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STUDIES OF DISPLAY SYMBOL LEGIBILITY: XXI. THE RELATIVE LEGIBILITY OF SYMBOLS FORMED FROM MATRICES OF DOTS.

Donald A. Shurtleff

FEBRUARY 1970

Prepared for

DEPUTY FOR TACTICAL SYSTEMS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

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Project 407A
Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract F 19(628)-68-C-0365

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FOREWORD

This study was done under project 407A on government contract number F 19(628)-68-C-0365 to The MITRE Corporation, Bedford, Massachusetts.

REVIEW AND APPROVAL

Publication of this technical report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

JOSEPH H. GRIFFIN, Colonel, USAF
Deputy for Tactical Systems

ABSTRACT

The purpose of this study was to determine the legibility of symbols formed from matrices which contained different numbers of dot elements. A set of alphanumeric symbols was constructed from each of the following dot matrices: 3 x 5, 5 x 7, 7 x 11, and 9 x 15. The four symbol sets were shown for identification to one group of operators under nearly optimal viewing conditions and to a second group under degraded viewing conditions. Both rate and accuracy of identification were recorded. The results indicate that the 5 x 7 symbols are as legible as 7 x 11 and 9 x 15 symbols for most of the conditions studied, but in one condition the 7 x 11 was more legible than the 5 x 7.

ACKNOWLEDGMENTS

Special thanks are given to Perryno Alexander for his care and patience in running the operators in this study. The assistance of Marion Marsetta and Claire Crook with the analysis of the data and with preparation of figures and tables for this report is gratefully acknowledged.

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SECTION I

INTRODUCTION

The purpose of the present study was to determine the legibility of svmbols formed from matrices which contained different numbers of dot elements. The results of this study were used to make recommendations about the smallest matrix (fewest number of dots) from which a legible set of alphanumeric symbols can be constructed.

In present displays, the number of dot elements from which symbol sets are constructed may vary from as few as 15 in a 3 x 5 matrix to as many as 150 in a 10 x 15 matrix. A 5 x 7 matrix means that symbols are constructed from a matrix of elements which has five columns of dots (width) and seven rows of dots (height). Similarly, other designations for matrices such as 3 x 5, 7 x 11, and so on, refer to the number of columns and rows of dots used to construct symbols. A 5 x 7 matrix of dot elements is the most frequently used for cathode ray tube (CRT) displays in modern computer-based systems.

Dot and other segmented symbols are used in a variety of displays. For examples, alphanumeric symbols of high speed printers, highway signs, score boards, plug-in display panels, and so on are often formed by dot matrices of one size or another. Digitalized television, which is currently gaining popularity for use in command and control systems, features segmented symbols which are constructed from a dot raster character generator. In digitalized television, the raster is controlled by a generator which is programmed typically to form symbols out of five raster segments horizontally and seven raster segments vertically. Although, as is the case with other dot-generator techniques, greater numbers of raster elements, such as 7 x 9 and 9 x 11, have been used to construct symbols(1).

The selection of the number of dot or raster elements for use in a given display application depends at the present time upon such things as personal opinions, engineering convenience, and economic considerations. It is faster and more economical to use, for example, a 5 x 7 dot matrix than a 9 x 15 dot matrix. One important, but often neglected, basis for selection of a matrix of a given size is the ease and accuracy with which a human is able to read symbols formed from this matrix. It is an important basis for selection after all since those displays are intended for human use. Consequently, it is important to determine if symbols formed, for example, by a 9 x 15 dot matrix are sufficiently superior in legibility to those formed by a 5 x 7 dot matrix to justify the additional expenses involved in using the 9 x 15 matrix.

The legibility of symbols formed from 3 x 5, 5 x 7, 7 x 11 and 9 x 15 matrices were compared in this study.

SECTION II

THE PROBLEM

A comprehensive evaluation of the legibility of symbols formed from different dot matrices must take into consideration factors such as symbol degradation, operator practice and the aspect of the operators' identification performance that is recorded.

SYMBOL DEGRADATION

The selection of a particular size dot matrix may depend upon the amount of symbol degradation that is anticipated. There is a possibility, for example, that a 3 x 5 or 5 x 7 matrix might be good enough when viewing conditions are nearly optimal, while greater numbers of elements (7 x 11 or 9 x 15) might be required to maintain symbol legibility in cases where viewing conditions are likely to be degraded. Therefore, two viewing conditions were used in the present study. In one condition the symbols were displayed under nearly optimal conditions, while in a second condition symbol quality was degraded by greatly reducing the visual size subtended by the symbols.

