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SHAPE CODING TECHNIQUE EFFECTS ON TACTICAL POINT SYMBOL PERCEPTIBILITY AND DISCRIMINABILITY

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Aberdeen Proving Ground, Maryland

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The primary purpose of the present investigation was to examine the effects of pictorial, abstract, and arbitrary shape coding on symbol perception and discrimination. This investigation also explored effects of varied or double border, regular or reverse screen, and augmentation coding. Perceptibility was assessed by measuring the time to detect a symbol's presence, recognize its coded affiliation, and identify its coded system type. Correct response times were analyzed with separate nested one-factor analyses of variance, and errors were analyzed with both confusion matrices and chi-square tests. Discriminability was assessed by recording errors made while determining if sequentially presented symbols were identical. Errors were analyzed with both confusion matrices and chi-square tests.

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Correct detection and recognition times did not differ significantly; identification times did, however. Post hoc analyses indicated that significantly more time was required to correctly identify symbols from the scheme coded with augmented arbitrary shapes than those coded with either pictorial or abstract shapes. Matrix analyses of affiliation recognition errors showed that symbols from the schemes coded with either varied or double borders and regular or reverse screening were most often confused. Chi-square tests indicated that the scheme coded with varied or double borders contained a significantly greater number of recognition errors than the one coded with regular or reverse screening, which had a significantly greater number than the one coded with arbitrary shapes. Matrix analyses of system identification errors showed that confusions occur between symbols from schemes coded with either pictorial or augmented arbitrary shapes. Chi-square tests indicated the scheme coded with abstract shapes contained a significantly smaller number of identification errors than those coded with either pictorial or augmented arbitrary shapes.

Matrix analyses of discrimination errors showed that confusions resulted from the same factors that caused both recognition and identification errors. Chi-square tests indicated the scheme coded with varied or double borders and abstract shapes had a significantly greater number of discrimination errors than the one coded with regular or reverse screening and pictorial shapes, which had more than the one coded with augmentations and arbitrary shapes. Exit survey results confirmed earlier findings. Finally, recommendations for future research were made.

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BACKGROUND

The current U.S. Army "counterair" initiative embodies a large scale doctrinal revision for both the aviation and air defense communities. Its thrust is to integrate their combined assets to deter the enemy air threat (Brittingham, 1987). It is contended that this effort will rely heavily on a coordinated command, control, and intelligence (C^2I) system (Tatum, 1987). One facet of a C^2I system that requires focused attention is how to effectively display battlefield information to increase awareness of the tactical situation (Shupe & Bernabe, 1986). Increased awareness would facilitate decision making, increase combat effectiveness, and reduce costly errors.

One crucial feature of a tactical situation display (TSD) is the symbology used to depict battlefield elements. The advent of modern weapon systems has proliferated a large number of symbol schemes for portraying tactical information (Knapp, 1986). Unfortunately, the majority of them are not standardized and use different techniques to encode information in symbols (Ciccone, Samet, & Channon, 1979). Further, of the various encoding techniques employed in different symbol schemes, some are preferred to others because of greater perceived meaningfulness (a product of both iconicity and stereotypicity), acquisition speed, and figural integration.

Several studies that examine operational requirements, user preferences, and potential applications for tactical military symbology have been conducted (for an in-depth discussion, see Schmidt, in press). Collectively, their results suggest a deficiency in the ability of present schemes to depict tactical elements. It is also recognized that an increased amount of information will have to be depicted on a TSD if the enemy is to be effectively monitored and engaged on the modern battlefield (Hawrylak & Miller, 1985). It can be concluded that a revision, update, and expansion of current tactical point symbology is required.

INTRODUCTION

The processing of a visual image (e.g., an incoming aircraft) from a human factors perspective entails extracting various information as it becomes available. Operationally, the perceptual process involves a continuum of detection, recognition, and identification (Erickson, 1972): detecting an aircraft's presence, recognizing its affiliation (e.g., friendly) from its markings, and identifying its type (e.g., fighter) by its shape.

The process is somewhat different for a TSD than for a passing aircraft because all pertinent information would be simultaneously present and available for processing. In this context, it is possible to influence a symbol's perceptibility by altering its configuration (Schmidt, in press).

Cognitively, perceived meaningfulness, familiarity, simplicity, and scheme size all influence a symbol's visual processing. Further, a symbol's figural integration in a gestalt sense and its use of psychophysical phenomena can also have a significant impact on its processing (Dember & Warm, 1979). In effect, information embedded in symbols can be manipulated to ensure that the most salient information is extracted first and that all information is processed. Information processing would become a function of the priority given to encoded information, the encoding technique employed, and how it is used.

One technique for encoding tactical information in point symbols is shape coding, and this technique can be separated into three categories according to associated perceived meaningfulness: pictorial (e.g., a helicopter silhouette), abstract (e.g., a helicopter rotor), and arbitrary (e.g., a circle). The pertinent literature indicates that greater perceived meaningfulness in a symbol is desirable since it has better semantic association and can be quickly learned and processed. It has also been discovered that simpler and more familiar shapes require less cognitive capacity and can be preattentively processed.

It can be contended then, that in some conjunctive format, the process of extracting information from symbols can be controlled and enhanced. For example, pictorial shapes representing system could be enclosed within arbitrary shapes indicating affiliation. The simpler and more familiar arbitrary shapes would initially be preattentively processed; the more perceived meaningful pictorial shapes would subsequently be processed through semantic association. As part of the Human Engineering Laboratory's Counterair Program (HELCAP), the Aviation and Air Defense Division (AADD) is developing recommendations for optimally engineering TSD symbology. This investigation is the first in a series intended to examine human performance associated with tactical point symbology encoding techniques.

EXPERIMENT 1

Objectives

The objectives of the first experiment were

a. to compare the time required for correctly detecting a symbol's presence, recognizing its affiliation code (e.g., hostile), and identifying its system code (e.g., fixed wing, fighter) as depicted by three representative symbol schemes on a cathode ray tube (CRT) display; and

b. to examine the errors made in perceiving information encoded in the symbols, and determine if there are any common patterns.

Methods

Test Subjects

Thirty-six people, who were unfamiliar with the symbol scheme with which they were tested, were recruited as subjects for this investigation. Subjects were separated into 3 groups of 12, each group tested with a specified scheme. The experiment required approximately 90 minutes to complete. Subjects were screened by verbal report to ensure that they had at least 20/20 corrected visual acuity.

Apparatus

The AADD Map Display Test Apparatus was used to present symbols to subjects and collect their responses (see Figure 1). Symbols were displayed on a monochrome, 9-inch diagonal CRT, and responses were made with a touch panel screen overlaid on a color, 9-inch diagonal CRT and stored on a mainframe computer. Characteristics of some specific components of the apparatus are given in Appendix A.

Stimuli

Each subject was randomly assigned to and tested with one symbol scheme designated either "A," "B," or "C" (see Figures 2, 3, and 4). Scheme A, which is based on symbology in Field Manual (FM) 101-5-1 (Department of the Army, 1985) for portraying the friendly or enemy tactical situation on paper map overlays, depicts affiliation with varied or double borders and system type with abstract shapes. Scheme B, which is based on symbology developed by Anacapa Sciences, Inc., (Rogers, 1987) for portraying the aviation tactical situation on digital map displays, depicts affiliation with varied borders and regular or reverse screening and system type with pictorial shapes. Scheme C, which is based on symbology in DoD-STD-1477 (Department of Defense, 1983) for portraying the air defense tactical situation, depicts affiliation with arbitrary shapes and systems with augmentations. Groups with their assigned schemes were tested sequentially. During training, symbols were presented at a fixed central point marked with a cross on a CRT, whereas during actual testing, they were presented randomly. Symbols were presented four times during each trial. Subjects were seated so that the normal viewing distance from the display was 28 inches. Symbol size was adjusted to subtend a 25-minute viewing angle. Subject responses were made using one of four touch panel formats, and each trial was initiated with the same display (see Figure 5).

