely refers to the case where a failure more nearly

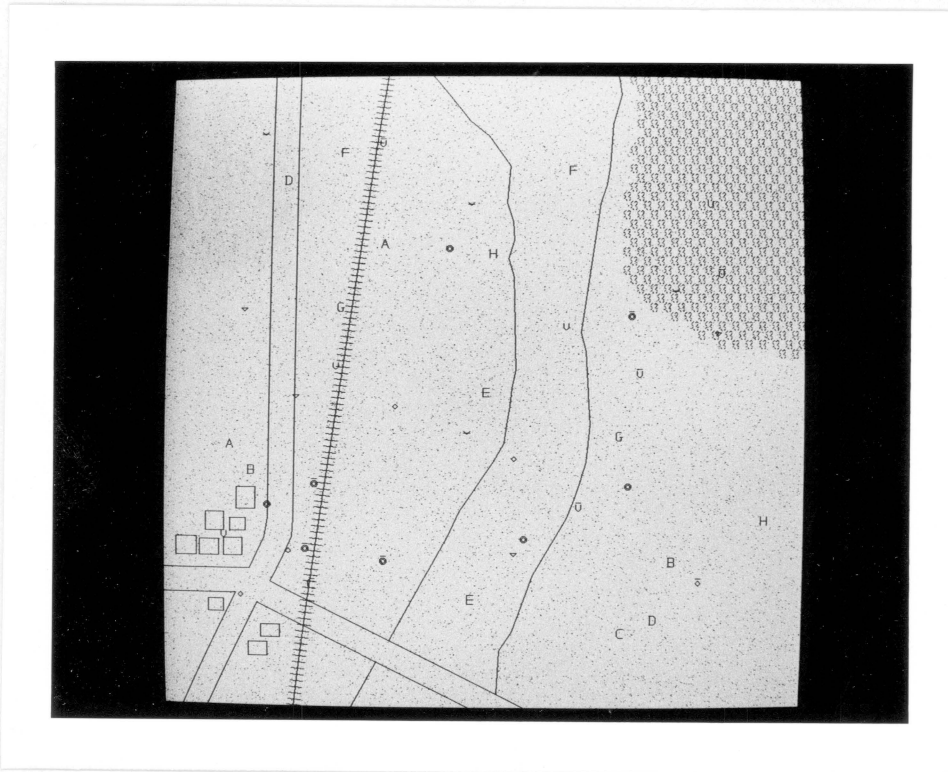


Figure 2. Cell failure, "on" mode, one percent, negative polarity, and low background clutter.

resembles the luminance of the background on a display (see Figure 3). Therefore, any failure will either turn the pixels comprising the information "off" (matching the background) or turn the pixels comprising the background "on" (matching the information). Obviously, when a failure matches the luminance of the information ("on" mode), it can be readily seen where it intrudes upon the background of the display (again, see Figures 1 and 2), but not where a character or symbol is commanded on the display. Likewise, an "off" failed line or cell is not seen in the background portion of a displayed image.

As mentioned, the amount of failure is typically the percentage of pixels failed, or failure percent. This is easily calculated by dividing the number of pixels failed by the total number of addressable pixels on the display and multiplying by 100.

Display Failure Research

Research on failures has examined the effects of failure mode on individual symbols as well as on entire display images. Riley and Barbato (1978) examined the relationship between five fonts and discrete element degradations (a cell failure). A set of 5 x 7 dot-matrix characters was drawn in the center of a 7 x 9 matrix. Dots in the 7 x 9 matrix were then turned on or off and individuals were asked to identify

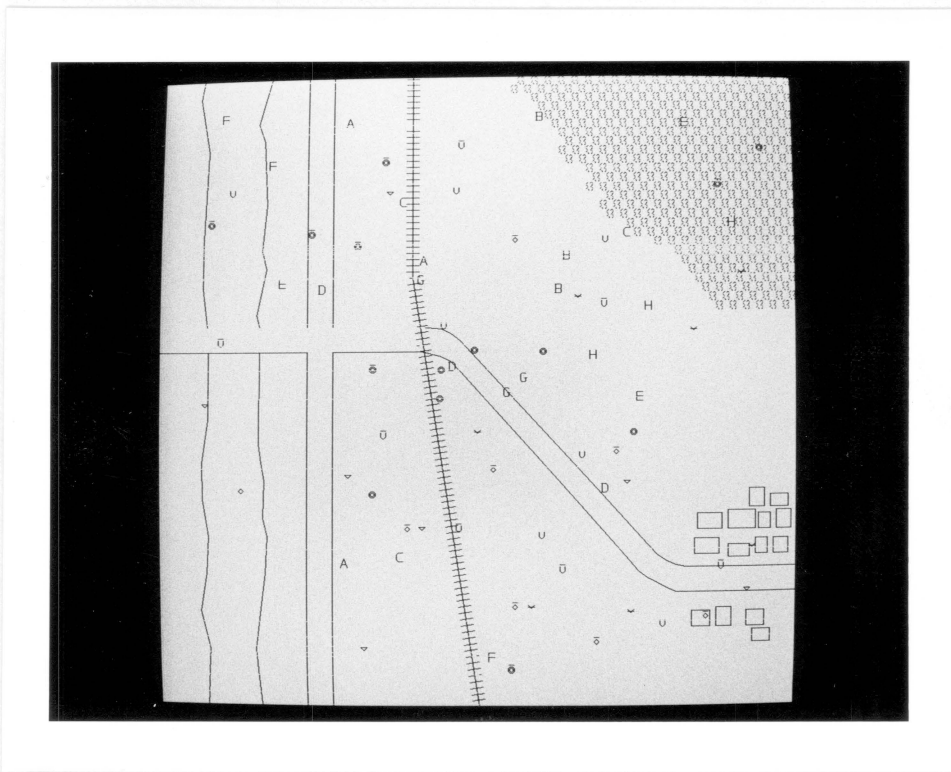


Figure 3. Horizontal line failure, "off" mode, three percent, negative polarity, and high background clutter.

the character. Riley and Barbato found no difference between the failure modes.

A similar study was conducted by Pastor and Uphaus (1982) which examined the confusability of 7 x 9 ASCII numerals with other ASCII numerals under varying percentages of dot loss (or cell failure). It was found that a linear relationship existed between specific dot loss and reading errors. Note that this study only examined the effects of "off" failures.

These studies, while informative, investigated only cell failures and failure mode for individual characters. It is also important to examine the effects of all types of failures (both cell and line), as well as failure mode and failure percent, on an image displaying a more complex field of characters as this more closely resembles an operator's actual experience.

Laycock (1985) suggested that line failures were disruptive when they aligned with major components of the characters comprising the text, and that "off" cell failures were less disruptive than "on" cell failures. Laycock also was of the opinion that less than 0.01% of "on" cell failures and up to 1.0% of "off" cell failures are tolerable.

When considering this last point, that of failure percent, it is important to note that Laycock defined failure percent as the percentage of pixels failed which comprise the

text, rather than the percentage of pixels failed on the entire display. While the locations of failures on any matrix-addressable display will be random, these locations are not likely to vary from image to image as will the text that is presented on the display. Therefore, it seems more meaningful to quantify failure percent as the percentage of pixels failed on the entire display. Only three studies were found which quantify failure percent in this manner.

Abramson and Snyder (1984) examined failure type, failure mode, and failure percent for a modified Tinker Speed of Reading Task. Cell failures generally resulted in slower reading speeds and a higher number of errors than did horizontal or vertical line failures. This was particularly evident when the failures were "on." When the failures were "off", line failures resulted in poorer performance than cell failures. Overall, "off" failures resulted in better performance than "on" failures. It was further shown that as failures increased above two percent, reading speed decreased and errors increased. At or below two percent, the failures had little effect on performance. These three failure variables showed markedly similar results for random search tasks (Decker, Dye, Kurokawa, and Lloyd, 1988; Lloyd, Decker, Kurokawa, and Snyder, 1988).

All of the above studies involved images of text passages or random patterns of alphanumerics and/or symbols.

To date, there are no data examining the effects of these failure variables on the search for symbols on more complex, cartographic images. The present study includes the failure variables and levels examined in the above research with the exception of failure percent. While levels of one to 12 percent were employed in the previous alphanumeric studies, it was believed that, due to the addition of map information to the images, effects should become evident at or below three percent failure.

Polarity Research

Polarity refers to whether the information is of greater or less luminance than the background: low luminance information on a high luminance background (negative polarity), or high luminance information on a low luminance background (positive polarity).

In a review of the literature, Rupp (1981) indicated that the preference in Europe for negative polarity is based almost entirely on an assumption that the pupillary response resulting from the switch in eye fixation from text on paper (negative polarity) to text on a positive polarity display induces visual fatigue and irritation. Alluding to the results of an informal experiment he conducted, Rupp contends that there is no difference in magnitude of pupillary response (attributable solely to the positive polarity

display) above that which occurs naturally during normal steady fixation, or pupillary hippus.

An experiment by Bauer and Cavonius (1980) examined the effects of polarity on people's ability to identify four-letter nonsense words. Error rates indicated that negative polarity produced better identification than positive polarity.

Semple, Heapy, Conway, and Burnett (1971) reviewed the literature and concluded that display polarity has no interpretable impact on symbol recognition, and that claimed differences are primarily due to inaccurate reporting of experimental methodology.

The literature suggests, then, that there is no difference in performance due to display polarity. Indeed, the newly released ANSI standard for video display terminals (ANSI/HFS 100-1988) indicates that either polarity is acceptable providing it meets the requirements for resolution, luminance, and contrast. This qualification proves to be quite important.

The previous articles offer little mention of display parameters such as luminance levels, modulation, or stroke widths, even though these parameters all have well documented effects upon legibility of characters (Snyder, 1980). In order to accurately compare positive to negative polarity,

modulation and stroke width must be kept constant for both polarity conditions.

Regarding display luminance, there has been some disagreement as to whether the eye adapts to the peak luminance of an image or to the space average luminance of an image. Recent evidence (Knox and Beaton, 1985) supports the notion that the eye adapts not to the maximum luminance on the display, but to the average luminance. This distinction is pertinent in that it is nearly impossible to establish equal stroke width and modulation as well as equal peak and space average luminances for images of both polarities on the same display. Snyder (1988) states that "... it appears ... that the adaptive state of the visual system is driven by the amount of light entering either the fovea (for a positive [polarity] display) or the parafoveal region (driven by the background in a negative [polarity] display)." It is apparent, then, that if adequate modulation, stroke width, and minimum luminance are maintained, there should be no adverse differences in visual adaptation for images of either positive or negative polarity.

These criteria were met and polarity was examined in the alphanumeric studies mentioned earlier (Decker et al., 1988; Kelly-Harrison, Decker, Pigeon, Snyder, and Kurokawa, 1988; and Lloyd et al., 1988). Negative polarity was found to produce significantly faster response times and to be more

accurate than positive polarity for random search tasks. Thus, the most recent and well-controlled data indicate an advantage to negative polarity.

Polarity has not been investigated in cartographic research. While it has been the natural practice of map makers to employ only negative polarity, there has been no empirical research to date to validate this stance.

Background Clutter Research

For the purposes of this work, background clutter may be defined as information on an image which should not be attended to or is irrelevant at a given time. Any information on a cartographic image which is not the target or does not directly contribute to the acquisition of the target can be considered to be background clutter, as it should not be attended to. This would include non-target symbols as well as map information which is unnecessary for the acquisition of the target.

Of those studies (Florence and Gieselmann, 1986; Silbernagel, 1982; Williges and North, 1973) which investigated the effect of background clutter (sometimes termed "density") on visual search for targets on CRT displays, all found that an increase in the number of non-target symbols increased response time and decreased accuracy, as would be expected. Only one of these studies

(Williges and North, 1973) involved the search for targets on cartographic images, but the topographic maps were presented by filming paper maps and displaying them to the subject via closed-circuit television; that is, the maps were not computer-generated.

All three of these studies defined background clutter as the number of non-target symbols present on the image. This definition of background clutter is not adequate for cartographic images on matrix-addressable displays because, as indicated in our operational definition of background clutter, it does not take into consideration the distracting effect of the non-essential map information in the image. A better, more quantitative definition of background clutter would be the percentage of pixels on a display which comprise the non-essential information, both map information and non-target symbols. Quantifying the relationship between user performance and the amount of background clutter will be increasingly important as technology provides avenues for such displays to develop in complexity and sophistication.

Research Objectives

Although matrix-addressable displays of cartographic images are becoming increasingly important and available, it seems they have largely been ignored by researchers of human performance.

The effects of failures have been examined for random search of alphanumerics and symbols, but not for symbol search on cartographic images. As a display intended for cartographic information will undoubtedly display alphanumerical information as well, the effects of failures on cartographic images must be ascertained in order to effectively define the acceptable limits of these failures for displays intended for both cartographic and alphanumeric presentation. One purpose of this research effort is to define such limits.

As mentioned earlier, it has been the natural practice of map makers to employ only negative polarity. Thus, what little cartographic research that has taken place regarding human performance has limited itself to negative polarity presuming a population stereotype as justification. This research will test the validity of this presumption. Further, since recent alphanumeric studies (Decker et al., 1988; Kelly-Harrison et al., 1988; Lloyd et al., 1988) have shown a slight advantage for performance with negative polarity, the present study will endeavor to determine whether this is likewise the case for cartographic images.

With the increasing sophistication and affordability of matrix-addressable displays and cartographic software, the amount of background clutter will eventually become limited only by the courtesy of the software programmer. While

discovering the acceptable limits of background clutter on a cartographic image is beyond the scope of this work, the present study will provide initial information regarding this effect and its limits.

It is not known the extent to which results may generalize from alphanumeric search tasks to cartographic search tasks and vice versa, although this information is needed in order to design an optimum cartographic/alphanumeric display. Hopefully, this research will produce information for comparing these two types of images.

Accordingly, two experiments were conducted which were identical in general procedure, but differed in the task required of the subjects. One study involved a random search task and the other involved an information extraction task.

The information extraction task required the subjects to find a target indicated solely by contextual information presented on the CRT prior to each trial. For instance, the user of such a display might be asked to find the enemy tank that is closest to the water. This requires the user to be able to make a quick distinction between both friendly versus enemy symbols as well as between the different types of fixed information. This task is similar to those which occur in the actual use of such a display.

Both studies included the variables of failure type, failure mode, failure percent, polarity, and background clutter.

METHOD

Subjects

The subjects for both experiments were college students at Virginia Tech who were paid for their participation in the study. There were 12 subjects (6 males) for each experiment. They ranged in age from 18 to 26. The subjects were tested for natural or corrected 20/22 near- and far-point visual acuity as well as lateral and vertical phorias using a Bausch and Lomb Orthorater. They were also tested for near and far contrast sensitivity using a Vistech chart system.

Apparatus

The stimuli were presented on a Video Monitors Incorporated (VMI) high resolution monochromatic CRT with a 48-cm diagonal screen. The area of the screen used for these studies was 27.94 cm² (1024 x 1024 pixels) due to bandwidth constraints of the graphics controller.

An 8-bit plane PEPE graphics controller by Vectrix Corporation was installed on an IBM PC-AT. The PC controlled the generation and presentation of the stimuli, as well as data collection. A three-button Mouse Systems mouse was used for subject responses. Responses were timed using the built-in clock of the PC, which has a resolution of plus or minus 55 ms.

Subjects were seated in a hydraulic dentist chair adjustable in height and distance from the CRT. Subjects were positioned such that their eyes were at a distance of 50.8 cm from the CRT. Their heads were made stationary through the use of the head rest on the dentist chair and the line of sight to the center of the CRT was 15 degrees below horizontal.

Photometric Measurements

Prior to these experiments, the luminance and modulation levels were set using a photometric system which consists of a GS-2110 scanning telemicroscope by Gamma Scientific, with a 10 x 3000 micron slit aperture, and a 1X objective lens, a photomultiplier tube (Gamma Scientific, model D-46), and an intelligent radiometer (Gamma Scientific, model GS-4100). The photometric system is controlled by an IBM PC-XT.