OPERATOR PRACTICE

There is a strong possibility that operator practice and familiarity with symbols constructed from different size matrices might alter in some way the relative differences in the legibility of the matrices(3). It may be, for example, that a 5 x 7 matrix is as legible as a 7 x 11 matrix if the operator is given some practice with the 5 x 7. At any rate, it was desirable to determine if relative differences in the legibility of these matrices are altered with practice. Consequently, operators in the present study were given two sessions on each of the four different matrices.

IDENTIFICATION PERFORMANCE

Previous legibility studies(4) have shown that the aspect of identification performance that is recorded is important. For example, two symbol sets may be identified with the same error rate, but one of the symbol sets may be identified at a faster rate than the other. Also, in many display situations both the accuracy and rate of the operators' symbol identification are important considerations. Therefore, in the present study both the operators' rate and accuracy in identifying symbols were recorded.

SECTION III

EQUATING SYMBOL PROPERTIES

There are a number of problems involved in any attempt to determine the relative legibility of symbols made up from different size dot matrices. To establish an optimal matrix size (number of elements) it is necessary to control the effects of a number of other factors known to affect symbol legibility so that these factors do not bias the results for any particular matrix studied. Some of the more important factors are symbol height and width, height-to-width ratio, stroke-width, style, luminance and luminance contrast[4].

SYMBOL SIZE

The height, width, and height-to-width ratio of symbols in each of the four matrices were partially equated by programming appropriate magnifications in a PDP-8 computer (see Apparatus Section). The height and width dimensions of the different size matrices are shown in Table I. The small variations in symbol height among the matrices were compensated for by seating the operators at different distances for each of the matrices and thereby equating the visual size subtended by symbol height in each of the four matrices.

SYMBOL STROKE-WIDTH

Symbol stroke-width was approximately the same for symbols in each size matrix and corresponds to the diameter of the dot used to construct these symbols. The values of stroke-width are shown in Table I.

SYMBOL STYLE

Symbol style is, of course, impossible to equate for each of the four matrices. In fact, the major advantage of increasing the number of dot elements is that the symbols can be designed to approximate more closely the conventional styles constructed with a solid stroke. While symbol style is inherently associated with increasing the number of dot elements, some degree of control can be placed on this factor by trying, with each matrix size, to form a set of symbols which approximate as closely as possible some standard design. In the present case, the standard design selected was the Lincoln/MITRE alphanumerics, known to be, by previous experimental evaluation, of superior legibility[2]. The closeness of approximating the geometry of the solid stroke L/M symbols decreased, of course, as the number

Table I

Some selected physical characteristics
of symbols in the four different dot matrices

	Height	Width	Height to Width Ratio	Stroke-Width
3 x 5	.140	.092	1.52	.024
5 x 7	.150	.092	1.63	.024
7 x 11	.140	.092	1.52	.024
9 x 15	.134	.084	1.60	.024

of elements making up a matrix decreased. A comparison of similarities among the solid-stroke L/M symbols and symbols in each of the four dot matrices may be made by inspection of Figure 1.

It should be stressed that increases in the number of dot elements did not result in any corresponding increase in the size of the matrix. For example, the overall size of the 9 x 15 matrix was approximately the same as that for the 3 x 5 matrix. This method of increasing the number of dot elements would be analogous in digitalized television, for example, to increasing the number of raster segments out of which a symbol set is formed without increasing the height or width of the symbol displayed. In the present method of increasing matrix size, the dot elements are placed closer and closer together, as matrix size increases, by decreasing the distance between adjacent dots in both the x and y dimension.

SYMBOL LUMINANCE

The luminance of symbols formed from the different matrices was equated by a Spectra Pritchard photometer with a 2 minute of arc aperture.

The luminance matching for each of the four matrices was accomplished by appropriate adjustment of the beam intensity control of the CRT for each of the four matrices. For the 3 x 5 matrix a sample of several different letters in several different arrays indicated that symbol luminance varied from 14 to 18 ft-L. The ranges of luminance for the other three matrices were within the range for that of the 3 x 5.