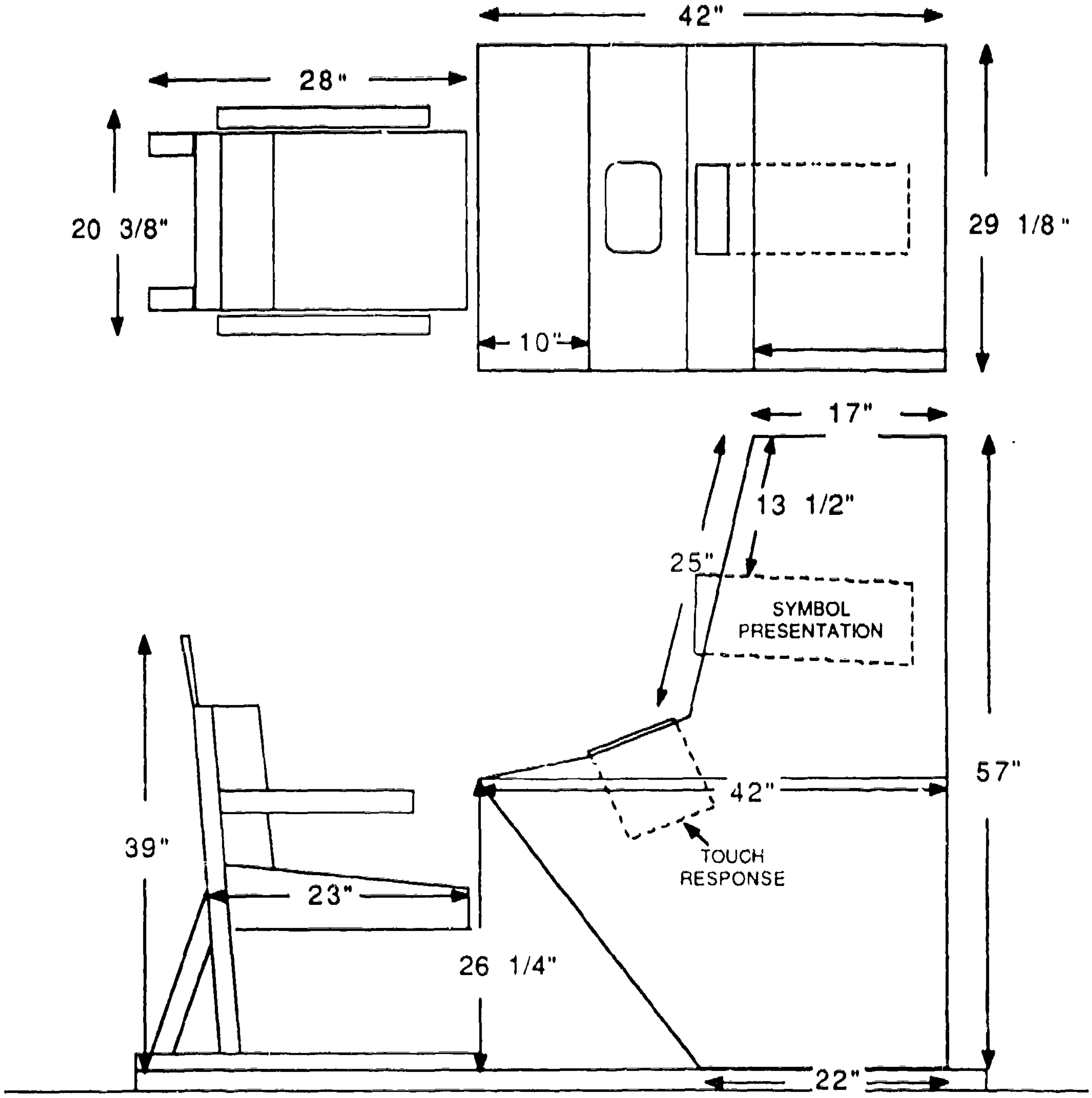

Figure 1. Map display test apparatus.

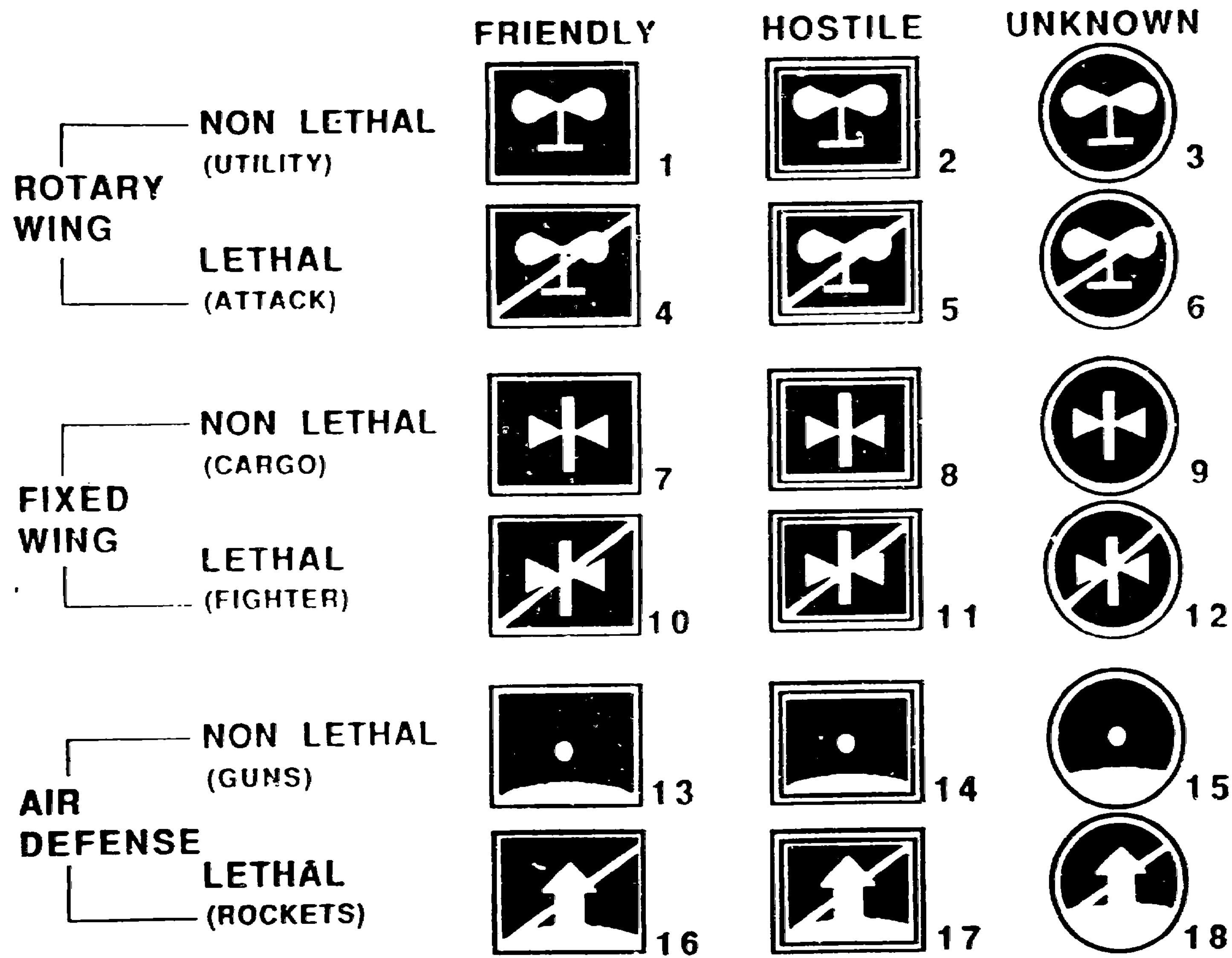

Figure 2. Symbol scheme A.