Calibration. The display luminance was set using the display brightness control so that the luminance level of an all-on field (255 bits) was 39.5 cd/m². This display brightness setting was kept constant and screen luminance was varied by changing bit levels.

The background luminance was then set as closely as possible to 35 cd/m² by making vertical scans across several columns of pixels. A zero bit line was then displayed against this background and the line was scanned. The bit

level for the line was then adjusted and scanned repeatedly until a modulation of 0.65 was reached. Due to constraints of the monitor, this was as high a modulation as was possible to achieve and still maintain comparable maximum luminances and stroke widths for both polarity conditions. This procedure set the bit levels for the negative polarity condition.

To set the bit levels for the positive polarity condition, an all-on (255-bit) line was displayed on an all-off background and the bit level of the background was increased until values for modulation, maximum luminance and stroke width were achieved which were comparable to those achieved for the negative polarity condition. Thus, the maximum luminance and stroke width for both polarity conditions were set as close as possible while maintaining nearly equal modulation levels.

The bit levels for the luminances of the background and symbols were programmed into the experimental software.

Independent Variables

The simulated failures consisted of lines of pixels or individual pixels that either matched the luminance of the information on the display or matched the luminance of the background on the display.

Failure Type includes no failure, a cell failure (where individual pixels are affected), or a line failure (where entire lines of pixels across the display are affected, either horizontally or vertically). Thus, there were four levels of Failure Type: none (Figure 4), horizontal (Figure 3), vertical (Figure 1), and cell (Figure 2). The locations of the cell and line failures were randomly selected for each trial by the experimental software.

Failure Mode, as previously described, has two levels: "on" or "off." "On" failures matched the luminance of the information on the image (Figures 1 and 2), and "off" failures matched the luminance of the background of the image (Figure 3).

Failure Percent varied from one percent of the display's pixels failed to three percent of the pixels failed, at one percent increments. Figures 2, 1, and 3 are examples of one, two, and three percent failures, respectively.

Background Clutter was set at two levels, high and low. It was quantified much the same as Failure Percent was quantified, in terms of the percentage of pixels associated with information displayed on the CRT or the percentage of pixels not matching the background luminance of the display. The high background clutter condition consisted of

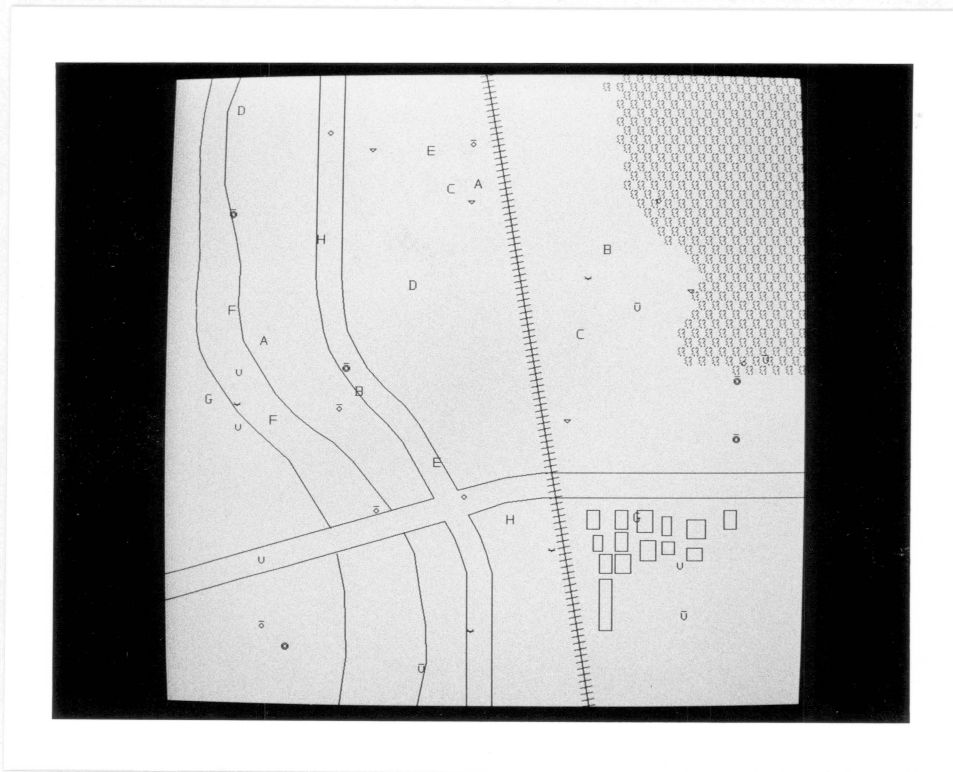


Figure 4. No failure, negative polarity, and low background clutter.

approximately 3.8% of the displayed pixels "on" and the low condition consisted of approximately 2.9% of the displayed pixels "on." While these percentages do not appear to be very high, they entail over 30 000 and 40 000 pixels "on" for low and high clutter levels, respectively. The clutter consisted of all map information, including fixed items as well as symbols; it did not include "on" pixel failures. Clutter was adjusted by increasing the number of non-target symbols on the display. The non-target symbols consisted of the other symbols in the symbol set as well as the capital letters A through H in a Huddleston 11 x 15 font. Of the non-target symbols, there was approximately a 2:1 ratio of symbols to letters on the images.

The last independent variable is Polarity, with two levels: negative (dark symbols on a light background) and positive (light symbols on a dark background).

Maps

The six maps used for this study were adapted from Army ROTC maps. Due to the lack of color coding (as the display used in this research was monochromatic), and because too much detail might have unnecessarily complicated the interpretation of the effects of the failure variables, the adaptations did not include all of the information on the source maps. Also, the information was enlarged such that

the different information on the maps could be readily identified. The types of information, exclusive of symbols, that were included are roads, rivers, trees, railroads, and buildings. Figures 1 through 4 illustrate four of the maps.

Symbols

The symbol set (Figure 5) was selected from a set of 26 Army symbols used in the previous alphanumeric research in this laboratory. Stimuli were drawn within an 11 x 15 dot matrix subtending 19 x 26 minutes of visual angle. The stimuli, then, are standard Army symbols redrawn as dot matrix symbols. The symbols were presented at random locations on the CRT without overlapping other symbols. Overlapping may occur, however, between fixed information on the cartographic image and the symbols, as this phenomenon will undoubtedly occur in an actual system.

The eight symbols for these studies were selected by averaging the response times and response accuracy for each symbol across two studies (Decker et al., 1988; Decker and Kurokawa, 1988) and selecting a representative sample from the ensuing distributions. The selection process was not entirely random for it was desired to arrive at a sample of four pairs of symbols, both symbols in the pair identical except for a single horizontal line which runs through or above one of the symbols in each pair to aid the subject in



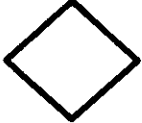
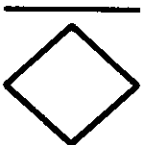
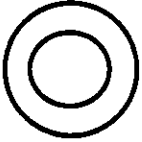

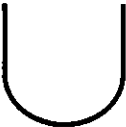
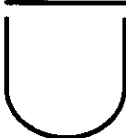
FRIENDLY		ENEMY
	AIRCRAFT	
	INFANTRY	
	TANK	
	ARTILLERY	

Figure 5. Symbols used for both tasks.

distinguishing between friendly and enemy symbols in the information extraction task.

The number of symbols (eight) was decided upon in order to facilitate long-term retention of the symbol set prior to the information extraction task, yet still require the subject to distinguish among symbols. Long-term retention of the symbols was deemed to be a requirement of an operator in the actual application of such a display system.

Dependent Variables

The dependent measures used for both studies are response time and response accuracy. Response times were recorded by capturing the elapsed time between the depression of the two buttons on the mouse which initiated and completed each trial. The response time and accuracy for each trial were written, along with information detailing the trial, to a data file on the IBM PC AT.

The response times were averaged across the 12 repetitions for each of the 1152 cells (96 conditions x 12 subjects) and these means were used in the ensuing analyses.

Accuracy was defined as the percentage of correct responses (0 - 100%), averaged across the 12 repetitions for each of the 1152 cells.

Design and Stimuli

The experimental design is identical for both experiments. The design was a 2 X 2 X 4 X 3 X 2 within-subjects full factorial combining Polarity X Background Clutter Level X Failure Type X Failure Percent X Failure Mode, respectively. There were 12 repetitions of each of the 96 cells for a total of 1152 trials per subject. These were spread across four days with 288 trials per day. The days were blocked by Failure Type.

It is reasonable to assume that the type of failure on any given matrix-addressable display in a workplace setting will remain constant throughout a certain portion of the operator's tasks. Presenting one failure type for each of the four days reproduces this situation in the experimental setting. This blocking provides greater validity as well as data on the ability of the operator to accommodate to such a situation. The order of presentation of Failure Type was balanced through use of a Latin Square and randomly assigned to each subject in order to minimize any effects from order of presentation.

Albert (1975) found that performance differs for contextual versus noncontextual word tasks. If we allowed that this effect may generalize to symbols, then it is potentially confounding to allow a subject to place in context, or attach meaning to, the symbols used for the random search task because the subject would no longer be

searching for simply a cognitive template, but for a meaningful and contextual representation. To avoid any potential confound of this nature, a different group of subjects was used for each of the two tasks.

The six maps were used an equal number of times, but not across all conditions. That is, they were not treated as a factor in the present studies.

Procedure

At the beginning of each experimental session, the CRT was warmed up for a minimum of 30 minutes. The CRT was adjusted to a luminance of 39.5 cd/m^2 with an all-on field (255 bits). Ambient illumination was set to provide a luminance of 15 cd/m^2 on the wall directly behind the CRT. The ambient did not illuminate the subject's display.

The two tasks performed were a random search task and an information extraction task. The random search task consisted of the subject finding a target symbol on the cartographic image and identifying its location. The target was presented to the subject graphically on the CRT prior to each trial.

The subject was seated in the dentist chair and asked to read the instructions (Appendices A and B) for the particular study he/she participated in. Following this, the subject was positioned the appropriate distance from the center of

the CRT. At this point, the procedure for the two studies diverged.

Random Search Study

For the random search study, the subject was given 30 practice trials. The practice trials were identical to the actual trials in terms of actions performed. The subject first saw a message screen with the following message appearing at the center of the CRT: "The next symbol is" followed by the target symbol. The symbol appearing with the message was identical in every respect to the actual target symbol (except for pixels of the target symbol which were affected by the failures of the ensuing trial) which appeared at a random position on the subsequent cartographic image.

Depressing the right button on the mouse (1) erased the message, (2) started the timer resident in the PC, and (3) displayed that trial's cartographic image with symbols and failures. Once the subject believed he/she had found the target symbol, the subject then depressed the left button on the mouse which stopped the timer. Immediately, the map and failures disappeared and all symbols on the display were replaced with numerical identification tags. The subject then reported aloud the number of the identification tag which replaced the perceived target symbol. This number was recorded by the investigator.

The next trial's message screen then appeared and the subject proceeded as before.

Following the completion of the final experimental session on the fourth day, the subject was given a debriefing sheet describing in detail the purpose and goals of the study. All questions regarding the study were answered at this time.

Information Extraction Study

The procedure for the information extraction study began the same as for the random search study, with the subject seated in the dentist chair and positioned with respect to distance from the center of the CRT. The subject was then given a sheet of paper containing the eight symbols and their assigned meanings. The subject was given as much time as needed to study the reference sheet and to learn the symbols and their respective meanings. After indicating that he/she was ready to begin, the subject was tested with another sheet of paper containing only the meanings and was told to draw the appropriate symbol. If the subject did not get all eight correct, he/she was given the reference sheet again and, when ready, was given another test sheet. This was repeated as many times as necessary for the subject to get all eight correct. No subject needed more than two tests to get all eight correct.

After the subject passed the learning test, he/she began 30 practice trials. As with the random search procedure, the practice trials were identical to the experimental trials. A message appeared on the screen in the form "Find the <symbol name> closest to the <fixed information>" where <symbol name> was the learned meaning of the particular symbol to search for and <fixed information> was the item on the cartographic image to search in relation to, such as woods, water, etc.

It is important to note that all the messages are approximately equal in demands on cognitive processing. That is, they all require the subjects to locate one learned symbol on the cartographic image relative to one other item of fixed information on the image. This procedure prevented any confounding due to the amount of processing required by the subject assuming that mental processing time is relatively equal across the learned symbols and across the fixed items on the cartographic images.

When ready to proceed, the subject depressed the right button on the mouse keypad which started the trial, whereby the subject proceeded as in the random search study.

After completing the 30 practice trials, each subject began the experimental trials. There were three groups of trials per session with 16 sections per group for a total of 48 sections per experimental session. Each section consisted of six trials at the same levels of polarity, background

clutter, failure percent, and failure mode. Thus, each of the 24 possible combinations of the above variables was repeated 12 times per experimental session: 6 times in each of 2 sections. A 5-minute rest break was allowed after each group of 96 trials.

Following the completion of the final experimental session on the fourth day, the subject was given a debriefing sheet describing the purpose and goals of the study in detail. All questions regarding the study were answered at this time.

RESULTS

Response time and accuracy (percentage of correct responses) were analyzed for both experiments. A five-way analysis of variance (ANOVA) was performed on the entire design (Polarity by Background Clutter Level by Failure Mode by Failure Type by Failure Percent) for each dependent variable in each experiment. Simple-effect F-tests and Newman-Keuls tests were performed on all interactions deemed meaningful.

Random Search Task

Response time. The total ANOVA for these data is found in Table 1. As indicated, three main effects and one interaction were statistically significant ($p < .05$).

Negative polarity produced significantly faster (6.13 s) responses than positive polarity (7.29 s). Response times are significantly shorter for low background clutter (5.56 s) than for high clutter (7.89 s). Finally, failures ($p = 0.0402$) at one percent led to faster responses (6.38 s) than at either two (6.95 s) or three (6.84 s) percent (Table 2, Figure 6).