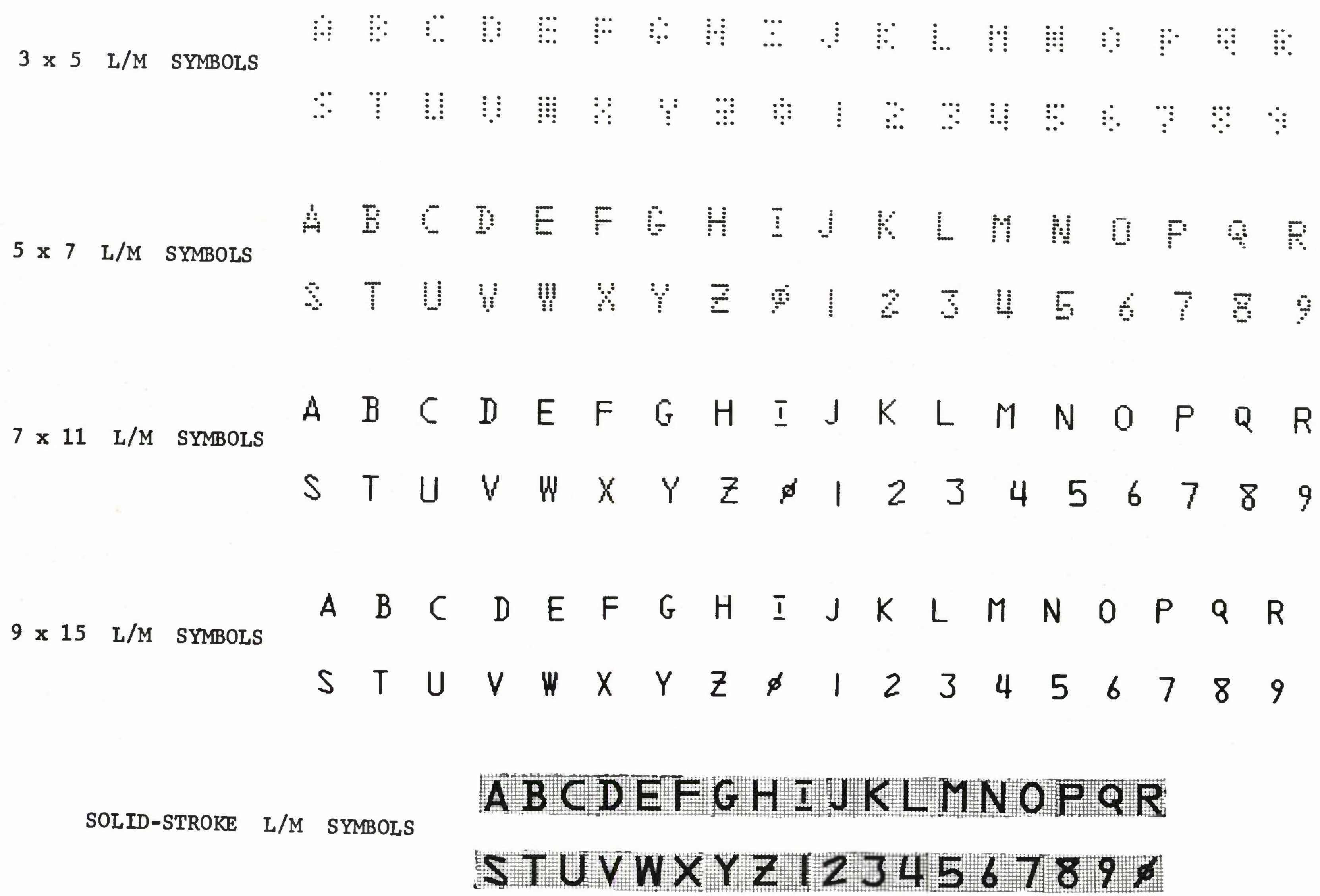

Figure 1. Approximation of L/M symbols constructed from four dot matrices and L/M solid-stroke symbols.

SECTION IV

APPARATUS, OPERATORS, PROCEDURE

APPARATUS

A PDP-8 computer was used to construct the symbols, generate symbol sequences and arrange the symbol sequences so that nine symbols could be displayed at one time. These nine symbols, arranged in a 3 x 3 array, were shown on a Tektronic type RM 503 oscilloscope (DEC Type 34) fitted with a P-7 phosphor. The front surface of the tube was covered by a clear plexiglass implosion shield.