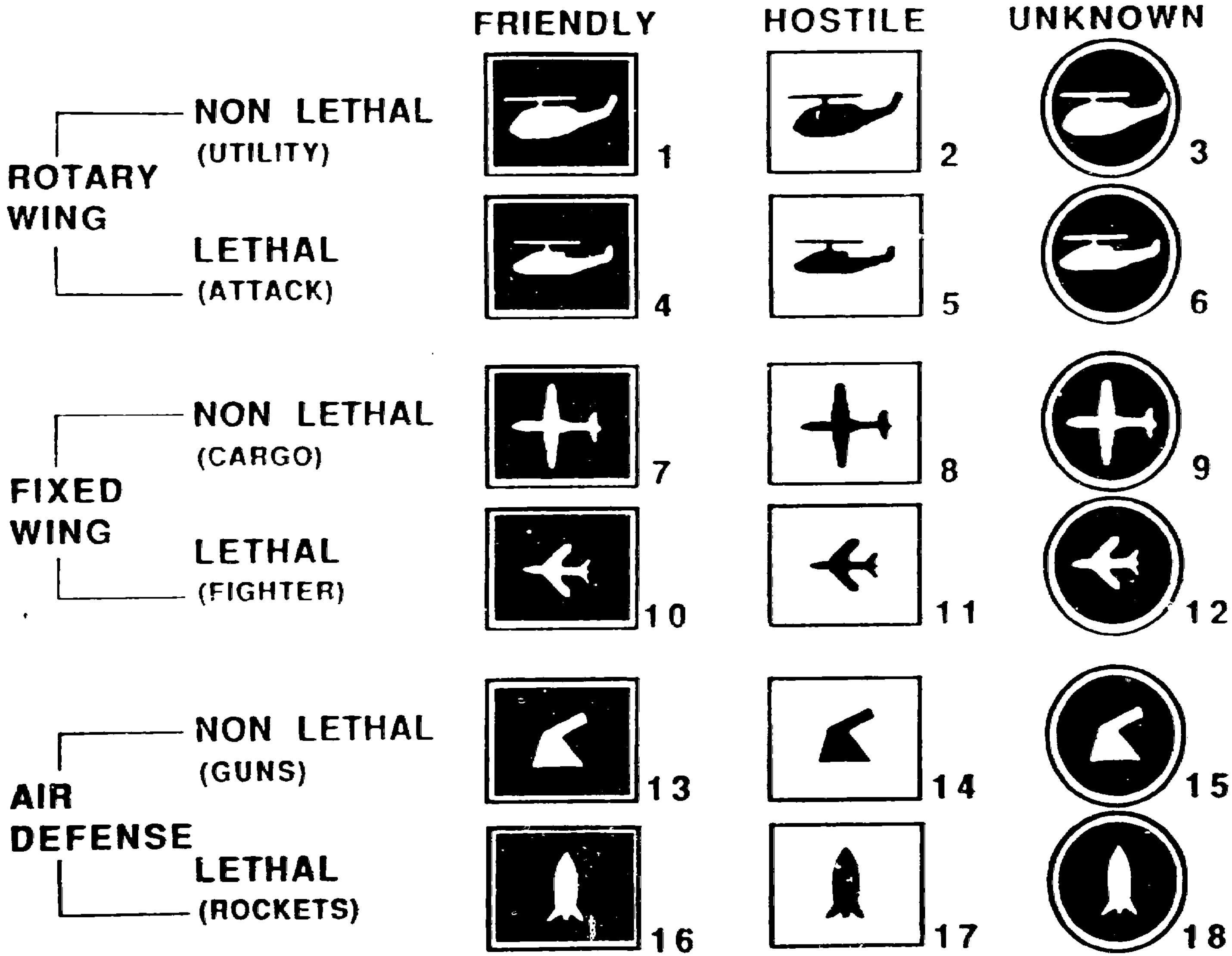

Figure 3. Symbol scheme B.

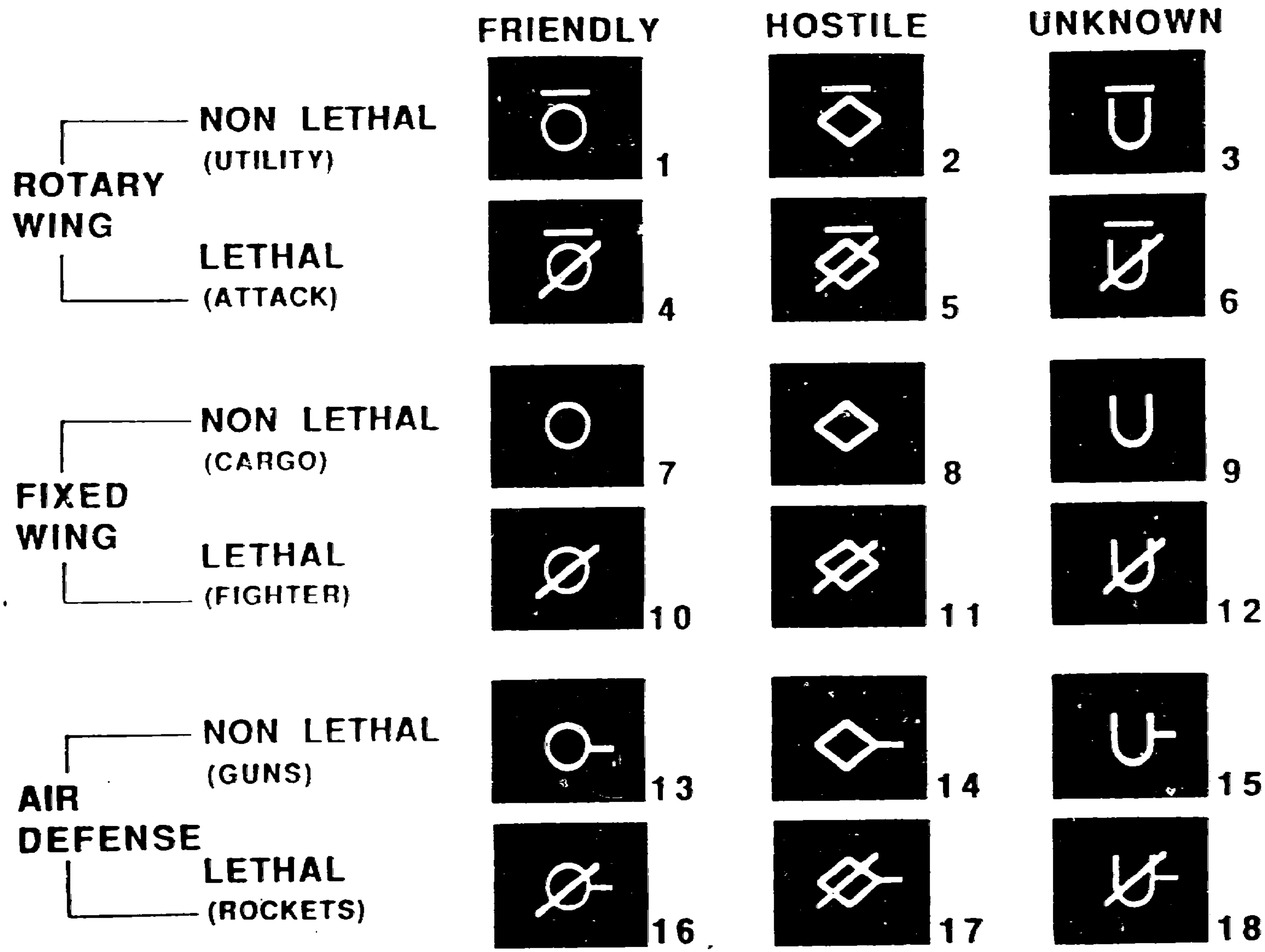

Figure 4. Symbol scheme C.