Of greater interest than the main effects, however, are the interactions between the factors. Failure Mode significantly interacts with Failure Type. The simple-effect

Table 1. ANOVA Summary Table for Random Search Task,
Dependent Variable = Response Time

SOURCE	df	MS	F	p
Subjects (SUB)	11	75.26		
Polarity (POL)	1	371.32	26.18	0.0003
SUB*POL	11	14.18		
Background Clutter Level (BCL)	1	1556.46	163.18	0.0001
SUB*BCL	11	9.54		
MODE	1	49.42	4.17	0.0658
SUB*MODE	11	11.84		
TYPE	3	59.95	1.95	0.1415
SUB*TYPE	33	30.82		
Percent (PCT)	2	35.52	3.73	0.0402
SUB*PCT	22	9.52		
POL*BCL	1	2.60	0.18	0.6801
SUB*POL*BCL	11	14.50		
POL*MODE	1	8.98	1.32	0.2750
SUB*POL*MODE	11	6.80		
POL*PCT	2	0.95	0.11	0.8952
SUB*POL*PCT	22	8.49		
POL*TYPE	3	3.54	0.32	0.8084
SUB*POL*TYPE	33	10.94		
BCL*MODE	1	5.22	0.39	0.5464
SUB*BCL*MODE	11	13.48		
BCL*PCT	2	2.24	0.34	0.7184
SUB*BCL*PCT	22	6.66		
BCL*TYPE	3	2.14	0.18	0.9111
SUB*BCL*TYPE	33	12.11		
MODE*PCT	2	12.11	1.60	0.2242
SUB*MODE*PCT	22	7.56		
MODE*TYPE	3	41.82	3.95	0.0163
SUB*MODE*TYPE	33	10.58		
PCT*TYPE	6	20.67	2.09	0.0658
SUB*PCT*TYPE	66	9.88		

POL*BCL*MODE	1	0.73	0.26	0.6210
SUB*POL*BCL*MODE	11	2.81		
POL*BCL*PCT	2	1.54	0.26	0.7726
SUB*POL*BCL*PCT	22	5.88		
POL*BCL*TYPE	3	16.90	1.87	0.1546
SUB*POL*BCL*TYPE	33	9.06		
POL*MODE*TYPE	3	17.87	1.94	0.1424
SUB*POL*MODE*TYPE	33	9.21		
POL*MODE*PCT	2	0.88	0.10	0.9098
SUB*POL*MODE*PCT	22	9.29		
POL*PCT*TYPE	6	1.67	0.21	0.9724
SUB*POL*PCT*TYPE	66	7.92		
BCL*MODE*PCT	2	23.16	2.12	0.1434
SUB*BCL*MODE*PCT	22	10.90		
BCL*PCT*TYPE	6	4.89	0.69	0.6586
SUB*BCL*PCT*TYPE	66	7.09		
BCL*MODE*TYPE	3	0.85	0.07	0.9772
SUB*BCL*MODE*TYPE	33	12.76		
MODE*PCT*TYPE	6	7.68	0.97	0.4498
SUB*MODE*PCT*TYPE	66	7.89		
POL*BCL*MODE*PCT	2	0.02	0.00	0.9972
SUB*POL*BCL*MODE*PCT	22	6.07		
POL*BCL*MODE*TYPE	3	6.02	0.68	0.5711
SUB*POL*BCL*MODE*TYPE	33	8.87		
POL*MODE*PCT*TYPE	6	6.75	0.57	0.7525
SUB*POL*MODE*PCT*TYPE	66	11.84		
POL*BCL*PCT*TYPE	6	1.28	0.15	0.9881
SUB*POL*BCL*PCT*TYPE	66	8.43		
BCL*MODE*PCT*TYPE	6	9.57	1.40	0.2273
SUB*BCL*MODE*PCT*TYPE	66	6.83		
POL*BCL*MODE*PCT*TYPE	6	13.36	1.60	0.1610
SUB*POL*BCL*MODE*PCT*TYPE	<u>66</u>	<u>8.35</u>		
	1151			

Table 2. Results of Newman-Keuls Test for Failure Percent, Random Search Task, Dependent Variable = Response Time

<u>Failure Percent</u>	<u>Means, s</u>
2	6.95 (A)
3	6.84 (A)
1	6.38 (B)

Means for Failure Percent sharing a common letter in parentheses are not significantly different, $p > .05$

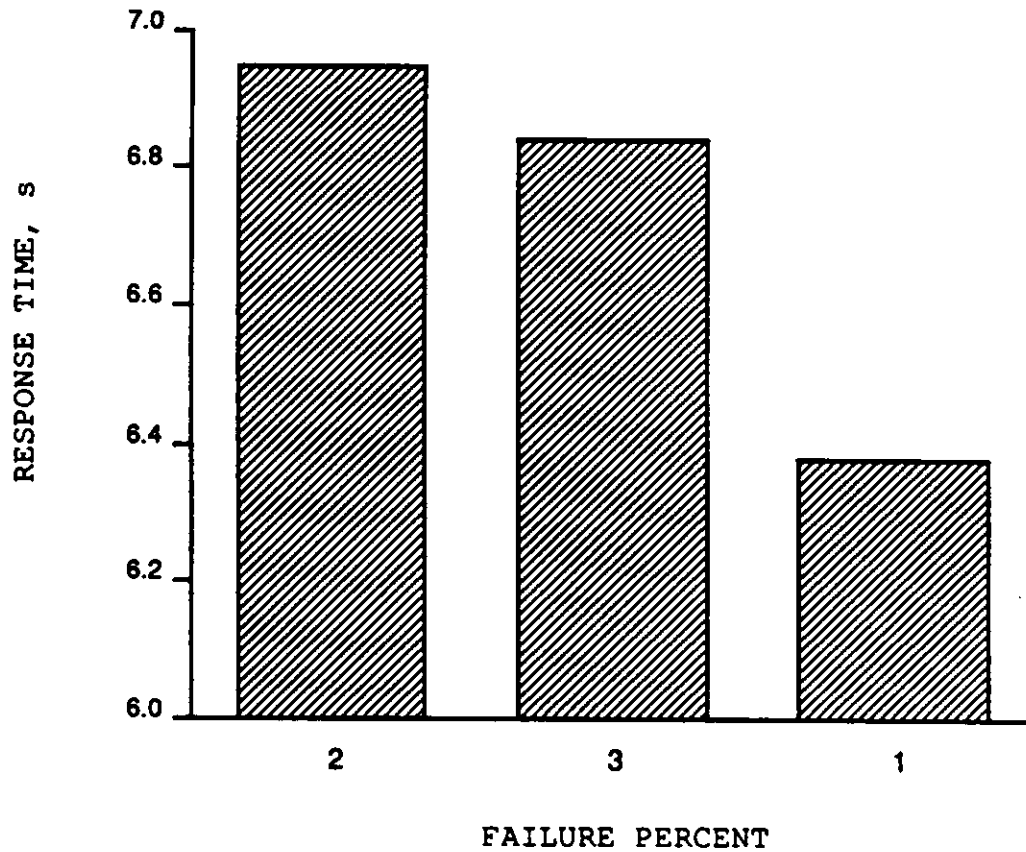


Figure 6. Failure Percent for the Random Search task, dependent variable = response time.

F-tests found that the effect of Mode is significant for cell failures only (Table 3 and Figure 7), with "off" failures producing significantly faster responses (5.99 s) than with "on" failures (7.44 s).

An additional ANOVA was performed to determine any effect over the four days. A significant effect was found ($F(3,33) = 10.72, p < .0001$) with Day One trials requiring significantly longer response times than the other three days (Table 4, Figure 8), which were not significantly different from one another. Thus, for all practical purposes asymptotic performance was reached on the second day although the best-fitting function suggests that the asymptote occurred at Day Four.

Accuracy. The five-way ANOVA for accuracy in the random search task found all main effects but Failure Percent to be significant (Table 5).

As with response time, Polarity and Background Clutter Level are both significant, with performance being more accurate for negative polarity (98.1%) than for positive (97.5%) and more accurate for low clutter (98.1%) than for high clutter (97.6%).

Table 3. Results of Simple-Effect F-Tests on Failure Mode for each Failure Type, Random Search Task, Dependent Variable = Response Time

Failure Type	MS _{Mode}	F	p
None	3.40	0.32	> .05
Horizontal Line	0.65	0.06	> .05
Vertical Line	19.34	1.83	> .05
Cell	151.51	14.32	< .01

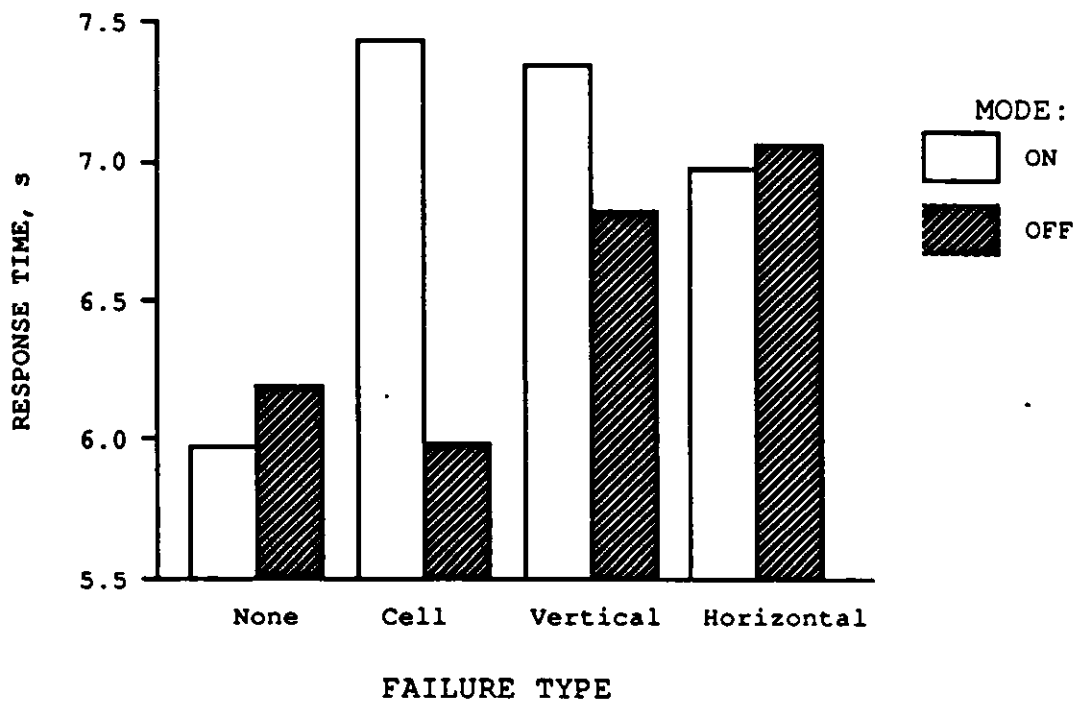


Figure 7. Failure Type by Failure Mode interaction, Random Search task, dependent variable = response time.

Table 4. Results of Newman-Keuls Test for Day, Random Search Task, Dependent Variable = Response Time

<u>Day</u>	<u>Means, s</u>
1	7.87 (A)
2	6.63 (B)
3	6.51 (B)
4	5.90 (B)

Means sharing a common letter in parentheses are not significantly different, $p > .05$

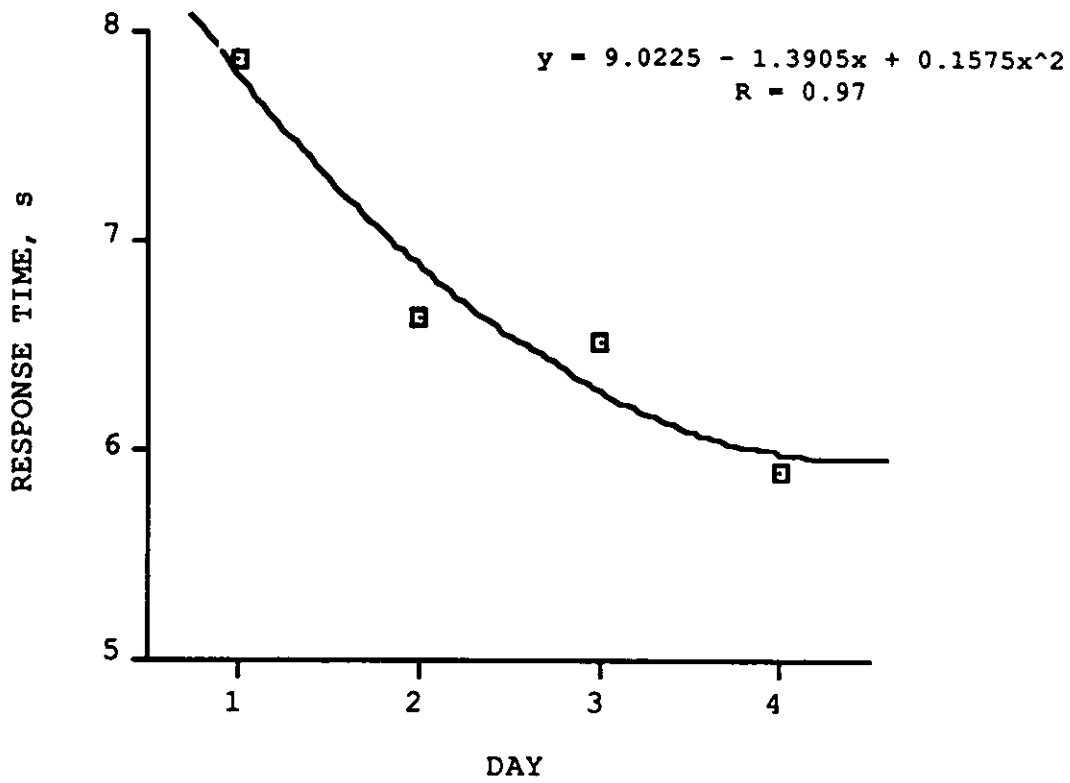


Figure 8. Day effect, Random Search task, dependent variable = response time.

Table 5. ANOVA Summary Table for Random Search Task,
Dependent Variable = Percent Correct Responses

SOURCE	df	MS	F	p
Subjects (SUB)	11	0.0111		
Polarity (POL)	1	0.0097	5.34	0.0419
SUB*POL	11	0.0018		
Background Clutter Level (BCL)	1	0.0070	5.27	0.0426
SUB*BCL	11	0.0013		
MODE	1	0.0151	8.65	0.0135
SUB*MODE	11	0.0017		
TYPE	3	0.0370	14.39	0.0001
SUB*TYPE	33	0.0026		
Percent (PCT)	2	0.0027	1.08	0.3564
SUB*PCT	22	0.0025		
POL*BCL	1	0.0041	2.13	0.1743
SUB*POL*BCL	11	0.0019		
POL*MODE	1	0.0029	1.92	0.1920
SUB*POL*MODE	11	0.0015		
POL*PCT	2	0.0024	1.21	0.3205
SUB*POL*PCT	22	0.0020		
POL*TYPE	3	0.0030	1.30	0.2925
SUB*POL*TYPE	33	0.0023		
BCL*MODE	1	0.0015	0.43	0.5190
SUB*BCL*MODE	11	0.0035		
BCL*PCT	2	0.0022	0.98	0.3934
SUB*BCL*PCT	22	0.0023		
BCL*TYPE	3	0.0029	2.04	0.1280
SUB*BCL*TYPE	33	0.0014		
MODE*PCT	2	0.0002	0.13	0.8642
SUB*MODE*PCT	22	0.0012		
MODE*TYPE	3	0.0063	3.29	0.0330
SUB*MODE*TYPE	33	0.0019		
PCT*TYPE	6	0.0082	6.08	0.0001
SUB*PCT*TYPE	66	0.0013		

POL*BCL*MODE	1	0.0047	3.17	0.1012
SUB*POL*BCL*MODE	11	0.0015		
POL*BCL*PCT	2	0.0007	0.39	0.6897
SUB*POL*BCL*PCT	22	0.0018		
POL*BCL*TYPE	3	0.0002	0.09	0.9694
SUB*POL*BCL*TYPE	33	0.0027		
POL*MODE*TYPE	3	0.0024	1.07	0.3742
SUB*POL*MODE*TYPE	33	0.0022		
POL*MODE*PCT	2	0.0047	3.59	0.0445
SUB*POL*MODE*PCT	22	0.0013		
POL*PCT*TYPE	6	0.0012	0.49	0.8116
SUB*POL*PCT*TYPE	66	0.0024		
BCL*MODE*PCT	2	0.0060	2.49	0.1053
SUB*BCL*MODE*PCT	22	0.0024		
BCL*PCT*TYPE	6	0.0019	1.51	0.1901
SUB*BCL*PCT*TYPE	66	0.0013		
BCL*MODE*TYPE	3	0.0034	1.08	0.3702
SUB*BCL*MODE*TYPE	33	0.0031		
MODE*PCT*TYPE	6	0.0001	0.09	0.9973
SUB*MODE*PCT*TYPE	66	0.0015		
POL*BCL*MODE*PCT	2	0.0022	1.08	0.3589
SUB*POL*BCL*MODE*PCT	22	0.0020		
POL*BCL*MODE*TYPE	3	0.0002	0.10	0.9625
SUB*POL*BCL*MODE*TYPE	33	0.0017		
POL*MODE*PCT*TYPE	6	0.0007	0.56	0.7642
SUB*POL*MODE*PCT*TYPE	66	0.0012		
POL*BCL*PCT*TYPE	6	0.0036	2.41	0.0367
SUB*POL*BCL*PCT*TYPE	66	0.0015		
BCL*MODE*PCT*TYPE	6	0.0020	1.05	0.4064
SUB*BCL*MODE*PCT*TYPE	66	0.0019		
POL*BCL*MODE*PCT*TYPE	6	0.0031	2.13	0.0607
SUB*POL*BCL*MODE*PCT*TYPE	<u>66</u>	0.0014		
	1151			

Two effects not found to be significant for response time that are significant for accuracy are Failure Mode and Failure Type. "On" mode produced significantly more accurate responses (98.1%) than "off" mode (97.4%) and horizontal line failures were found to yield significantly less accuracy than any of the other three failure types (Table 6 and Figure 9). Cell and vertical line failures did not reduce accuracy below that obtained with no failures.