OPERATORS

Eight MITRE employees served as operators. All operators had 20/20 near and far acuity, normal phoria, normal depth perception and normal color vision.

PROCEDURE

The eight operators were randomly assigned to one of two groups, A or B. Each group had four operators. Group A viewed the symbols at a near viewing position in which the symbols subtended 22 minutes of arc at the operator's eyes. Group B viewed the symbols from a far distance where the symbols subtended only 6 minutes of arc at the operator's eyes. Consequently, Group A identified symbols under nearly optimal viewing conditions (large symbol size) while Group B identified symbols under degraded viewing conditions (small symbol size).

Each operator had eight experimental sessions. In the eight sessions, he saw each of the four matrices two times. The order in which the matrices were assigned to the operator for the first four sessions is shown in Table II. In the orders of assignments shown in Table II, each matrix appeared an equal number of times in each ordinal position, and each matrix was preceded and followed an equal number of times by each of the other matrices. In these assignments of matrices, improvement resulting from practice was equally distributed over the four matrices, and the assignments guarded against the possibility that a given matrix might either suffer or excel because it was always preceded by the same matrix.

In the remaining four experimental sessions, the sequence shown in Table II was repeated for each of the eight operators.

In each session, the operator was first familiarized with each symbol in the matrix size he was to see for that session. The symbols

Table II

The orders in which operators in Groups A and B identified symbols in each of the four different dot matrices

		ORDER			
		1st	2nd	3rd	4th
Operator	O_1	3 x 5	5 x 7	7 x 11	9 x 15
	O_2	5 x 7	9 x 15	3 x 5	7 x 11
	O_3	7 x 11	3 x 5	9 x 15	5 x 7
	O_4	9 x 15	7 x 11	5 x 7	3 x 5

were presented one-at-a-time on the CRT and the operator was free to study each symbol as long as he liked. In addition, he was given a photograph of the symbol set which he was free to study during breaks in the test run.

Following familiarization training, the operator was administered the test runs in which he saw 20 arrays of symbols in succession. Over the 20 arrays, each of the 36 alphanumeric symbols was presented 5 times each. The symbols were assigned to arrays by a procedure that ensured random symbol sequences. Each array contained 9 symbols which were arranged in 3 rows and 3 columns. In a given array, the symbols were spaced horizontally 50 percent of the symbol height and vertically 100 percent of symbol height. While making his identification, the operator was seated at a modified typewriter table which was equipped with a headrest and eye shield which obscured his peripheral vision. The operator was asked to read each array as fast and as accurately as possible. He was instructed to identify the symbols in a normal reading fashion, namely, left to right and top to bottom. The time to read each symbol array was recorded. The operator's symbol identifications were tape-recorded and the tape was scored later to determine his identification accuracy.

The sessions were conducted in a sound deadened room. The room was illuminated with overhead fluorescent lights so that 10 ft. candles of light fell at the operator's station and 15 ft. candles of light fell at the scope face. The scope face was hooded, and reflecting objects were shaded so that there were no reflections off the scope face to annoy or distract the operator.

SECTION V

RESULTS AND CONCLUSIONS

The results of this study for both Groups A and B are shown in Figures 2 and 3.

GROUP A

Results

Figures 2 and 3 show two different characteristics of operator performance for Group A and for each of the four different matrices. The filled bars show performance for the first session while the unfilled bars show performance for the second session.

Rate of Correct Identification

The rates at which operators of Group A were able to identify and transmit data correctly (CI/min) are shown in Figure 2.

There are several interesting aspects to note about the CI/min for Group A. First, the major increase in CI/min occurs, for both the first and second session, when matrix size was enlarged from a 3 x 5 to 5 x 7. In the first session, CI/min did not increase further when matrix size was enlarged from 5 x 7 to 7 x 11 or 9 x 15. However, in contrast to the first session, the second session shows that an increase in rate did occur when matrix size was enlarged from 5 x 7 to 7 x 11.