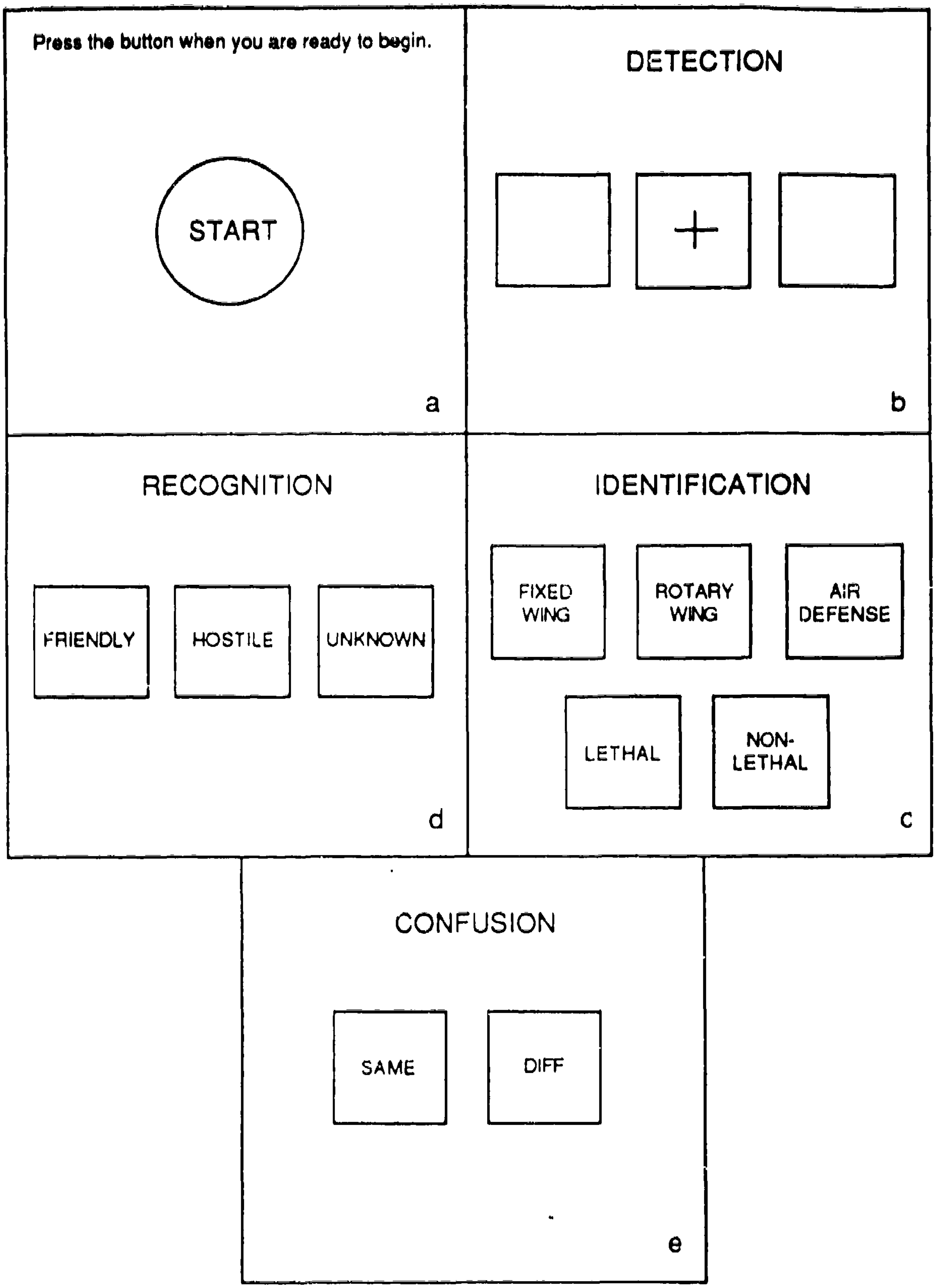

Figure 5. Subject response display formats.

Design

Independent Variables

Two independent variables were considered in the first experiment:

1. the encoding techniques used in each symbol scheme to code system type, and

2. the encoding techniques used in each symbol scheme to code affiliation.

Dependent Variables

Two dependent measures were observed in the first experiment:

1. the response time measured in seconds required for correctly detecting a symbol's presence, recognizing its coded affiliation, and identifying its coded system type; and

2. the errors made in recognizing coded affiliation and identifying coded system type.

Procedures

Subjects were initially asked to read and sign a volunteer consent form that provided a general synopsis of the study and acknowledged their rights as subjects. The subjects were verbally screened to ensure that they had at least 20/20 corrected visual acuity. They were then trained with one of the three symbol schemes. Training consisted of reviewing symbol schemes and receiving instruction about their construction. Subjects were then situated in the Map Display Test Apparatus and were familiarized with their assigned symbols as they appear on a CRT. Finally, subjects were put through a series of training trials to become acquainted with responding to stimuli presented on the screen with a touch panel device. Once a criterion of 90 percent correct on each type of training trial was reached, the actual test phase was initiated.

Each subject went through a series of counterbalanced test trials (see Table 1) with stimuli being presented at random locations on the screen. The subjects were required to either detect the presence of a symbol, recognize a symbol's coded affiliation, or identify a symbol's coded system type. Random X and Y values ranging from 0 to 450 determined the XY screen coordinate for the symbol's center. The symbol remained on screen until the subject made a touch panel push in response to it. A random interval ranging from 3 to 5 seconds after a response was used to vary the time between symbol presentations.

Table 1

Counterbalancing Scheme

Symbol scheme group assignment A Subject	B Subject	C Subject	Trial sequence
01	13	25	D R I / C
02	14	26	R I D / C
03	15	27	I D R / C
04	16	28	D I R / C
05	17	29	R D I / C
06	18	30	I R D / C
07	19	31	C / D R I
08	20	32	C / R I D
09	21	33	C / I D R
10	22	34	C / D I R
11	23	35	C / R D I
12	24	36	C / I R D

Note. D = detection
R = recognition
I = identification
C = confusion

Data Analysis

Two analyses were performed on the data collected during this investigation. The first involved the analysis of correct detection, recognition, and identification times for the three symbol schemes. Three separate nested one-factor analyses of variance (ANOVA) were conducted. All appropriate post hoc tests were performed and corrected for family-wise error with a Scheffe' technique. The second analysis entailed constructing confusion matrices for the errors from the recognition and identification tasks. In addition, the assumptions for a chi-square goodness-of-fit test were met, and separate tests were run on the recorded recognition and identification errors.

Results

The descriptive statistics for symbol detection time are presented in Table 2, and the results of the nested one-factor ANOVA for symbol detection time are presented in Table 3.

Table 2

Descriptive Statistics for Symbol Detection Time

Group	*n*	Grand mean	*SD*
A	12	.513	.130
B	12	.508	.102
C	12	.521	.134

Table 3

Nested One-Factor ANOVA for Symbol Detection Time

Source	*df*	*SS*	*MS*	*F*	*p*
Between groups	2	.001	.001	.035	>.05
Within groups	33	.499	.015		
Total	35	.500			

The test was not significant ($p>.05$), indicating that the encoding techniques employed for each respective scheme did not differentially affect symbol detection time.

The descriptive statistics for symbol recognition time are presented in Table 4, and the results of the nested one-factor ANOVA for recognition time are presented in Table 5.

Table 4

Descriptive Statistics for Affiliation Recognition Time

Group	*n*	Grand mean	*SD*
A	12	.856	.122
B	12	.963	.200
C	12	.858	.124

Table 5

Nested One-Factor ANOVA for Affiliation Recognition Time

Source	*df*	*SS*	*MS*	*F*	*p*
Between groups	2	.090	.05	1.918	>.05
Within groups	33	.772	.023		
Total	35	.862			

The test was not significant (p>.05), indicating that the encoding techniques employed for each respective scheme did not differentially affect affiliation recognition time.

The descriptive statistics for system identification time are presented in Table 6, and the results of the nested one-factor ANOVA for system identification time are presented in Table 7.

Table 6

Descriptive Statistics for System Identification Time

Group	*n*	Grand mean	*SD*
A	12	1.127	.252
B	12	1.121	.187
C	12	1.351	.189

Table 7

Nested One-Factor ANOVA for System Identification Time

Source	*df*	*SS*	*MS*	*F*	*p*
Between groups	2	.412	.206	4.596	<.02
Within groups	33	1.478	.045		
Total	35	1.890			

The test was significant ($p<.05$), indicating that the encoding techniques employed for each respective scheme had a differential effect on system identification time. The results of the post hoc tests corrected for family-wise error with a Scheffe' technique are presented in Table 8.

Table 8

Post Hoc Comparison Tests

Comparison	Mean difference	Scheffe' test	p
A versus B	.006	.002	>.05
A versus C	-.224	3.358	<.05
B versus C	-.230	3.533	<.05

Schemes A and B required significantly less time ($p<.05$) for system identification than Scheme C. Schemes A and B were not significantly different ($p>.05$) for required system identification time.

The confusion matrices of recognition and identification errors for Schemes A, B, and C are respectively presented in Figures 6, 7, and 8.

Scheme A had the lowest number of system identification errors ($n = 12$) but the highest number of affiliation recognition errors ($n = 27$). Scheme B had a high number of system identification errors ($n = 30$) and a lower number of affiliation recognition errors ($n = 11$). Scheme C had the highest number of system identification errors ($n = 3$) and fewest affiliation recognition errors ($n = 3$).

The chi-square test results for recognition and identification errors and their comparisons are respectively presented in Tables 9 and 10.