Again, there is a significant Failure Mode by Failure Type interaction. Failure Mode showed an effect only for horizontal line failures (Table 7 and Figure 10); performance for "off" mode being more accurate (97.2%) than for "on" (95.1%).

Failure Percent also interacted significantly with Failure Type and, as with response times, percent only shows an effect for horizontal line failures (Table 8 and Figure 11). The Newman-Keuls Test revealed that all three failure percents differed significantly within this failure type (Table 9).

Finally, there is a three-way interaction among Polarity, Failure Mode, and Failure Percent. The effect of Polarity was found to be significant for the "off" mode at two percent and for the "on" mode at three percent (Table 10 and Figures 12 through 14). In both cases, performance for negative polarity (97.9% and 98.6% for the "off" and "on"

Table 6. Results of Newman-Keuls Tests on Failure Type, Random Search Task, Dependent Variable = Percent Correct Responses

<u>Failure Type</u>	<u>Means, s</u>
None	98.6 (A)
Cell	98.3 (A)
Vertical Line	98.2 (A)
Horizontal Line	96.1 (B)

Means for Failure Types sharing a common letter in parentheses are not significantly different, $p > .05$

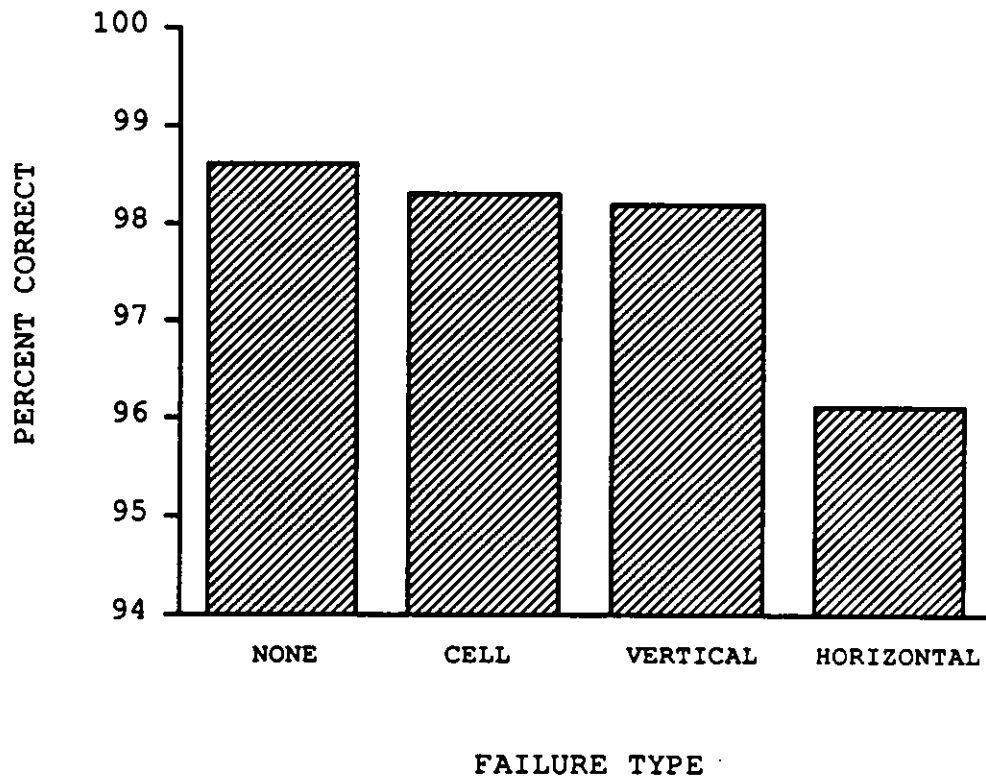


Figure 9. Failure Type for the Random Search task, dependent variable = percent correct responses.

Table 7. Results of Simple-Effect F-tests on Mode for each Failure Type, Random Search Task, Dependent Variable = Percent Correct Responses

Failure Type	MS _{Mode}	F	p
None	0.00	0.00	> .05
Horizontal Line	0.0313	16.47	< .01
Vertical Line	0.0024	1.26	> .05
Cell	0.0004	0.21	> .05

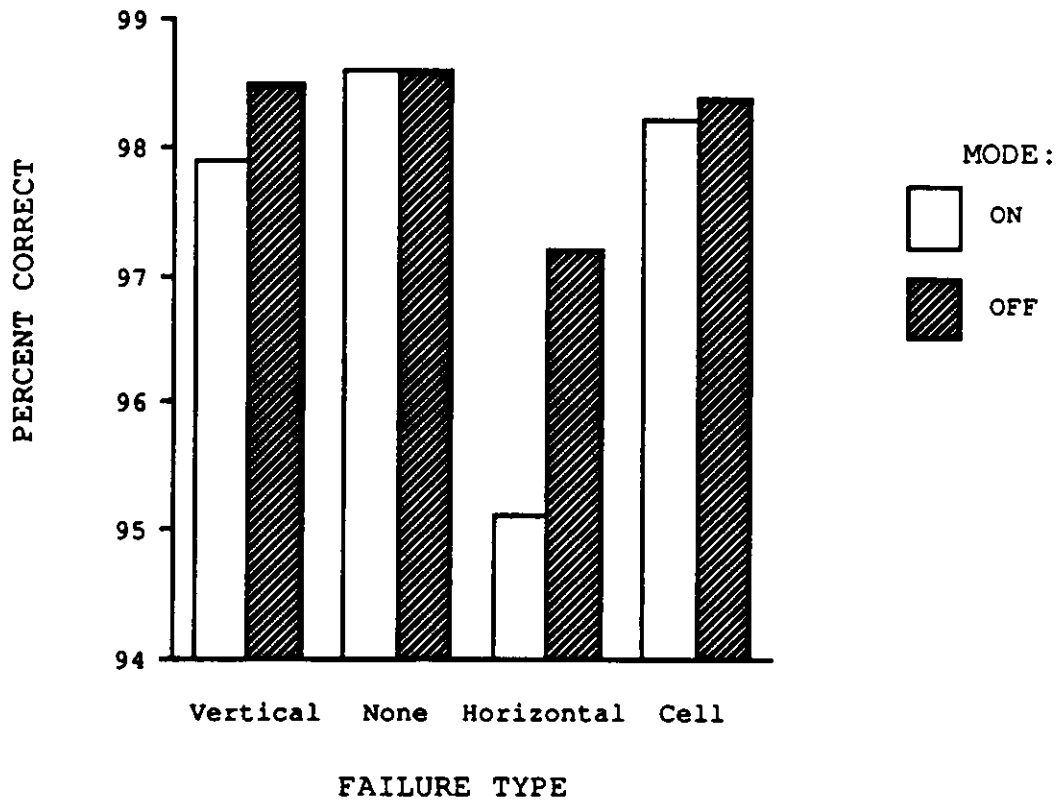


Figure 10. Failure Type by Failure Mode interaction, Random Search task, dependent variable = percent correct responses.

Table 8. Results of Simple-Effect F-tests on Failure Percent for each Failure Type, Random Search Task, Dependent Variable = Percent Correct Responses

Failure Type	MSpercent	F	p
None	0.002	1.54	> .05
Horizontal Line	0.0241	18.54	< .01
Vertical Line	0.00002	0.02	> .05
Cell	0.0012	0.92	> .05

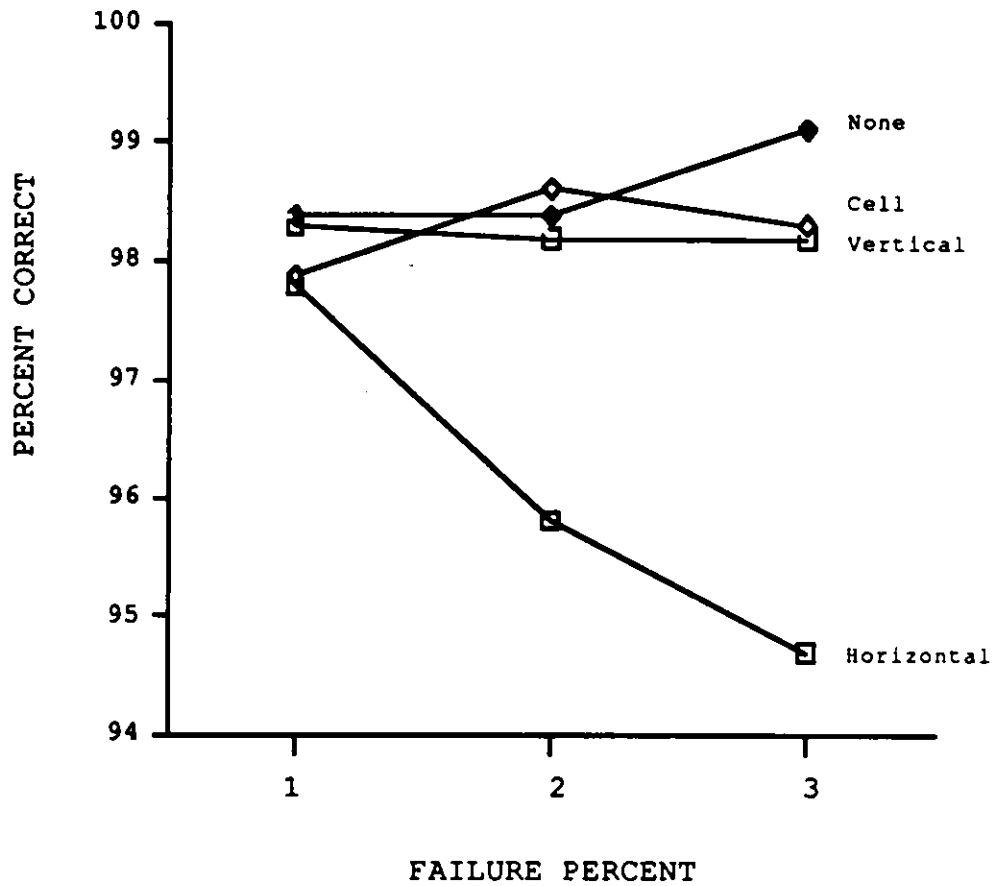


Figure 11. Failure Type by Failure Percent interaction, Random Search task, dependent variable = percent correct responses.

Table 9. Results of Newman-Keuls Tests on Failure Percent for Horizontal Line Failure, Random Search Task, Dependent Variable = Percent Correct Responses

<u>Failure Percent</u>	<u>Means, s</u>
1	97.8 (A)
2	95.8 (B)
3	94.7 (C)

Means sharing a common letter in parentheses are not significantly different, $p > .05$

Table 10. Results of Simple-Effect F-Tests on Polarity for all combinations of Failure Mode and Failure Percent, Random Search Task, Dependent Variable = Percent Correct Responses

Mode	Percent	MS _{polarity}	F	p
Off	1	0.0023	1.77	> .05
Off	2	0.0071	5.46	< .05
Off	3	0.0029	2.23	> .05
On	1	0.0002	0.15	> .05
On	2	0.0036	2.77	> .05
On	3	0.0105	8.08	< .01

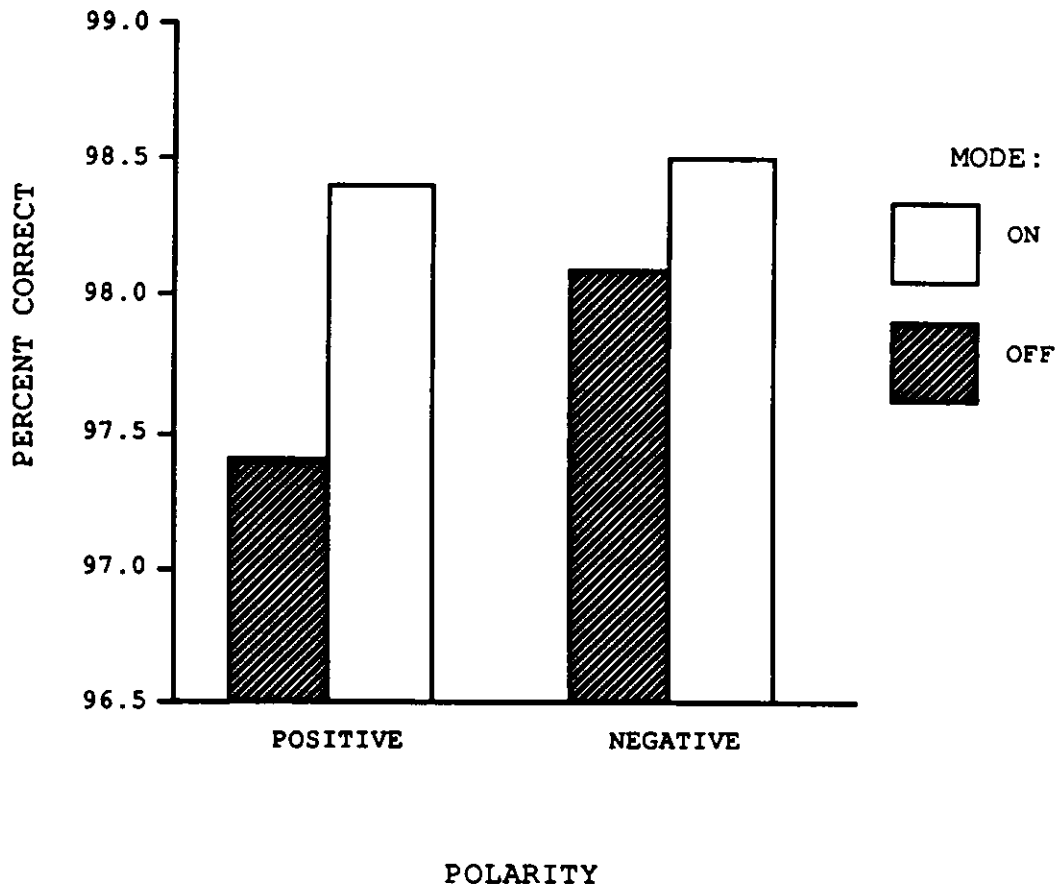


Figure 12. Polarity by Failure Mode interaction, one percent failure, Random Search task, dependent variable = percent correct responses.

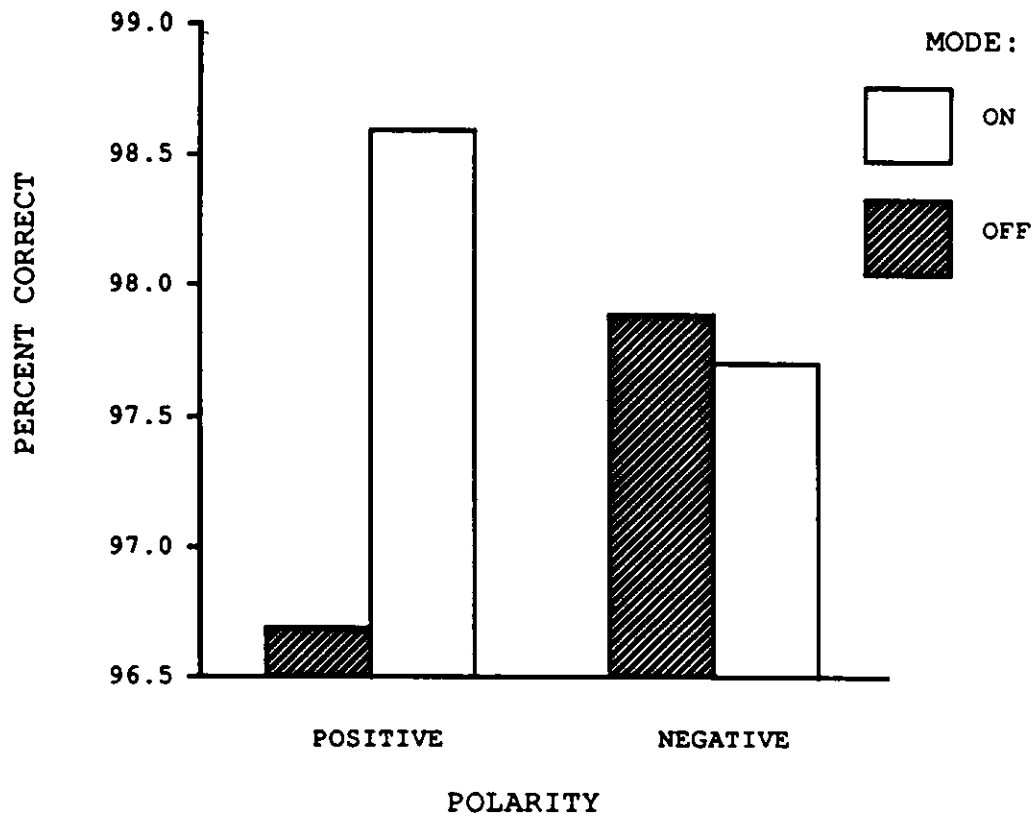


Figure 13. Polarity by Failure Mode interaction, two percent failure, Random Search task, dependent variable = percent correct responses.