Statistical tests were performed to determine the significance of the above observations. The analysis of variance of CI/min for the first session indicated that matrix size was a significant source of variance (Table III). Follow-up t tests showed a significant difference in performance for the 3 x 5 vs. the 5 x 7 ($t = 7.40$, df = 3, $p < .01$), but no significant difference in performance between the 5 x 7 and 7 x 11 ($t = 1.26$, df = 3, $.3 > p > .2$). The analysis of variance of the data for the second session also indicated that matrix size was a significant source of variance (Table IV). Follow-up t tests showed that a significant difference in performance for the 3 x 5 vs. the 5 x 7 ($t = 7.71$, df = 3, $p < .01$) and a significant difference occurred in performance between the 5 x 7 and 7 x 11 ($t = 4.46$, df = 3, $.05 > p > .02$). There were no significant differences between the 7 x 11 and 9 x 15 ($t = 1.03$, df = 3, $.4 > p > .3$).

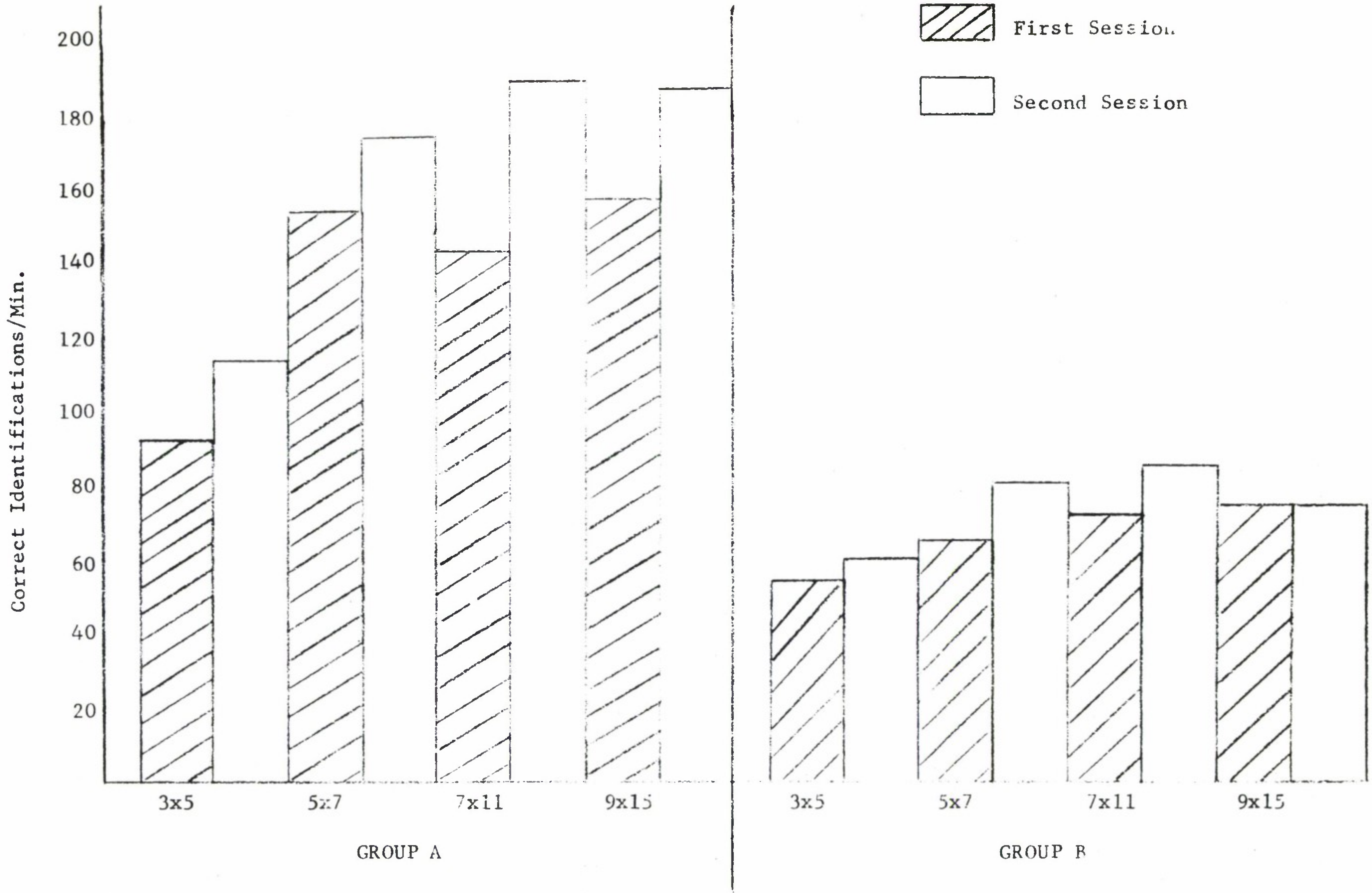

Figure 2. Correct identifications per minute for Groups A and B for the first and second sessions.