	F	H	U
F			
H	18		
U	5	4	

n = 27

F = Friendly

H = Hostile

U = Unknown

a. Affiliation Recognition Errors

	U	A	C	F	G	R
U						
A	2					
C	1					
F		4	2			
G			1			
R					2	

n = 12

U = Utility

A = Attack

C = Cargo

F = Fighter

G = Guns

R = Rockets

b. System Identification Errors

Figure 6. Symbol scheme A recognition and identification confusions.

	F	H	U
F			
H	3		
U	6	2	

n = 11

F = Friendly

H = Hostile

U = Unknown

a. Affiliation Recognition Errors

	U	A	C	F	G	R
U						
A	11					
C	1					
F		2	5			
G			2	1		
R		1	1	1	5	

n = 30

U = Utility

A = Attack

C = Cargo

F = Fighter

G = Guns

R = Rockets

b. System Identification Errors

Figure 7. Symbol scheme B recognition and identification confusions.

	F	H	U
F			
H	1		
U	1	1	

n = 3

F = Friendly

H = Hostile

U = Unknown

a. Affiliation Recognition Errors

	U	A	C	F	G	R
U						
A	4					
C	2					
F		4	8			
G			7	1		
R		2	1	6	3	

n = 38

U = Utility

A = Attack

C = Cargo

F = Fighter

G = Guns

R = Rockets

b. System Identification Errors

Figure 8. Symbol scheme C recognition and identification confusions.

Table 9

Affiliation Recognition Error Chi-Square Analyses

f	x^2	p
2	68.454	<.01

Comparison	*df*	x^2	p
A versus B	1	5.738	<.05
A versus C	1	4.572	<.05
B versus C	1	14.200	<.01

Table 10

System Identification Error Chi-Square Analyses

df	x^2	p
2	32.401	<.01

Comparison	*df*	x^2	p
A versus B	1	7.700	<.01
A versus C	1	13.520	<.01
B versus C	1	.942	>.05

The chi-square tests indicated that the distribution of both affiliation recognition errors and system identification errors was not proportional to what would be expected by chance (both were $p<.01$) for the three symbol schemes. Scheme A had a statistically greater proportion of recognition errors than both Schemes B and C (both were $p<.05$), and Scheme B had a statistically greater proportion of recognition errors than Scheme C ($p<.05$). Scheme A had a statistically smaller proportion of identification errors than both Scheme B and C (both were $p<.01$); there was no statistical difference, however, in the proportion of identification errors between Schemes B and C ($p>.05$).

EXPERIMENT 2

Objectives

The objectives of the second experiment were:

1. to assess symbol discriminability within each of the three schemes.

2. to survey subjects about their method of processing symbols in their assigned scheme.

Methods

Subjects

The same subjects tested in Experiment 1 were tested in Experiment 2.

Apparatus

The same apparatus used in Experiment 1 was used in Experiment 2.

Stimuli

The same schemes presented in Experiment 1 were presented in Experiment 2. Symbol pairs containing same or different items were sequentially presented at a fixed point marked with a cross at the center of the screen. Each symbol was presented for 100 milliseconds with a blank screen inserted between presentations for 150 milliseconds to prevent visual masking. A 3-second interval was placed between discriminations.

Design

Independent Variables

Two independent variables were considered in the second experiment:

1. the three symbol schemes with their respective encoding techniques.

2. the sequentially presented symbol pairings from each of the symbol schemes.

Dependent Variables

Two dependent measures were observed in the second experiment:

1. the number of confusions between symbol pairings.
2. the type(s) of confusions between paired symbols.

Procedures

Subjects were asked to compare pairs of sequentially presented symbols taken from their assigned scheme and to indicate with a touch panel press if they were the same or different. Each symbol was paired with all other members in its scheme as well as itself the same number of times. Presented symbol pairs were preset and stored in look-up tables on a mainframe computer, which also recorded each subject's responses. Upon completion of the test trial, subjects were debriefed and asked to answer a short survey describing their approach to perceiving symbols in their assigned scheme.

Data Analysis

Two analyses were conducted of the data collected during this experiment. The first analysis involved the construction of a confusion matrix to identify patterns of errors found in discriminating between symbols. In addition, the assumptions for a chi-square goodness-of-fit test were met, and a test was run on the recorded discrimination errors. The second analysis entailed the tabulation of survey responses, which were used in interpreting the test data from Experiments 1 and 2. The survey is in Appendix B.

Results

The confusion matrices for the discrimination errors for the three symbol schemes A, B, and C are respectively presented in Figures 9, 10, and 11.

The greatest number of confusion errors were by subjects using Scheme A ($n = 87$), followed by those using Scheme B ($n = 63$), and the fewest number by those using Scheme C ($n = 39$). Scheme A subjects generally confused similar systems with different affiliations ($n = 12$, 32.4%) and lethalities ($n = 13$, 35.1%). Scheme B subjects confused similar systems with different affiliations ($n = 34$, 70.8%). Scheme C subjects had only a few confusions, which were randomly distributed.

The chi-square test results for discrimination errors and their comparisons are presented in Table 11.

1	2																	
2	1	4																
3	1		3															
4				3														
5		3		3	4													
6						2												
7							4											
8		2	1		2		1	4										
9						2	1		1									
10			1		1		1			2								
11		2		1				2		1								
12												7						
13										1			3					
14													1	3				
15															1			
16																3		
17																5	3	
18													1		1	1	1	1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Responded different when same

$\boxed{n = 50}$ Shaded

Responded same when different

$\boxed{n = 37}$ Unshaded

TOTAL n = 87

(Note: Refer to #'s listed in Figure 2)

Figure 9. Symbol scheme A discrimination confusions.

1																		
2		1																
3	5		1															
4	1		2	1														
5		1			2													
6	1			5		3												
7							1											
8																		
9							5		2									
10								1										
11								2										
12						1				5								
13																		
14									1					1				
15								1					8	1				
16															1	1		
17																	1	
18				1												6		1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Responded different when same

$\boxed{n = 15}$ Shaded

Responded same when different

$\boxed{n = 48}$ Unshaded

TOTAL n = 63

(Note: Refer to #'s listed in Figure 3)

Figure 10. Symbol scheme B discrimination confusions.

1	1																	
2																		
3			1															
4				3														
5		1			2													
6						1												
7						1												
8							1	1										
9			1	1	1				1									
10	1																	
11				1		1					1							
12						2						2						
13					1						1	1						
14	1		1															
15									1					1	2			
16					1											1		
17																	1	
18						1		1								1		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Responded different when same

n = 17 Shaded

Responded same when different

n = 22 Unshaded

(Note: Refer to #'s listed in Figure 4)

TOTAL n = 39

Figure 11. Symbol scheme C discrimination confusions.

Table 11

Discrimination Error Chi-Square Analyses

df	x^2	*p*
2	18.286	<.01

Comparison	*df*	$x2$	*p*
A versus B	1	3.840	<.05
A versus C	1	18.286	<.01
B versus C	1	5.647	<.03

The chi-square test results were statistically significant and indicated that the distribution for the confusion errors made during the discrimination task was not proportional to what would be expected by chance for the three symbology schemes. Scheme A had a statistically greater proportion of confusion errors than either Scheme B or C ($p>.05$ and $p>.01$, respectively), and Scheme B also had a statistically greater proportion of confusion errors than Scheme C ($p>.03$).

The break-out of errors for each symbol scheme by responding either same when the symbols presented were actually different (SWD) and different when they were actually the same (DWS) is presented in Table 12.

Table 12

Discrimination Error Distribution

	Symbol Scheme		
Response	A	B	C
Same when different	37	48	22
Different when same	50	15	17
Total	87	63	39

The chi-square tests for the two discrimination error conditions and their comparisons are respectively presented in Tables 13 and 14.

Table 13

Same When Different Error Chi-Square Analyses

df	x^2	*p*
2	9.542	<.01

Comparison	*df*	x^2	*p*
A versus B	1	1.424	>.05
A versus C	1	3.814	<.05
B versus C	1	9.657	<.01

Table 14

Different When Same Error Chi-Square Analyses

df	*x2*	*p*
2	28.484	<.01

Comparison	*df*	*x2*	*p*
A versus B	1	18.846	<.01
A versus C	1	16.854	<.01
B versus C	1	.134	>.05

The test results were statistically significant (both were $p<.01$) and indicated that the distribution of both types of confusion errors made during the discrimination task were not proportional to what would be expected by chance for the three symbology schemes. Schemes A and B had greater proportions of responding SWD confusions than Scheme C ($p<.05$ and $p<.01$, respectively); no statistical difference was discovered in the proportion of SWD confusions between Schemes A and B ($p>.05$). Further, in the proportion of DWS confusions between Schemes B and C ($p>.05$), Scheme A had a greater proportion of responding DWS confusion errors than both Schemes B and C (both were $p<.01$); no statistical difference was detected in the proportion of DWS confusions between Schemes B and C ($p>.05$).