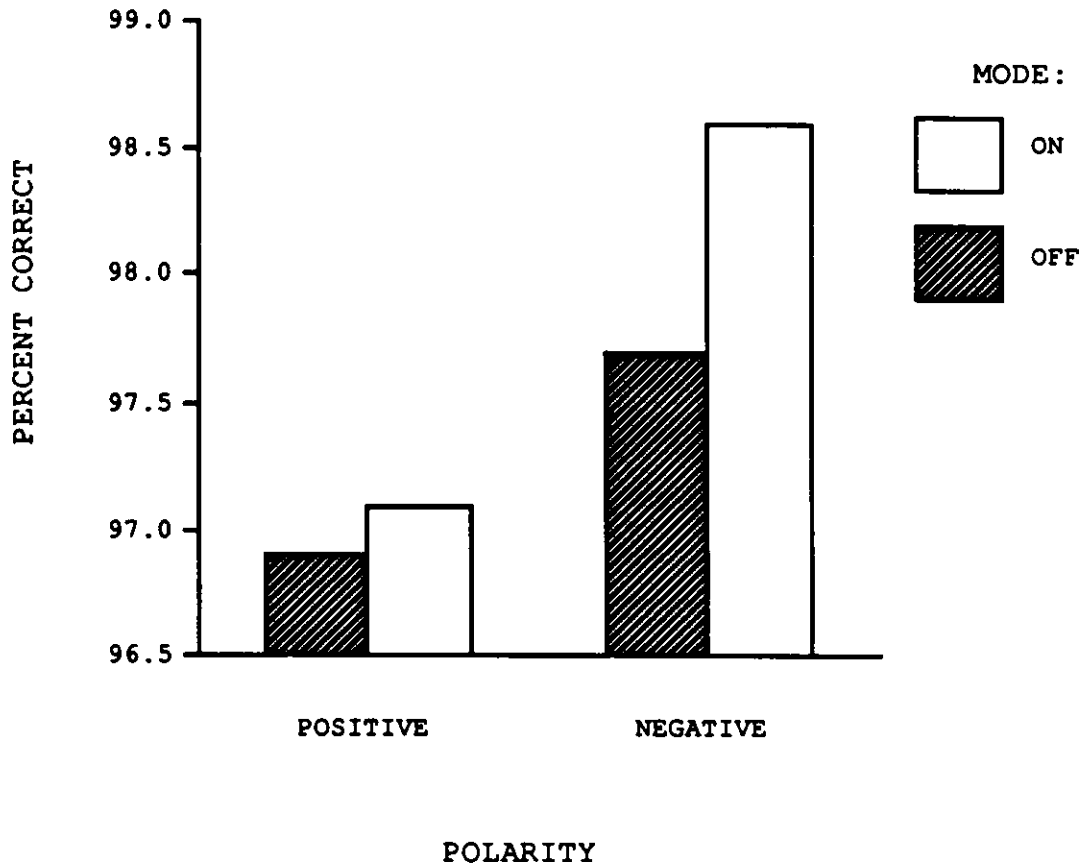


Figure 14. Polarity by Failure Mode interaction, three percent failure, Random Search task, dependent variable = percent correct responses.

mode combinations, respectively) was more accurate than for positive polarity (96.7% and 97.1%, respectively).

No significant change ($p > .05$) in accuracy over the four days was found in a separate ANOVA.

Information Extraction Task

Response time. Polarity, Background Clutter Level, and Failure Percent were found to be significant as in the random search task ANOVA for response time, and all displayed the same trends (Table 11). Performance with negative polarity was faster (4.13 s) than with positive (4.45 s); performance with low clutter was faster (3.83 s) than with high (4.74 s); and a failure percent of one produced significantly faster responses (4.14 s) than a failure percent of either two (4.31 s) or three (4.41 s, Table 12 and Figure 15).

In addition, the effect of Failure Mode shows significance with the "off" mode producing faster (4.16 s) times than the "on" mode (4.41 s).

The Failure Mode by Failure Type interaction is again significant. Failure Mode displayed an effect for vertical line ("off" mode = 4.12 s; "on" mode = 4.65 s) and cell ("off" mode = 4.00 s; "on" mode = 4.51 s) failure types, "off" mode producing consistently faster responses (Table 13 and Figure 16).

Table 11. ANOVA Summary Table for Information Extraction Task, Dependent Variable = Response Time

SOURCE	df	MS	F	p
Subjects (SUB)	11	231.27		
Polarity (POL)	1	28.89	48.52	0.0001
SUB*POL	11	0.60		
Background Clutter Level (BCL)	1	238.55	73.61	0.0001
SUB*BCL	11	3.24		
MODE	1	18.21	26.60	0.0003
SUB*MODE	11	0.68		
TYPE	3	2.51	0.27	0.0851
SUB*TYPE	33	9.23		
Percent (PCT)	2	7.33	6.91	0.0047
SUB*PCT	22	1.06		
POL*BCL	1	0.04	0.06	0.8196
SUB*POL*BCL	11	0.69		
POL*MODE	1	0.09	0.24	0.6354
SUB*POL*MODE	11	0.38		
POL*PCT	2	1.08	1.63	0.2189
SUB*POL*PCT	22	0.66		
POL*TYPE	3	0.16	0.26	0.8547
SUB*POL*TYPE	33	0.61		
BCL*MODE	1	1.54	4.60	0.0551
SUB*BCL*MODE	11	0.33		
BCL*PCT	2	0.02	0.05	0.9573
SUB*BCL*PCT	22	0.28		
BCL*TYPE	3	1.07	1.05	0.3824
SUB*BCL*TYPE	33	1.01		
MODE*PCT	2	1.21	1.41	0.2660
SUB*MODE*PCT	22	0.86		
MODE*TYPE	3	7.16	5.02	0.0056
SUB*MODE*TYPE	33	1.43		
PCT*TYPE	6	1.54	1.17	0.3357
SUB*PCT*TYPE	66	1.32		

POL*BCL*MODE	1	0.06	0.09	0.7755
SUB*POL*BCL*MODE	11	0.65		
POL*BCL*PCT	2	0.03	0.05	0.9479
SUB*POL*BCL*PCT	22	0.57		
POL*BCL*TYPE	3	1.16	0.92	0.4440
SUB*POL*BCL*TYPE	33	1.26		
POL*MODE*TYPE	3	0.51	0.84	0.4795
SUB*POL*MODE*TYPE	33	0.61		
POL*MODE*PCT	2	1.78	2.41	0.1135
SUB*POL*MODE*PCT	22	0.74		
POL*PCT*TYPE	6	1.08	1.85	0.1023
SUB*POL*PCT*TYPE	66	0.58		
BCL*MODE*PCT	2	1.58	2.07	0.1507
SUB*BCL*MODE*PCT	22	0.76		
BCL*PCT*TYPE	6	2.66	3.06	0.0105
SUB*BCL*PCT*TYPE	66	0.87		
BCL*MODE*TYPE	3	0.27	0.50	0.6869
SUB*BCL*MODE*TYPE	33	0.55		
MODE*PCT*TYPE	6	0.37	0.45	0.8426
SUB*MODE*PCT*TYPE	66	0.81		
POL*BCL*MODE*PCT	2	2.36	2.38	0.1161
SUB*POL*BCL*MODE*PCT	22	0.99		
POL*BCL*MODE*TYPE	3	0.53	0.79	0.5101
SUB*POL*BCL*MODE*TYPE	33	0.68		
POL*MODE*PCT*TYPE	6	1.00	1.33	0.1211
SUB*POL*MODE*PCT*TYPE	66	0.75		
POL*BCL*PCT*TYPE	6	1.41	1.76	0.2555
SUB*POL*BCL*PCT*TYPE	66	0.80		
BCL*MODE*PCT*TYPE	6	0.46	0.52	0.7899
SUB*BCL*MODE*PCT*TYPE	66	0.94		
POL*BCL*MODE*PCT*TYPE	6	0.58	1.09	0.3796
SUB*POL*BCL*MODE*PCT*TYPE	<u>66</u>	0.53		
	1151			

Table 12. Results of Newman-Keuls Test for Failure Percent, Information Extraction Task, Dependent Variable = Response Time

<u>Failure Percent</u>	<u>Means, s</u>
3	4.41 (A)
2	4.31 (A)
1	4.14 (B)

Means sharing a common letter in parentheses are not significantly different, $p > .05$

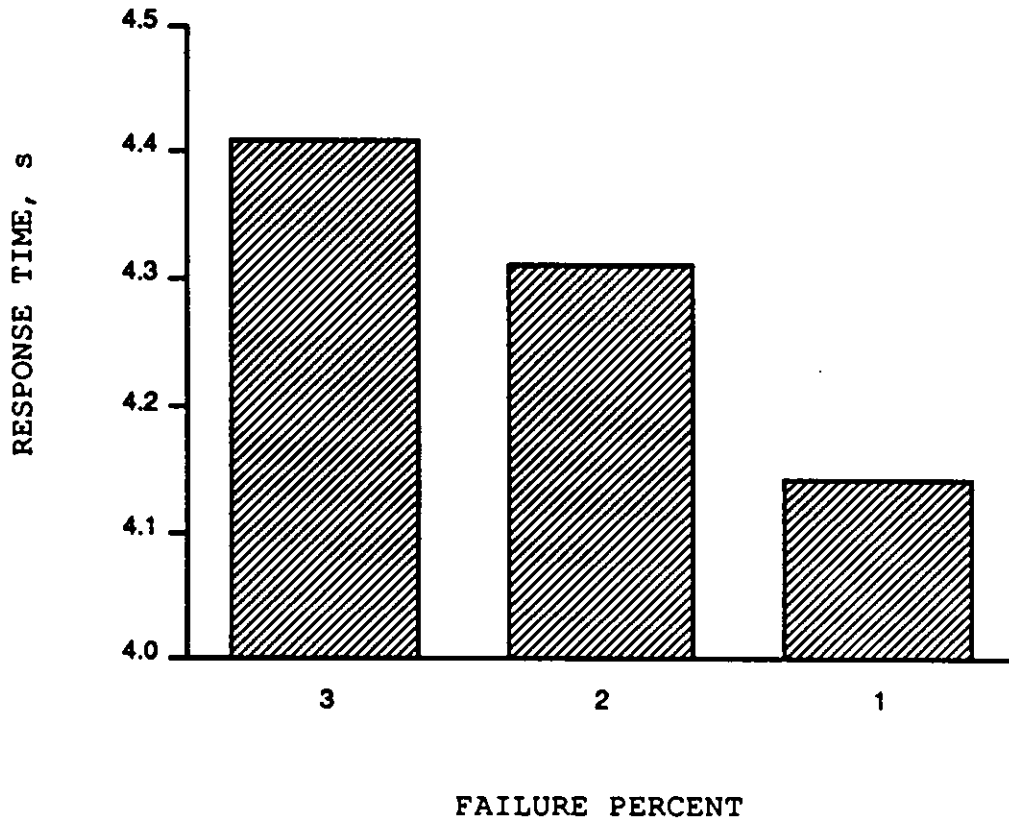


Figure 15. Failure Percent for the Information Extraction task, dependent variable = response time.

Table 13. Results of Simple-Effect F-Tests on Failure Mode for each Failure Type, Information Extraction Task, Dependent Variable = Reaction Time

Failure Type	MS _{Mode}	F	p
None	0.58	0.41	> .05
Horizontal Line	0.23	0.16	> .05
Vertical Line	20.22	14.14	< .01
Cell	18.67	13.06	< .01

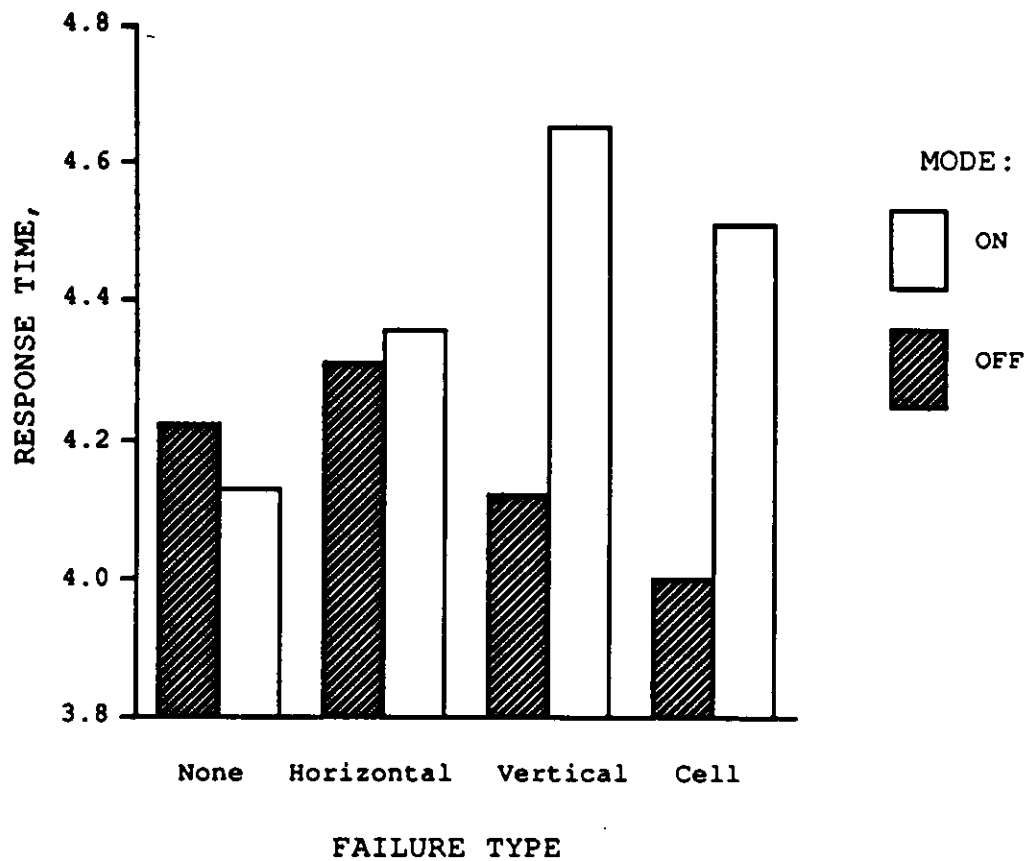


Figure 16. Failure Mode by Failure Type interaction, Information Extraction task, dependent variable = response time.

The three-way interaction of Background Clutter Level, Failure Percent, and Failure Type is also statistically significant. Simple-effect F-tests showed that Failure Percent is significant for both types of line failures at high clutter, and for horizontal line failures at low clutter (Table 14 and Figures 17 - 20). For the horizontal line failure with low clutter and the vertical line failure with high clutter combinations, the Newman-Keuls test found that a three percent failure rate provides significantly slower responses than both one and two percent failures (Table 15). For the horizontal line with high clutter combination, the two percent failure rate provides slower responses than a failure of one percent, but not three percent (Table 15).