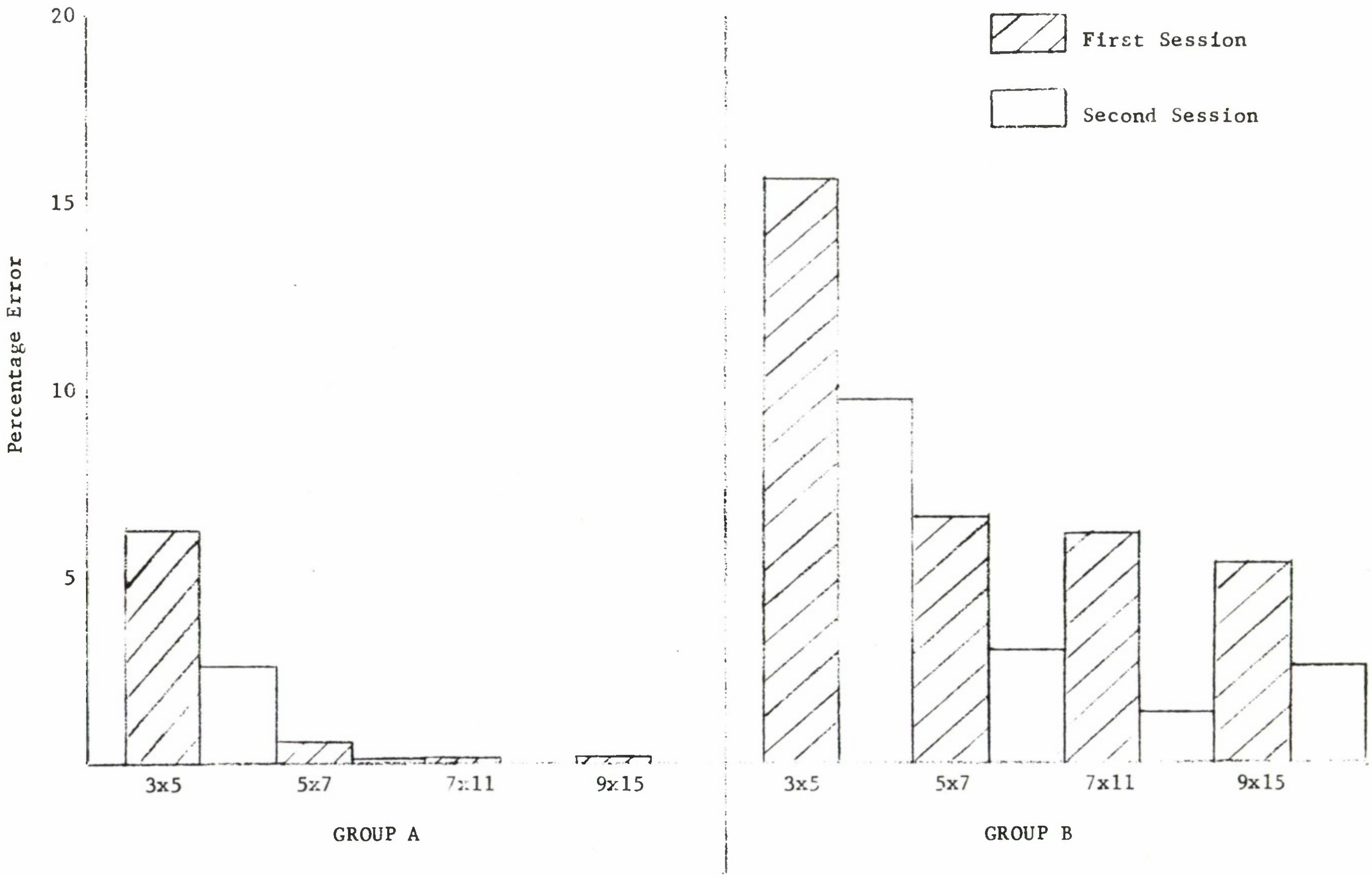

Figure 3. Percentage error for Groups A and B for the first and second sessions.