On the exit survey, Scheme A subjects reported that similarities between single and double border configurations (10/12, 83.3%) and the use of augmenters (7/12, 58.3%) adversely impacted symbol perception and discrimination. Scheme B subjects observed that reverse screening was a very effective encoding technique (11/12, 91.6%). They tended to overgeneralize, however, and experienced difficulty in differentiating between scheme items not coded with reverse screening (10/12, 83.3%). They also had problems with the subtle differences between some of the pictorial shapes used (8/12, 66.6%). Finally, Scheme C subjects found it relatively easy to discriminate between arbitrary shapes (8/12, 66.6%), but had problems with augmenters (7/12, 58.3%).

DISCUSSION

The intent of the present investigation was not to provide a forum to evaluate a specific scheme or individual symbol, but to examine the relative effects of different encoding techniques on symbol perception and discrimination. Detection times did not significantly vary between schemes, indicating that the combined attributes of the encoding techniques employed in each scheme did not create a novel effect to elicit quicker symbol detection, which could have impacted the subsequent speed in extracting other encoded information. Further, recognition times did not significantly vary between schemes, indicating that the present application of double or varied border, regular or reverse screen, and arbitrary shape coding had no effect on enhancing a subject's ability to recognize a symbol's coded affiliation. Identification times did, however, vary significantly between schemes, indicating that the present application of pictorial, abstract, and augmented arbitrary shape coding had a differential effect on a subject's ability to identify a symbol's coded system type. Subsequent post hoc analyses indicated that the schemes that used pictorial and abstract shapes to encode system types statistically required less time for system identification than the scheme that used augmented arbitrary shapes. It could be contended from these results that more perceived meaningful and integrated pictorial and abstract shapes reduce system identification time.

Examination of the recognition and identification confusion matrices for the three symbology schemes revealed some unique error patterns. Affiliation recognition confusions occurred between symbols coded with single and double borders and those coded with regular screening. Subjects tended to either ignore the presence of a second border and respond "friendly" or overgeneralize that the lack of a reverse screen meant to respond "friendly." Subjects did not tend to confuse the arbitrary shapes used to code affiliation. System identification confusions occurred between some symbols composed of pictorial shapes embedded in borders as well as those consisting of augmented arbitrary shapes. Subjects had experienced difficulty in discriminating between some pictorial shapes because of their similarity and between most augmented arbitrary shapes because of their poor integration. Subjects did not tend to confuse abstract shapes used to code system type. Chi-square tests, as well as exit survey results, confirmed these observations.

Examination of the discrimination confusion matrices for the three symbology schemes revealed similar patterns. The greatest number of confusion errors were experienced by subjects using symbols composed of abstract shapes embedded in varied or double borders. Subjects confused similar systems with different affiliations and lethalities, resulting from the respective similarity between border configurations and the augmenters used; they did not tend to confuse different systems because of distinctness of the abstract shapes, however. The next largest number of confusions were by subjects using symbols composed of pictorial shapes embedded in varied borders with regular or reverse screening. Subjects confused similar systems with either the same or different affiliation, because of the respective similarity between some pictorial shapes and overgeneralization connected with regular or reverse screen coding. The fewest number of confusions was by subjects using symbols composed of arbitrary shapes with augmentations. Subjects had only a few confusions, which were random in nature. The chi-square tests and exit survey results also supported these findings. Finally, subjects tended to indicate symbols were DWS when composed of abstract shapes embedded in varied or double borders and SWD when composed of pictorial shapes embedded in varied borders with regular or reverse screening or arbitrary shapes with augmenters.

RECOMMENDATIONS

Given the short run cockpit requirement for display compatibility with night vision devices, the limited image capability of displays, and the difficulties of controlling lighting conditions, the development of monochrome encoding techniques for avionics such as a TSD would be very beneficial. The results from the present investigation show a potential for using simple arbitrary shapes as borders to designate affiliation in conjunction with distinct pictorial or abstract shapes as embedded figures to designate a system. It would provide for good figural integration, capitalize on the preattentive processing potential of arbitrary shapes, and accrue the perceived meaningfulness of either abstract or pictorial shapes. In effect, this combination could enhance the speed and accuracy associated with extracting information from symbols and should be explored.

It was determined that the conventional use of single or double borders to signify affiliation and the use of augmenters to designate system type were for the most part problematic and to be avoided. Further, similar pictorial shapes were difficult to distinguish, and figures must be distinctly different to be used simultaneously in a scheme. Regular or reverse screening in its present inconsistent application was determined to cause overgeneralization, but it was an effective cue for distinguishing specific symbols. It indicates a potential for using shading as a monochromatic encoding technique. Recognizing that only a few shades could be discriminated and subsequently used, they could be used much the same as color and employed redundantly with shape coding to designate affiliation. It is suggested that these preliminary recommendations be considered in constructing future symbology schemes and that they also be investigated further to effectively provide for the expected tactical informational requirements of the counterair mission.

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APPENDIX A

SOFTWARE DEVELOPMENT AND PROGRAM LOGIC

SOFTWARE DEVELOPMENT AND PROGRAM LOGIC

INTRODUCTION

All of the software for the symbology investigation was written in FORTRAN and run on the VMS® operating system using a MicroVAX II® based VAXLAB®. The graphics system used to display symbols was a PERITEK VCX-Q/U®. Symbols were displayed on a CONRAC® 9-inch monochrome black and white monitor. Subject responses were made by touching keys programmed with a VECTRIX VX384-A® graphics processor and an ELOGRAPHICS E270® touch sensor. The graphics were displayed and the touch sensor overlaid on a Sony 9-inch color monitor. The following sections describe the testing procedure and hardware features and provide flow charts of the major software routines.

TEST PROCEDURE

To begin the test, the operator logged onto the MicroVAX II® and ran a program called "MAIN." The program, written in VAX® FORTRAN, queries the operator for subject and test mode information and sets up random tables for symbol presentation order, delay time interval selection, and symbol display location selection (see Figure A-1). After the preliminary data have been verified for accuracy, the "START" screen is displayed on the VECTRIX®. When a subject is ready to begin, he or she would touch the start button and wait for the appropriate menu to appear (i.e., detection, recognition, identification, confusion). See Figures A-2 and A-3 respectively for the perception and discrimination program logic.

ELOGRAPHICS E270® TRANSPARENT POSITION SENSOR

The E270 Transparent Position Sensor, which is a system which form-fits the 9-inch Sony monitor, consists of a glass sheet coated with a transparent resistive substrate. It operates by alternately impressing a voltage along orthogonal axes. When pressure is applied to a point by the touch of a finger, the transparent conductive layer of the plastic cover sheet contacts the resistive substrate. The voltages at the point of contact are then selected and digitized to produce the numerical coordinates of the point. These coordinates are then transmitted to the computer system for processing. It features 0.004-inch resolution, 6 milliseconds per coordinate read time, point and stream modes, 70 percent light transmission, 1/8-inch thick with 1/4-inch border, ± 0.2 percent to ± 0.2 percent accuracy, and requires ± 3 ounces of activation force.