A Day effect was found ($F(3,33) = 18.23, p < .0001$) with times slowest on Day One and not significantly different among the other three days (Table 16 and Figure 21). Again, the best-fitting function indicates an asymptote at Day Four.

Accuracy. For the dependent measure of percentage of correct responses, only the main effects of Background Clutter Level ($p < .0001$) and Failure Type ($p = .0475$) were found to be significant (Table 17).

Low clutter produced significantly more accurate (90.3%) responses than high clutter (86.1%), and only the failure types of no failure (89.5%) and horizontal line failure

Table 14. Results of Simple-Effect F-Tests on Failure Percent for all Combinations of Failure Type and Background Clutter Level, Information Extraction Task, Dependent Variable = Reaction Time

Failure Type	BCL	MSpercent	F	p
None	Low	0.02	0.03	> .05
None	High	0.73	0.84	> .05
Horizontal Line	Low	5.21	5.99	< .01
Horizontal Line	High	4.17	4.79	< .05
Vertical Line	Low	2.05	2.36	> .05
Vertical Line	High	6.57	7.55	< .01
Cell	Low	0.62	0.72	> .05
Cell	High	0.55	0.63	> .05

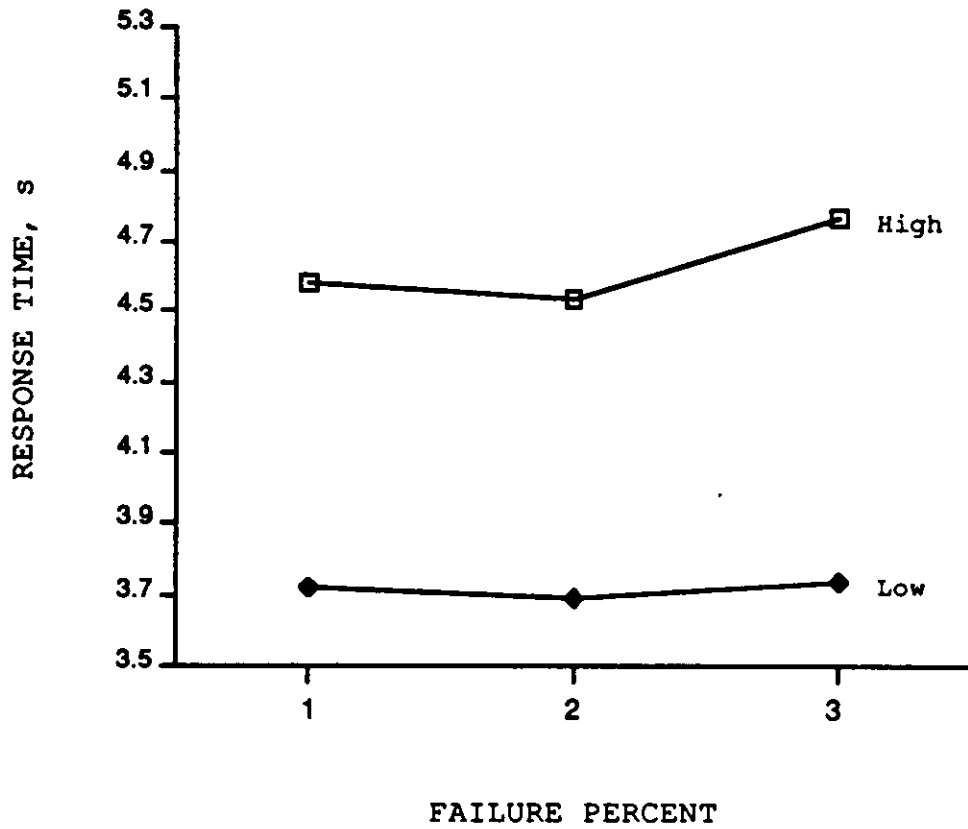


Figure 17. Background Clutter Level by Failure Percent interaction, no failure, Information Extraction task, dependent variable = response time.

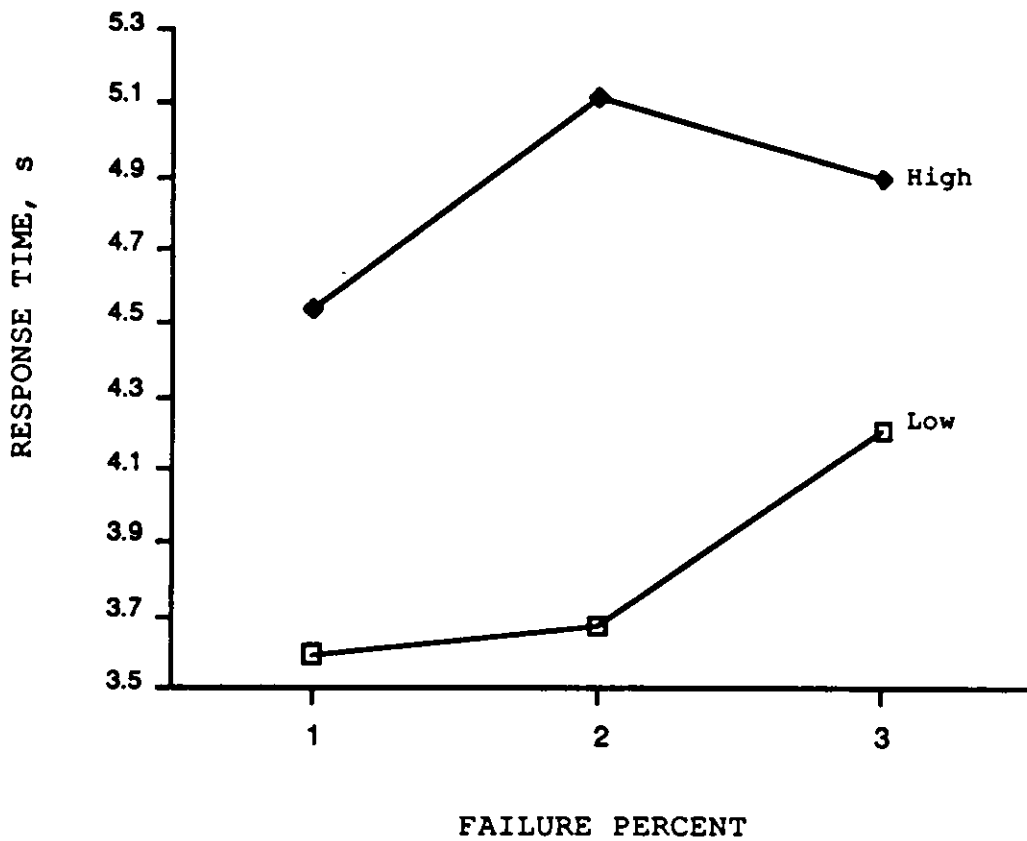


Figure 18. Background Clutter Level by Failure Percent interaction, horizontal line failure, Information Extraction task, dependent variable = response time.

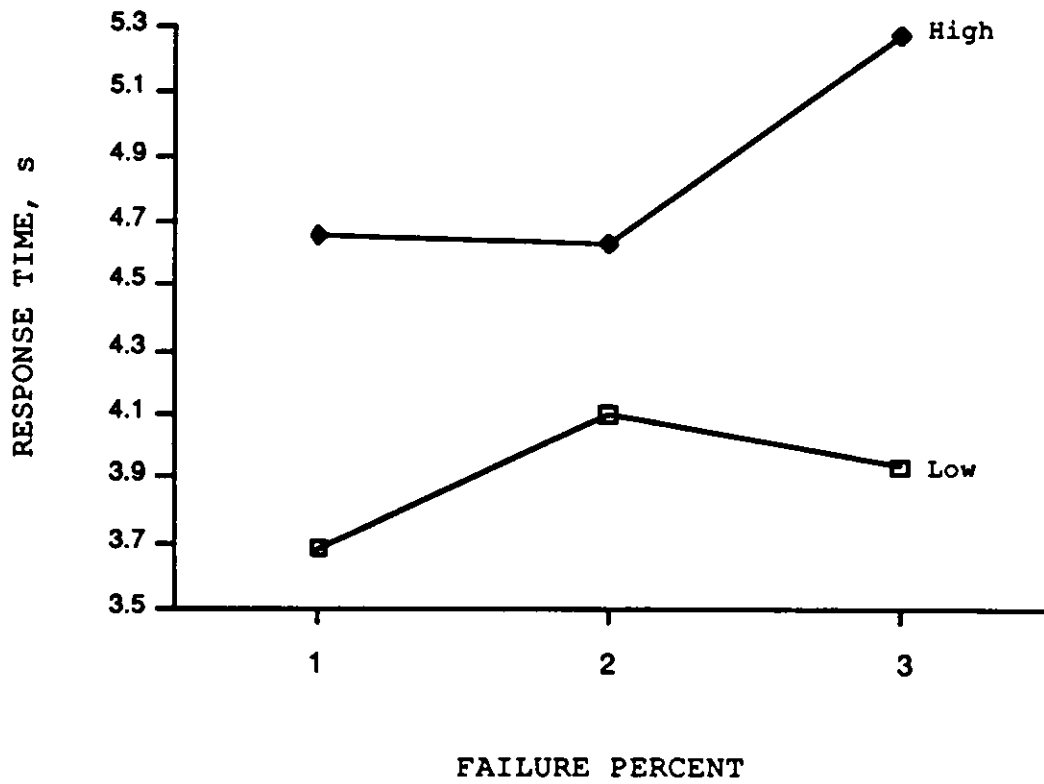


Figure 19. Background Clutter Level by Failure Percent interaction, vertical line failure, Information Extraction task, dependent variable = response time.

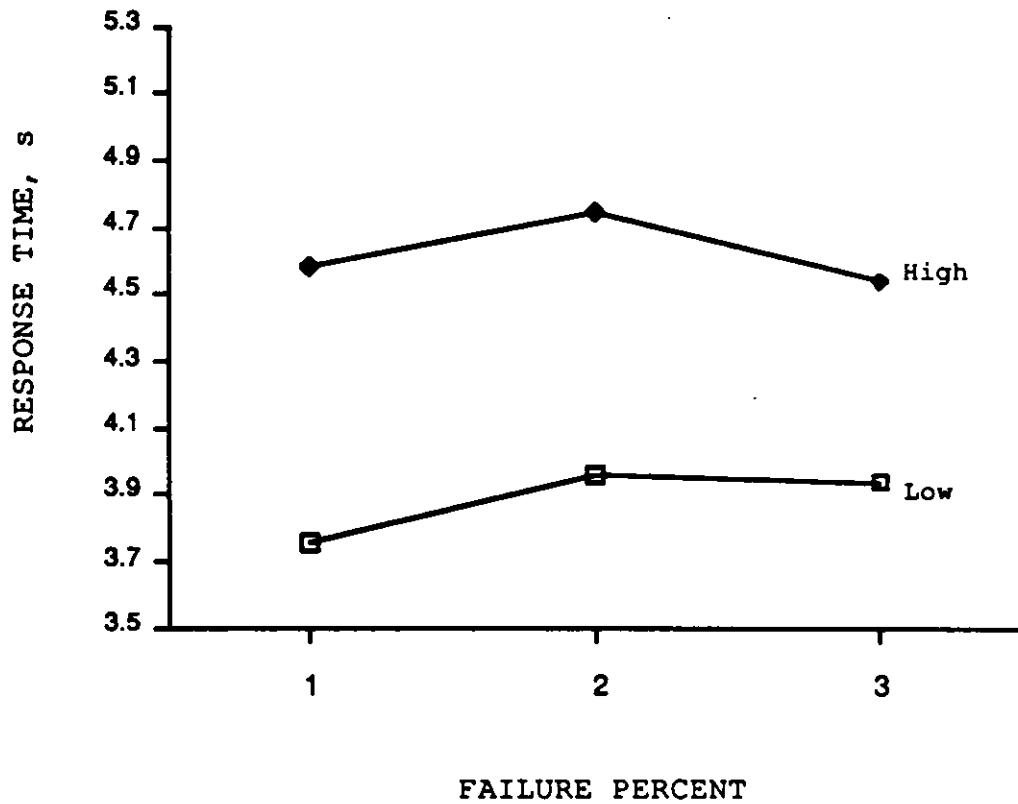


Figure 20. Background Clutter Level by Failure Percent interaction, cell failure, Information Extraction task, dependent variable = response time.

Table 15. Results of Newman-Keuls Tests on Failure Percent for Background Clutter Levels and Vertical and Horizontal Line Failures, Information Extraction Task, Dependent Variable = Response Time

Failure Type	BCL	Percent	Means, s
Vertical Line	High	3	5.282 (A)
		1	4.651 (B)
		2	4.632 (B)
Horizontal Line	Low	3	4.196 (A)
		2	3.673 (B)
		1	3.588 (B)
Horizontal Line	High	2	5.118 (A)
		3	4.900 (AB)
		1	4.535 (B)

Means for each Background Clutter Level sharing the same letter in parentheses are not significantly different, $p > .01$

Table 16. Results of Newman-Keuls Test for Day, Information Extraction Task, Dependent Variable = Response Time

<u>Day</u>	<u>Means, s</u>
1	4.97 (A)
2	4.20 (B)
3	4.11 (B)
4	3.87 (B)

Means sharing the same letter in parentheses are not significantly different, $p > .05$

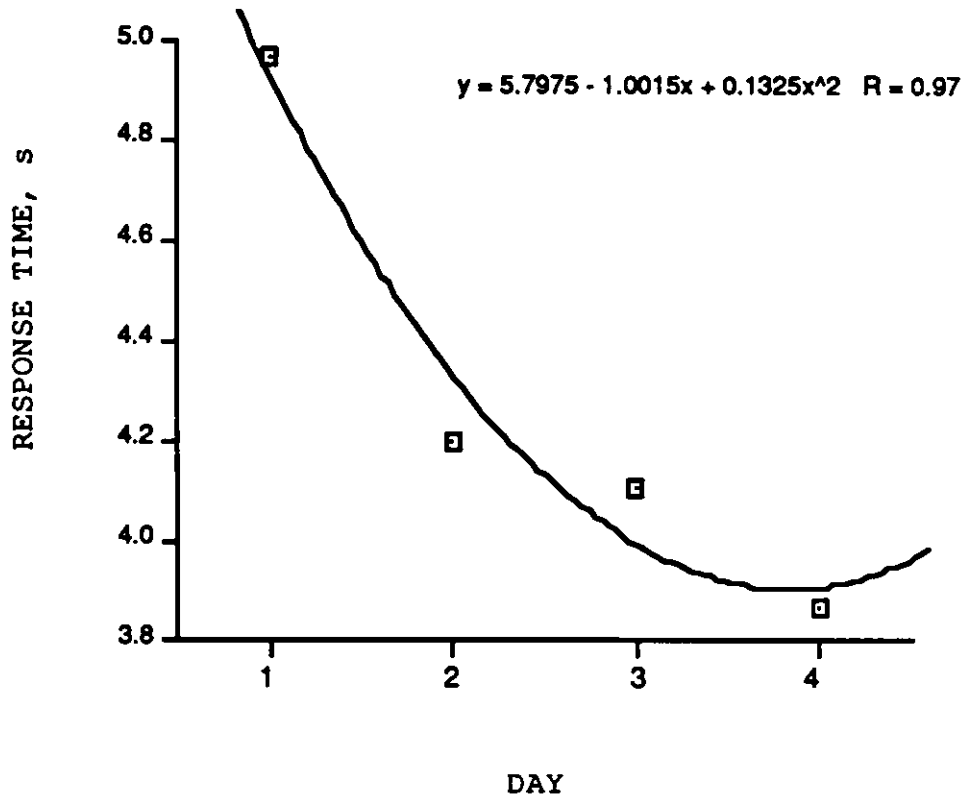


Figure 21. Day effect, Information Extraction task, dependent variable = response time.