Table III

Analysis of correct identifications per minute
for the first session for Group A

Source of Variance	Variance	df	MS	F	P
Matrix Size	7750.81	3	2583.60	12.37	.01
Operators	167.13	3	549.04	2.63	NS
Residual	1879.62	9	208.85		

Table IV

Analysis of correct identifications per minute
for the second session for Group A

Source of Variance	Variance	df	MS	F	P
Matrix Size	9818.01	3	3272.67	68.88	.01
Operators	2792.51	3	930.84	19.59	.01
Residual	427.55	9	47.51		

Errors of Identification

The percentage errors made by operators in Group A are shown in Figure 3. Again, Figure 3 shows that the greatest decrease in errors occurred as matrix size was enlarged from 3 x 5 to 5 x 7. Errors were negligible for the 5 x 7, 7 x 11 and 9 x 15. Errors were too few to permit use of analysis of variance tests, but $\underline{t}$ tests between the 3 x 5 and 5 x 7 for the first and second sessions showed no significant differences ($t = 2.97$, $df = 3$, $.1 > p > .05$ for the first session, and $t = 1.70$, $df = 3$, $.21 > p > .1$ for the second session).

Symbol Confusions

Confusions that occurred among symbols for Group A for the 3 x 5 matrix are shown in Table V a & b (errors for Group A for the 5 x 7, 7 x 11 and 9 x 15 were too few to be reported in confusion matrices). Table V a shows that most of the errors for Group A were concentrated in just a few symbols, N, Ø, O, V and W. Comparison of Table V a and b shows that errors for most of the symbols (Ø, O, W and N) were greatly reduced by practice while errors for only one symbol (V) remained at nearly the same level.

Conclusions

When the operator or viewer does not have much practice with the symbol font, legibility improves as matrix size is enlarged from 3 x 5 to 5 x 7. When the operator is given additional practice with the symbol font, legibility improves for each enlargement of symbol size from 3 x 5 to 5 x 7 to 7 x 11. If only accuracy of symbol identification is important, and not rate of identification, a 3 x 5 matrix may be suitable if several of the 3 x 5 symbols are redesigned and the operator is given practice with the 3 x 5 font.

GROUP B

Results

The results for Group B who viewed symbols under degraded conditions are shown in Figures 2 and 3.

Rate of Correct Identification

Figure 2 indicates that the differences among matrices in correct identifications per minute (CI/min) for Group B are not as pronounced as they were for Group A, especially for the first session.

Character Called

Character Shown

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B																																					
C																																					
D																																					
E																																					
F																																					
G			1																																		1
H													2																								2
I																																					
J																																					
K																																					
L																																					
M																																					
N								1					4										8														13
O																																				6	6
P																																					
Q																																					
R																																					
S																																					
T																																					
U																																					
V																					2		3														5
W													4											1													5
X								1																													1
Y																																					
Z																									1												1
1									3																												3
2																										1											1
3																																					
4																																					
5																																					
6																																					
7																																					
8																																					
9																																					
Ø															8																						8
Σ			1					2	[illegible]				10		8						2		11	1	1	[illegible]										6	46

Table V a. [illegible] intersymbol confusions for first session for Group A.

Character Called (columns) / Character Shown (rows)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B																																					
C																																					
D																																					
E																																					
F																																					
G																																					
H													4																								4
I																																					
J																																					
K																																					
L																																					
M																																					
N													3																								3
O																																					
P																																					
Q																																					
R																																					
S																																					
T																																					
U																																					
V																					5		2														7
W														1																							1
X																																					
Y																																					
Z																																					
1									2																	1											3
2																										1											1
3																																					
4																																					
5																																					
6																																					
7																																					
8																																					
9																																					
Ø															1																						1
Σ									2				7	1	1						5		2			2											20

Table V b. 3x5 intersymbol confusions for second session for Group A.