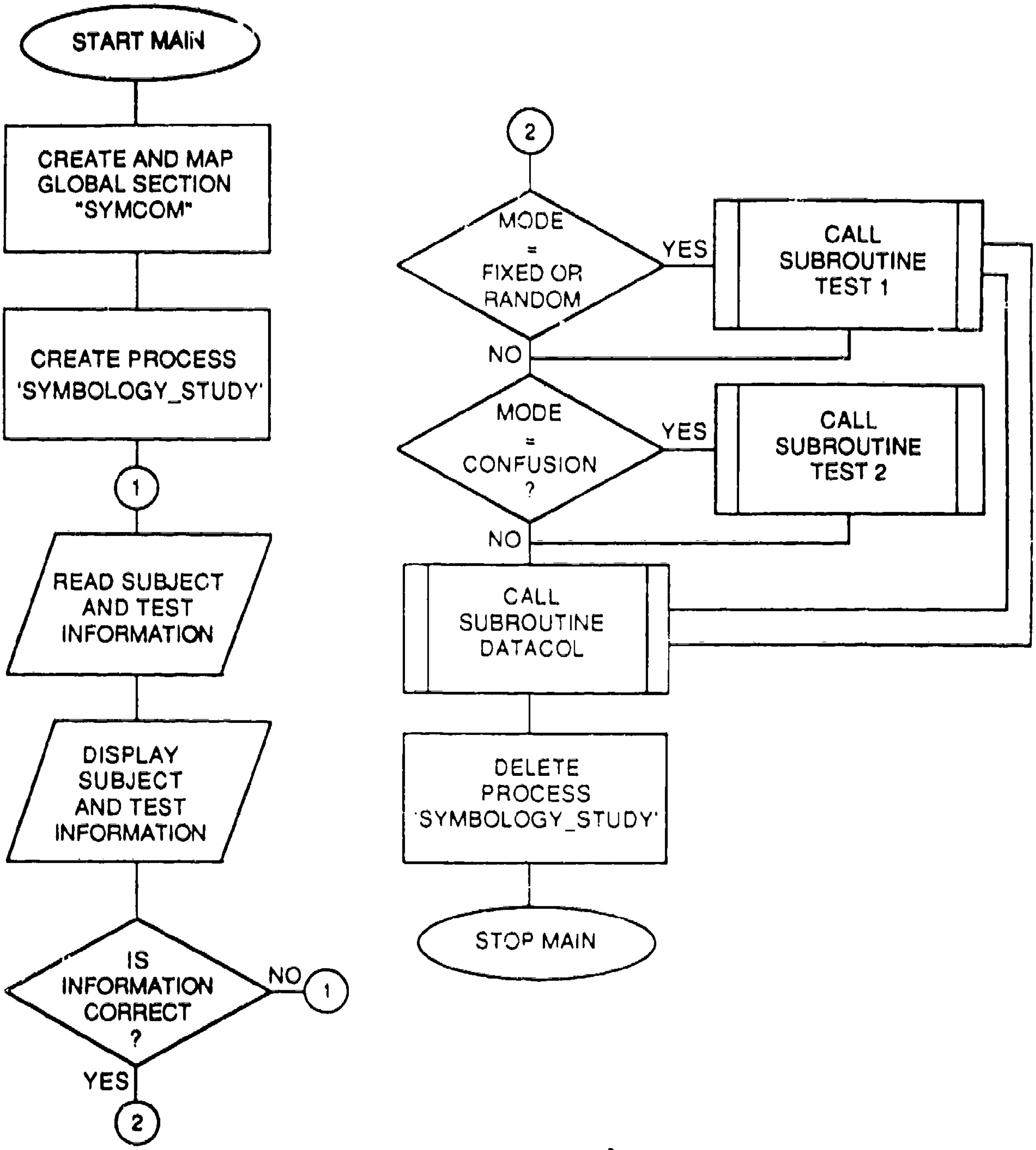
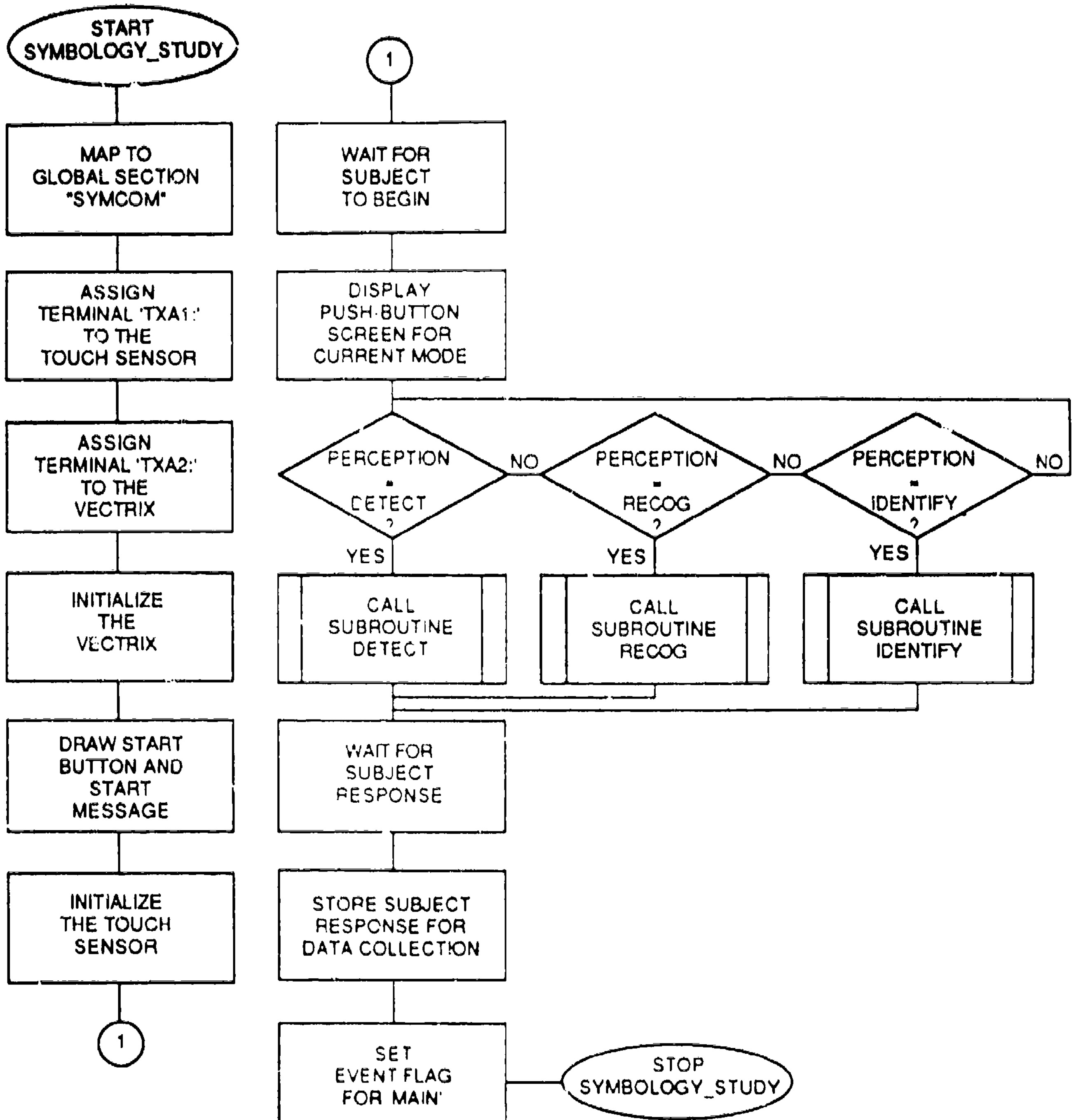


Figure A-1. Main program logic.



(continued)

Figure A-2. Perception program logic.