Table 17. ANOVA Summary Table for Information Extraction Task, Dependent Variable = Percent Correct Responses

SOURCE	df	MS	F	p
Subjects (SUB)	11	0.0777		
Polarity (POL)	1	0.0467	2.07	0.1779
SUB*POL	11	0.0225		
Background Clutter Level (BCL)	1	0.4931	32.31	0.0001
SUB*BCL	11	0.0153		
MODE	1	0.0087	0.85	0.3761
SUB*MODE	11	0.0102		
TYPE	3	0.0390	2.94	0.0475
SUB*TYPE	33	0.0133		
Percent (PCT)	2	0.0133	1.34	0.2819
SUB*PCT	22	0.0099		
POL*BCL	1	0.0024	0.29	0.5984
SUB*POL*BCL	11	0.0082		
POL*MODE	1	0.0000*	0.00	1.0000
SUB*POL*MODE	11	0.0053		
POL*PCT	2	0.0142	1.61	0.2221
SUB*POL*PCT	22	0.0088		
POL*TYPE	3	0.0042	0.52	0.6716
SUB*POL*TYPE	33	0.0081		
BCL*MODE	1	0.0232	2.97	0.1129
SUB*BCL*MODE	11	0.0078		
BCL*PCT	2	0.0110	1.21	0.3186
SUB*BCL*PCT	22	0.0091		
BCL*TYPE	3	0.0105	1.34	0.2779
SUB*BCL*TYPE	33	0.0078		
MODE*PCT	2	0.0214	2.08	0.1493
SUB*MODE*PCT	22	0.0103		
MODE*TYPE	3	0.0142	2.71	0.0612
SUB*MODE*TYPE	33	0.0053		
PCT*TYPE	6	0.0087	0.75	0.6116
SUB*PCT*TYPE	66	0.0116		

POL*BCL*MODE	1	0.0703	7.91	0.0169
SUB*POL*BCL*MODE	11	0.0089		
POL*BCL*PCT	2	0.0084	0.94	0.4084
SUB*POL*BCL*PCT	22	0.0089		
POL*BCL*TYPE	3	0.0010	0.09	0.9663
SUB*POL*BCL*TYPE	33	0.0112		
POL*MODE*TYPE	3	0.0099	1.52	0.2273
SUB*POL*MODE*TYPE	33	0.0065		
POL*MODE*PCT	2	0.0167	2.40	0.1137
SUB*POL*MODE*PCT	22	0.0069		
POL*PCT*TYPE	6	0.0065	0.80	0.5747
SUB*POL*PCT*TYPE	66	0.0082		
BCL*MODE*PCT	2	0.0151	1.67	0.2107
SUB*BCL*MODE*PCT	22	0.0090		
BCL*PCT*TYPE	6	0.0075	0.92	0.4905
SUB*BCL*PCT*TYPE	66	0.0081		
BCL*MODE*TYPE	3	0.0102	1.65	0.1979
SUB*BCL*MODE*TYPE	33	0.0062		
MODE*PCT*TYPE	6	0.0069	0.60	0.7332
SUB*MODE*PCT*TYPE	66	0.0116		
POL*BCL*MODE*PCT	2	0.0079	1.34	0.2828
SUB*POL*BCL*MODE*PCT	22	0.0059		
POL*BCL*MODE*TYPE	3	0.0021	0.20	0.8951
SUB*POL*BCL*MODE*TYPE	33	0.0107		
POL*MODE*PCT*TYPE	6	0.0051	0.88	0.3856
SUB*POL*MODE*PCT*TYPE	66	0.0058		
POL*BCL*PCT*TYPE	6	0.0079	1.08	0.5167
SUB*POL*BCL*PCT*TYPE	66	0.0073		
BCL*MODE*PCT*TYPE	6	0.0049	0.52	0.7939
SUB*BCL*MODE*PCT*TYPE	66	0.0094		
POL*BCL*MODE*PCT*TYPE	6	0.0062	0.64	0.6974
SUB*POL*BCL*MODE*PCT*TYPE	<u>66</u>	0.0096		
	1151			

* This unlikely value was calculated independently to insure its validity.

(86.7%) are significantly different from one another (Table 18 and Figure 22).

The only higher order interaction was that among Polarity, Background Clutter Level, and Failure Mode. The simple-effect F-Tests found that Polarity was significant for low clutter and "on" mode, and for high clutter and "off" mode combinations (Table 19, Figures 23 and 24), with responses for negative polarity being more accurate than for positive polarity for both combinations (91.7% > 88.5%, and 86.7% > 84.1%, respectively).

It should be noted that this was the only one of the four ANOVAs in which the Failure Mode by Failure Type interaction was not found to be significant albeit by a small margin ($p = .0612$).

The Day effect was again significant ($F(3,33) = 3.64$, $p = .0227$), with Day One producing fewer accurate responses than Days Three and Four (Table 20 and Figure 25). There were no significant differences among the last three days, although the best-fitting function reaches asymptote at Day Four.

Table 18. Results of Newman-Keuls Test on Failure Type, Information Extraction Task, Dependent Variable = Percent Correct Responses

<u>Failure Type</u>	<u>Means</u>
None	89.5 (A)
Cell	88.6 (AB)
Vertical Line	88.0 (AB)
Horizontal Line	86.7 (B)

Means for Failure Type sharing a common letter in parentheses are not significantly different, $p > .05$

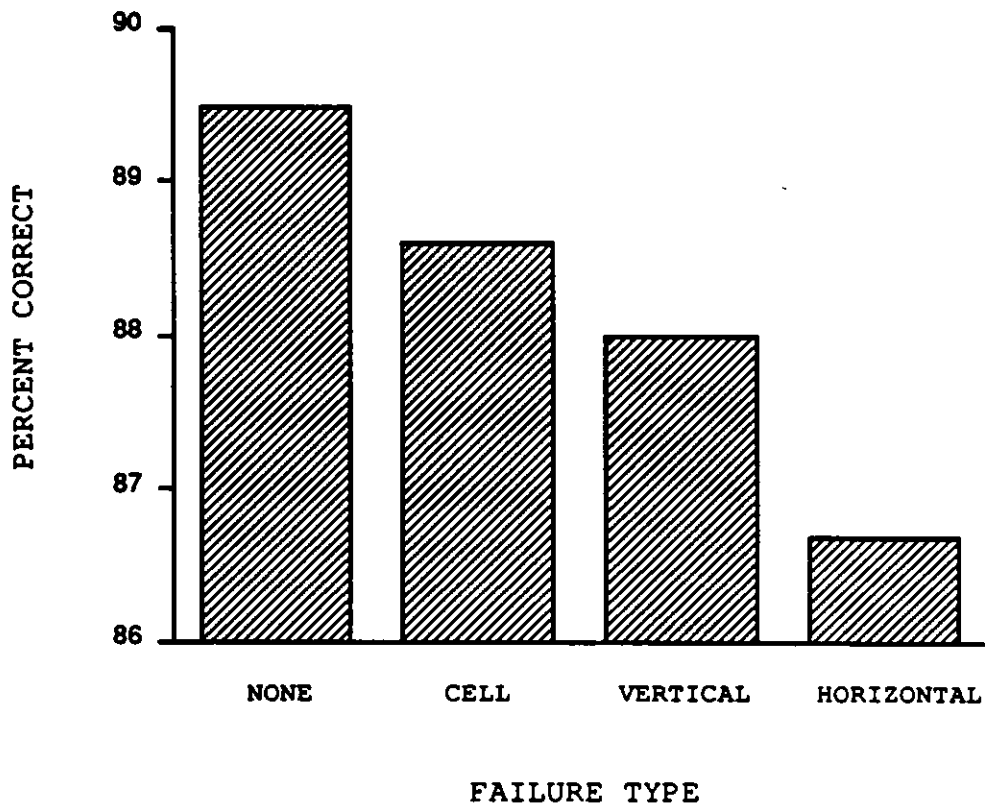


Figure 22. Failure Type for the Information Extraction task, dependent variable = percent correct responses.

Table 19. Results of Simple-Effect F-Tests on Polarity for all Combinations of Background Clutter Level and Failure Mode, Information Extraction Task, Dependent Variable = Percent Correct Responses

BCL	Mode	MSpolarity	F	p
Low	Off	0.000	0.00	> .05
Low	On	0.070	7.87	< .05
High	Off	0.047	5.25	< .05
High	On	0.002	0.27	> .05

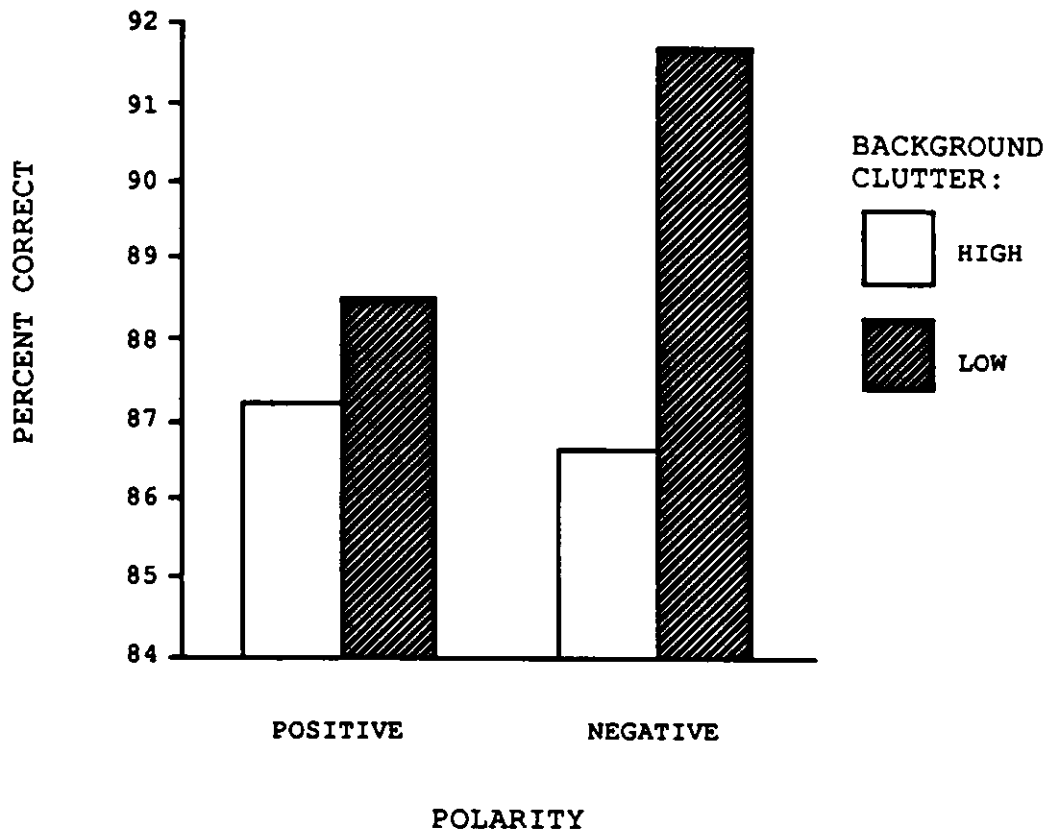


Figure 23. Polarity by Background Clutter interaction, on mode, Information Extraction task, dependent variable = percent correct responses.

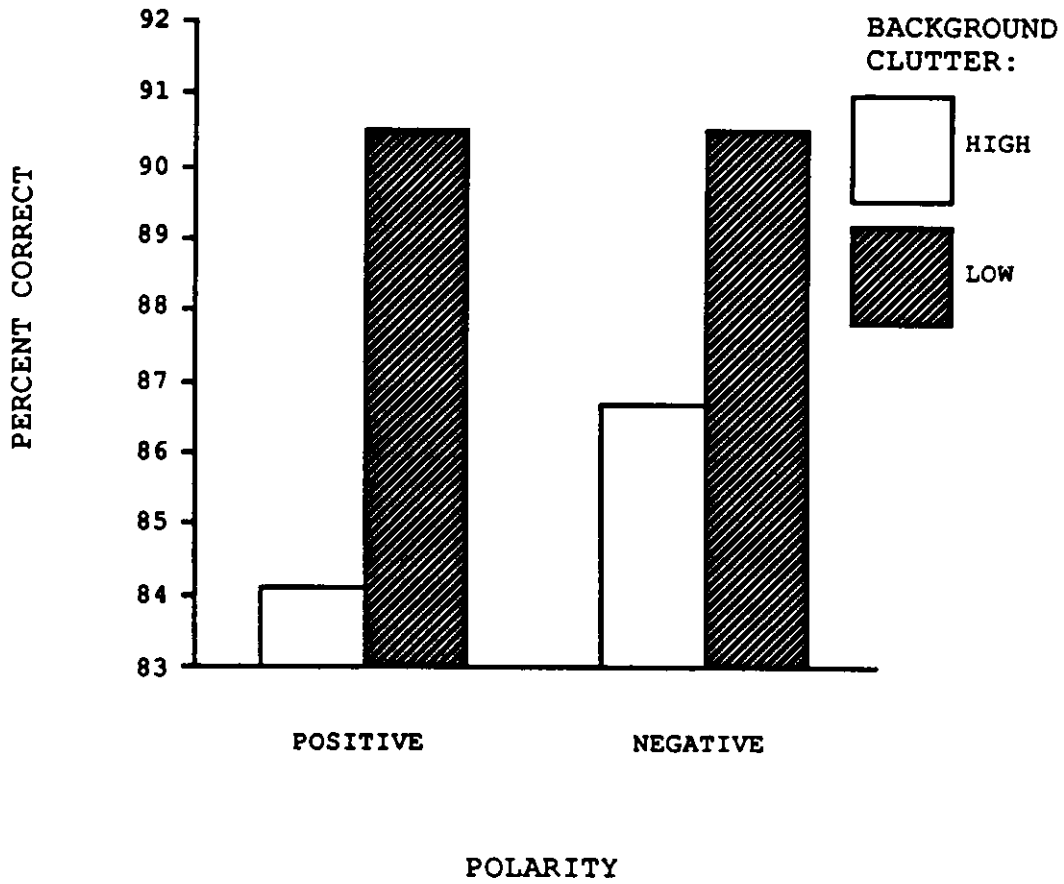


Figure 24. Polarity by Background Clutter interaction, off mode, Information Extraction task, dependent variable = percent correct responses.

Table 20. Results of Newman-Keuls Test for Day, Information Extracftion Task, Dependent Variable = Percent Correct Responses

<u>Day</u>	<u>Means</u>
1	86.6 (A)
2	87.8 (AB)
4	89.1 (B)
3	89.4 (B)

Means sharing the same letter in parentheses are not significantly different, $p > .05$

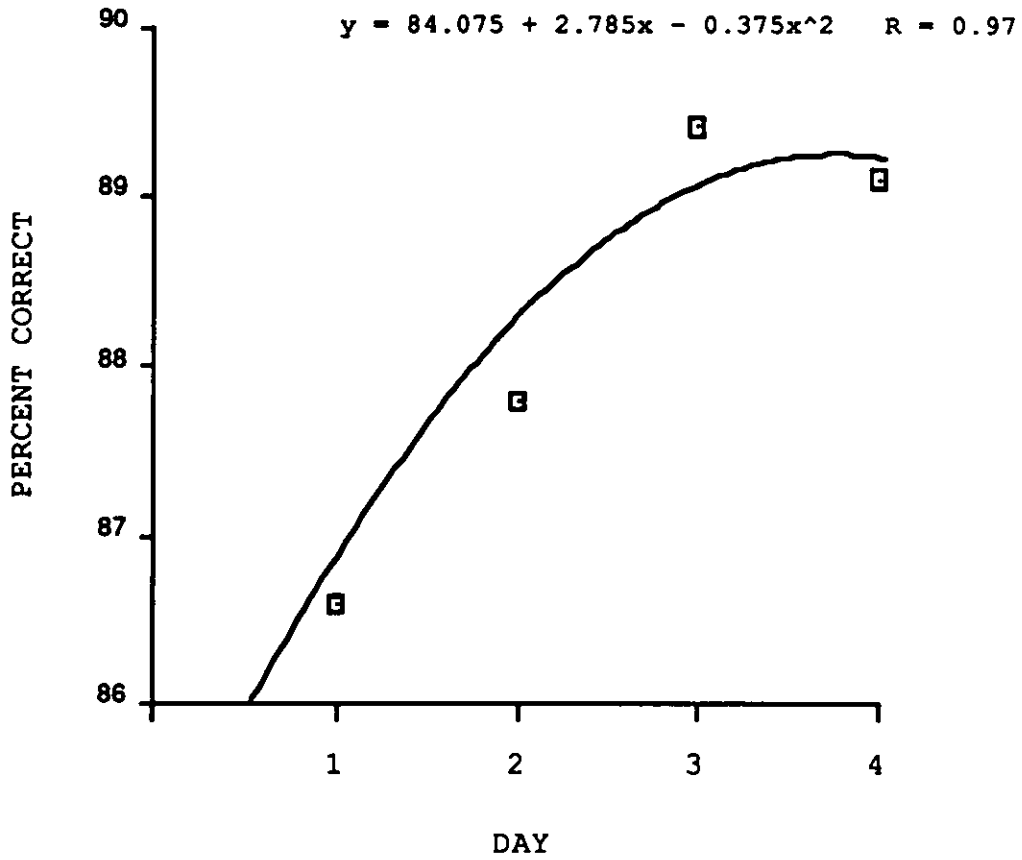


Figure 25. Day effect, Information Extraction task, dependent variable = percent correct responses.