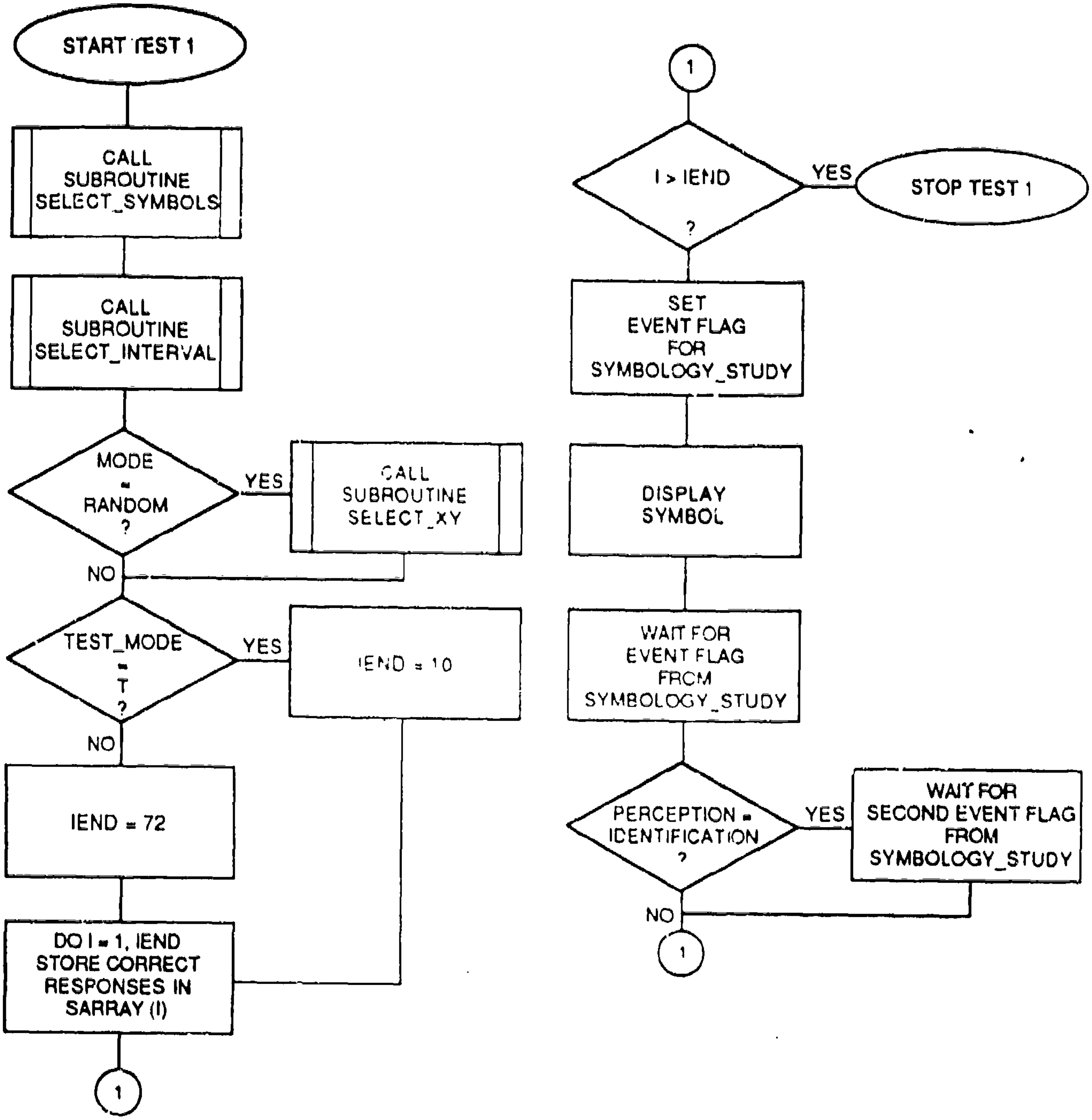


Figure A-2 (continued). Perception program logic.

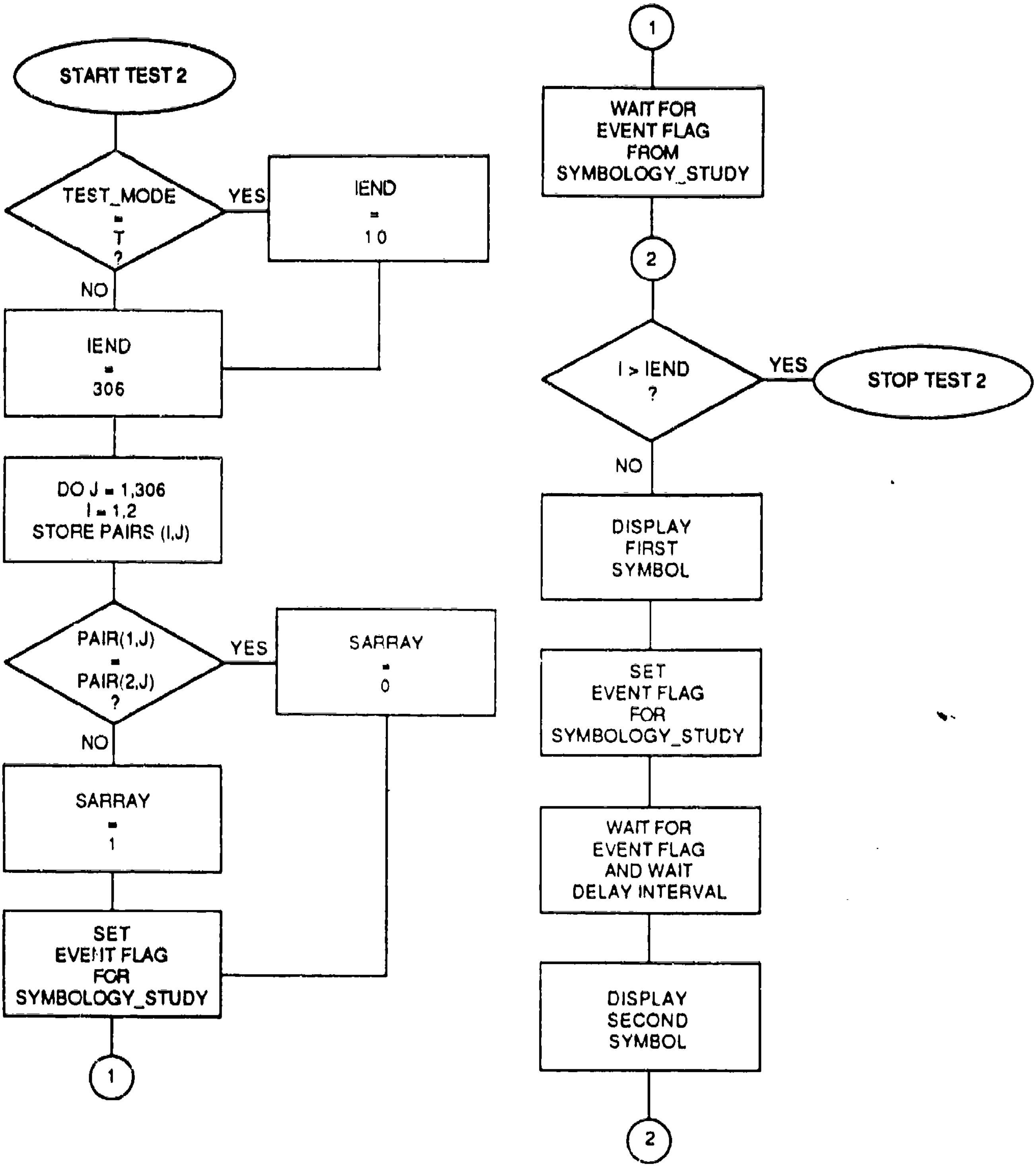


Figure A-3. Discrimination program logic.

ELOGRAPHICS E271-140 CONTROLLER®

The E271-140 controller was used to operate the ELOGRAPHICS E270® Touch Sensitive Screen. It contains a microprocessor that detects touches on the screen, provides the drive voltages for the X and Y axes, converts the analog signals from the screen to digital coordinates, and transmits the coordinates to the host processor. The analog-to-digital converter on the controller is a single ramp type with a maximum conversion time of 200 microseconds for a resolution of 12 bits (4,096 x 4,096).

PERITEK VCX-Q/U® VIDEO DISPLAY INTERFACE

The VCX-Q/U® is a multi-plane, color graphics frame buffer video interface for the Q-BUS® or UNIBUS® and features a 512- by 512-pixel resolution, 16 million color capability, independent 48-line by 80-character alphanumeric overlay, graphics memory consisting of three frame buffers each, 512 by 512 by 8 pixels, 8 K by 16-bit words of alphanumeric memory, 8 K by 8-character generator random access memory (RAM) and 64 foreground and background colors.

VECTRIX VX384-A® GRAPHICS PROCESSOR

The VECTRIX VX384-A® is a medium performance graphics system and features a 672- by 480-pixel resolution, 512 simultaneous color capability from a palette of 16.8 million, 1.6-microsecond pixel write time, and RS-232 host interface.

APPENDIX B

SYMBOLOGY EXIT SURVEY

Subject No.______ Date______

SYMBOLOGY EXIT SURVEY

1. Of the symbols contained in your assigned scheme, which do you most easily confuse and why?

2. Of the symbols contained in your assigned scheme, which do you most easily discern and why?

3. What (if any) strategy did you use in perceiving symbols for each of the three task levels: detection, recognition, and identification?

4. How would you improve the symbols in your scheme to make them easier to use? Examples may be drawn.

5. What experience have you had using symbols?