DISCUSSION

One of the less obvious, yet important results of the study was the difference in overall response times and accuracy between the two experiments. Performance was slower yet more accurate for the random search task than for the information extraction task. This is really not too surprising since there is a smaller potential target area in the information extraction task. That is, in this task, the subject is told the target is near some reference information on the map, while in the random search task, the target may be located anywhere on the screen. Thus, response times should be shorter in the information extraction task.

Further, accuracy should be better for the random search task since there is a unique target symbol to search for, whereas in the information extraction task there are four to seven symbols which are identical in appearance to the target, but only one closest to the indicated reference on the map. Thus, the subject would quickly find a symbol which looks like the target, but it simply would not be the closest to the target reference.

Background Clutter Level

Background Clutter Level showed expected results, with a high clutter condition requiring more search time and

producing less accuracy than a low clutter condition for both tasks. Search time seems to suffer more than accuracy as clutter is increased. The differences were not that large for accuracy, but response times were 20% and 30% faster for low clutter than for high clutter in the information extraction and random search tasks, respectively. It should be noted that the displays were really not as cluttered as they might be (approximately 2.9% of the display pixels "on" for low clutter, and approximately 3.8% of the display pixels "on" for high clutter, Figures 4 and 3). With such seemingly low overall levels of clutter as were present in this study, asymptotic degradation of performance certainly was not attained. It is reasonable to assume, then, that performance would be increasingly degraded if clutter were increased above the modest levels used in these experiments.

Polarity

As found in the earlier polarity studies (Decker et al., 1988; Kelly-Harrison et al., 1988; Lloyd et al., 1988), negative polarity produced better performance than positive polarity. While statistically significant, response times were not much faster for negative than positive polarity, 16% faster in the random search task and 7% faster in the information extraction task. The difference between the two

polarities for accuracy in the random search task was quite small (0.6%).

Snyder (1980) found that increasing space-average luminance increases contrast sensitivity. It is possible that the higher space-average luminance which exists in the negative polarity condition increased contrast sensitivity over that found in the positive polarity condition. This may have led to greater legibility for the images appearing in negative polarity, thereby increasing the task performance for that condition.

Certainly more research on the issue of polarity needs to be performed, but the results of this and previous studies seems to give a consistent nod to negative polarity. Those performing future research in this area are again cautioned that stroke width, modulation, and luminances for both polarities must be set as equal as possible in order to provide meaningful and unconfounded results.

Failure Variables

Failures affect only the symbols for the random search task, but they affect both the symbols and the target references for the information extraction task. This is readily apparent in Figure 3, where one of the lines of a road is entirely erased due to a horizontal line failure in "off" mode (left hand side of the figure). A similar type of

interference would exist in the case where a line failure is "on," and is parallel to a line which is part of the map information, as is the case in Figure 1.

Horizontal line failures seem to have the greatest effect on performance overall. The cause of this effect can be explained by referring to the symbol set in Figure 5. Half the symbols have a horizontal bar over or through them. This bar is used to distinguish the enemy symbols from the friendly ones. It should be readily apparent that of the three types of failures (excluding no failure), the type that presents the most interference to the greatest number of symbols is the horizontal line failure.

Interpreting the effects of Failure Mode is slightly more difficult. The results show that "on" failures produced slower response times than "off" failures in the information extraction task. This is not surprising and it agrees with the results found in the recent alphanumeric search studies (Abramson and Snyder, 19884; Decker et al., 1988; Lloyd et al., 1988). Simply comparing the two modes visually (Figures 1 and 3 for "on" and "off" modes, respectively) is evidence that the "on" failures are much more disturbing.

In the random search task, there was greater accuracy for "on" failures than for "off" failures. This is not consistent with previous research. However, while the results for accuracy were statistically significant, for all

practical purposes there was very little difference in accuracy for the two modes. The "on" mode averaged 98.1% accuracy and the "off" mode averaged 97.4% accuracy. In an actual task of this nature, either of these modes is probably acceptable.

It is of interest to note that the previous alphanumeric studies (Decker et al., 1988; Lloyd et al., 1988) found "off" failures to be slightly more accurate than "on" failures. The overall accuracy was fairly high in these studies, as well. The averages of the two experiments were approximately 91% and 88% for the "off" and "on" modes, respectively. There does not appear to be a logical explanation for the slight advantage of "on" failures found in the present search task.

Generally, as Failure Percent increased from one to two to three percent, response times increased and accuracy decreased, with the greatest effects at two and three percent. Response times were affected the most, with one percent failures producing faster responses than either two or three percent failures. These results support the concept that performance would be sensitive to lower percentages of failure for cartographic images than for alphanumeric images due to the added interference and complexity of map information. Previous studies (Abramson and Snyder, 1984; Decker et al., 1988; Lloyd et al., 1988) found that failure

percents of three or greater significantly degraded response time and accuracy in random search for alphanumeric and symbols. However, these studies required the subjects to search for targets on a plain background. It was believed that due to the more complex background inherent in the cartographic images employed in this research, effects would become evident at lower failure percents. This was indeed the case, as effects were realized between one and two percent for this study, as opposed to between two and three percent for the previous studies.

Let us now summarize the effects of the failure variables. There were no significant differences in performance under the no failure condition, as there should not have been. The lack of any effects for this condition confirms the integrity of the data and of the design. It is intuitively obvious that if the individual is working with a display in good operating condition, there should be no measurable change in performance, except to the extent that the image characteristics change (due to background clutter, for instance).

Horizontal line failures on cartographic images generally impede accuracy more than vertical line or cell failures, and are particularly less accurate in the "on" failure mode than in the "off" failure mode. Also, performance tends to be less accurate as the percentage of

horizontal failures on the display increases. Yet, horizontal line failures seem to have less effect on response time. It should be realized that the results of this study regarding the effects of horizontal line failures may not be generalizable to other display formats due to the specific nature of the symbols used in this research.

Vertical line failures seemed to have a greater effect on the information extraction task than on the random search task. Specifically, in the information extraction task, it was shown that vertical line failures slowed response time significantly more in "on" mode than in "off" mode. It is possible that the vertical line failures interfered with the map information which was used as target references in the information extraction task. As there was no relevance of the map information in the random search task, the vertical lines would not have interfered with it.

Finally, cell failures produced slower response times when "on" than when "off" in both tasks.

In previous studies (Decker et al., 1988; Lloyd et al., 1988) it was found that cell failures reduced accuracy and produced significantly slower response times than either type of line failure. Cell failures were not significantly injurious to performance in this study, but horizontal line failures were. At the failure percents used in the present study, the cell failures would not necessarily make one

symbol look much like another symbol, as would horizontal (and sometimes vertical) line failures. The cell failures do tend to distort the outline of the symbol by either adding or subtracting elements depending upon the mode of the failure. This distortion, while significant to some degree, does not evidently produce the same effects that line failures do when they block out whole attributes of symbols.

Additional Analyses

It was desired to find the symbols which were most readily confused with other symbols. As the eight symbols were not used an equal number of times, only the Chi-Square Test was applicable. However, the distribution of errors did not meet the minimum requirements for the Chi-Square Test, as more than five percent of the cells had zero values. Thus, a confusion analysis could not be made.

There were differences in the accuracy and response times among the various maps and target references. These results, however, are situationally dependent. That is, search time and accuracy will vary depending upon the relative complexity of the cartographic information present in the image and the specific location of that information. It is reasonable to assume, for instance, that images of topographic maps will place different demands on the operator

than, say, images of maps used for road navigation in the downtown area of a large city.

It could be argued that the data from such experiments are only appropriate for the particular maps employed in each study; that is, the results can not be generalized to other map images due to the undefinable effects of the maps on performance. This argument can be circumvented by using maps that have generalizable characteristics. For instance, it was necessary that the six maps used in this study all show much detail, due to the inability to otherwise code the various types of information on the monochrome monitor. The maps varied in the orientation of the information, but all showed approximately equal amounts of each type. Thus, the maps were varied intentionally in order to provide for more generalizable results, but confounds due to the amount of information on each map were avoided.

To provide greater generalization of the results of research in this area, it will be necessary to do similar research with additional types of cartographic images.

SUMMARY AND RECOMMENDATIONS

Relatively low levels of background clutter impede performance. Only two levels of clutter were studied in these experiments. Future research on cartographic images should establish definitions and limits on the amount of clutter that is tolerable. Further, the research should employ quantitative levels of clutter, as was done in this research, rather than subjective levels. The percentage of a display's pixels which are "on" (comprising the information) would be one way of quantifying this variable.

Negative polarity seems to produce better performance than positive polarity for both alphanumeric and cartographic images. This recommendation assumes that the stroke width, modulation, and luminance values are nearly equal for both polarities. Different results may be evident for the two polarities if these parameters are not maintained the same.

Cartographic images should not be used if more than one percent of the image's pixels are failed; otherwise, performance will be significantly reduced.

Regarding symbol design, one should avoid the use of symbols with essential markers or components which are susceptible to full obscuration by a display's failures. This recommendation is supported by Laycock (1985), who found

that line failures were particularly disruptive when they aligned with major components of the characters.

As mentioned, half of the symbols used in this study had an essential component which was susceptible to a horizontal line failure. A similar study should be conducted using all 26 of the symbols used in the previous alphanumeric research (Decker et al., 1988; Lloyd et al., 1988). Such a study would be able to draw much more complete comparisons to the findings of the alphanumeric research previously mentioned.

Finally, in this study, the luminance of the failures was equal to the luminance of the information and symbols. Thus, these results are directly applicable to one bit-level displays or images on gray-scale displays that only employ two intensity levels per image.

It is possible that, for gray-scale displays, the failures may be of different luminances than the information. If the software program assigned different bit levels during its execution, it is possible that the failures would be displayed at different bit levels than some or all of the information that is displayed. If the information was therefore displayed at a luminance sufficiently different than that of the failures, it is possible that performance would be increased by the increased ability to discriminate the information from the failures. To the author's

knowledge, this area of research has not previously been explored.

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APPENDIX A

RANDOM SEARCH TASK INSTRUCTIONS

In this experiment, you will be asked to search for a symbol on a map among other symbols, all of which will be presented on the screen in front of you. The map will consist of lines and shaded areas on the screen. The lines will represent roads, railroads, and streams while the shaded areas will represent wooded areas. Buildings will also be present in the form of squares and rectangles.

The placement of your target symbol will be random. At the beginning of each trial you will see the words, "READY" and "THE NEXT TARGET IS ___" followed by followed by the target for that trial. The target symbol will appear in only one position on the screen.

During each experimental session, noise may be introduced on the screen and you will be required to search for the target which is imbedded in the noise. The noise consists of lines or individual "dots" which are either turned on or off such that they either match the screen background or they match the symbols and map information.

When you are ready to begin searching, press the right button on the mouse input device. A map will appear with many symbols on it and possibly the noise discussed earlier.

Your task is to locate the target symbol and identify its position to the experimenter. When you visually locate the target, press the left button on the mouse. The symbols on the screen will be replaced by numbers. You then tell the experimenter the number which replaced the target symbol. You should keep your eyes fixated where the target appeared on the screen so that when the numbers appear, you will be able to accurately report the correct identification tag number.

During the experiment, we want you to respond **as quickly and as accurately as possible** - both are important. Please keep your head in a straight and upright position against the headrest while searching.

We will begin the session with 30 practice trials. If you have any questions, please ask. If you are comfortable with the procedure, we will begin the experiment. The session will take approximately 2 hours. You will be offered the opportunity to take short rest breaks at various intervals during the session.

Before beginning the experiment, please examine the hard copy of the symbols. It is important that you learn these symbols before we begin. The symbols are very similar; therefore, please pay attention to the differences between them. You will be given as long as you need to review and learn these symbols.

APPENDIX B

INFORMATION EXTRACTION TASK INSTRUCTIONS

In this experiment, you will be asked to search for a symbol on a map among other symbols, all of which will be presented on the screen in front of you. The map will consist of lines and shaded areas on the screen. The lines will represent roads, railroads, and streams while the shaded areas will represent wooded areas. Buildings will also be present in the form of squares and rectangles.

The placement of your target symbol will be random. At the beginning of each trial you will see the words, "READY" and "FIND THE _____ CLOSEST TO THE _____." This describes your target symbol for the next trial in relation to some item on the map, such as a road. There may be several symbols identical in appearance to the target symbol, but only one closest to the reference item.

During each experimental session, noise may be introduced on the screen and you will be required to search for the target which is imbedded in the noise. The noise consists of lines or individual "dots" which are either turned on or off such that they either match the screen background or they match the symbols and map information.

When you are ready to begin searching, press the right button on the mouse input device. A map will appear with many symbols on it and possibly the noise discussed earlier. Your task is to locate the target symbol and identify its position to the experimenter. When you visually locate the target, press the left button on the mouse. The symbols on the screen will be replaced by numbers. You then tell the experimenter the number which replaced the target symbol. You should keep your eyes fixated where the target appeared on the screen so that when the numbers appear, you will be able to accurately report the correct identification tag number.

During the experiment, we want you to respond **as quickly and as accurately as possible** - both are important. Please keep your head in a straight and upright position against the headrest while searching.

We will begin the session with 30 practice trials. If you have any questions, please ask. If you are comfortable with the procedure, we will begin the experiment. The session will take approximately 2 hours. You will be offered the opportunity to take short rest breaks at various intervals during the session.

Before beginning the experiment, please examine the hard copy of the symbols. It is important that you learn these symbols before we begin. The symbols are very similar;

therefore, please pay attention to the differences between them. You will be given as long as you need to review and learn these symbols. When you think you have learned them, you will be tested on the symbols and their meanings. You will be given as many opportunities as needed until you can identify the meanings of all 8 symbols correctly. At that point, we will begin the practice trials.

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THE EFFECTS OF DISPLAY FAILURES, POLARITY, AND CLUTTER
ON VISUAL SEARCH FOR SYMBOLS ON
CARTOGRAPHIC IMAGES

by
Craig J. Dye

(ABSTRACT)

Little research has been conducted dealing with human performance in symbol search of cartographic images on matrix-addressable displays. Alphanumeric studies have researched failures and polarity on such displays, but not using cartographic images. Two studies were conducted which required the subject to search for symbols on cartographic images under various conditions of failure, polarity, and background clutter. Response time and accuracy were measured. Generally, high clutter impeded performance more than low clutter, and negative polarity produced slightly better performance than positive. Horizontal line failures affected search ability more than vertical line or cell failures, particularly when the failures were in "on" mode rather than "off" mode. Further, it was found that while previous alphanumeric studies found effects at three percent failures or greater, effects were observed for the present

studies at two percent or greater, apparently due to the presence of map information on the display. Recommendations for cartographic display design and future research are discussed.