The analysis of variance of CI/min for the first session showed that matrix size was not a significant source of variance. This analysis is shown in Table VI. However, CI/min was a significant source of variance during the second session. This latter analysis is in Table VII. Follow-up $\underline{t}$ tests of CI/min for the second session showed that a significant difference occurred between the 3 x 5 and 5 x 7 ($t = 6.39$, $df = 3$, $p < .01$), but not between 5 x 7 and 7 x 11 ($t = 2.14$, $df = 3$, $.2 > p > .1$).

Errors of Identification

In contrast to CI/min, analysis of variance of percentage errors (Table VIII) showed that matrix size was a significant source of variance for the first session. Follow-up $\underline{t}$ tests showed no significant difference between the 3 x 5 and 5 x 7 ($t = 2.86$, $df = 3$, $.1 > p > .05$), nor did any of the other pairs of means differ significantly. In the second session, matrix size was a significant source of variance again (Table IX). Follow-up $\underline{t}$ tests show a significant difference between the 3 x 5 and 5 x 7 ($t = 4.51$, $df = 3$, $.05 > p > .02$), but no significant difference between the 5 x 7 and 7 x 11 ($t = 1.50$, $df = 3$, $.3 > p > .2$).

Symbol Confusions

Confusions that occurred among symbols for Group B for the 3 x 5 matrix are shown in Table X a & b. A comparison of the two tables shows that most of the symbols which were major sources of errors for the first session continued to be major sources of error for the second session, namely, the W, G, M and N. Errors for letters I and Z were reduced with practice.

Confusion among symbols for Group B for the 5 x 7 are shown in Tables XI a & b. Comparison of Tables XI a and b shows that the major sources of error for the first session, the W, Z and 5, were not reduced very much by practice, while errors for symbols M and B were reduced by practice. Similar practice effects or the lack of them for symbols of matrices 7 x 11 (Table XII a & b) and 9 x 15 (Table XIII a & b) may be detected by the reader by inspection of these tables.

Conclusions

When the visual size of the symbol is greatly reduced, legibility improves as matrix size is enlarged from 3 x 5 to 5 x 7, but legibility does not improve for matrices larger than 5 x 7. Even when the operator is given some practice, no additional improvement in legibility occurs for matrices larger than the 5 x 7. The 3 x 5 matrix is not suitable for use when symbol size is reduced.

Table VI

Analysis of correct identifications per minute for first session for Group B

Source of Variance	Variance	df	MS	F	P
Matrix Size	896.35	3	298.78	3.62	NS
Operators	388.67	3	129.56	1.57	NS
Residual	744.85	9	82.43		

Table VII

Analysis of correct identifications per minute for second session for Group B

Source of Variance	Variance	df	MS	F	P
Matrix Size	1271.43	3	423.81	15.83	.01
Operators	190.54	3	63.51	2.37	NS
Residual	241.91	9	26.77		

Table VIII

Analysis of percentage error
for first session for Group B

Source of Variance	Variance	df	MS	F	P
Matrix Size	284.01	3	92.38	5.31	.05
Operators	142.52	3	48.09	2.76	NS
Residual	153.60	9	17.41		

Table IX

Analysis of percentage error
for second session for Group B

Source of Variance	Variance	df	MS	F	P
Matrix Size	176.18	3	58.73	9.84	.01
Operators	104.58	3	34.86	5.83	.05
Residual	53.72	9	5.97		

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Ƶ	1	2	3	4	5	6	7	8	9	Ø	Σ
A															1			2												1							4
B																1																					1
C																																					
D																																					
E																																					
F																																					
G			6												2																	1				2	11
H													2	1																							3
I																								3		5											8
J																																					
K																																					
L																																					
M								10																													10
N													7										1														8
O																																				4	4
P						1																															1
Q																														1					1		2
R																																		1			1
S																															1						1
T																																					
U																						1								1							2
V																					5		1														6
W														3				13																			16
X								2					1	1																							4
Y																																					
Ƶ																												4	3								7
1									4																												4
2																										2											2
3																																					
4																					1				1												2
5																			3																		3
6							1																														1
7																																					
8																			3									1									4
9																																					
Ø							1								5																						6
Σ			6			1	2	12	4				10	5	8	1		15	6		6	1	2	3	1	7	6		5	3	3	1	1		1	1	111

Table X a. 3x5 intersymbol confusions for first session for Group B.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Ƶ	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B																																1					1
C																																					
D																																					
E																																					
F																																					
G			6												1																	1					8
H													2	2																							4
I																								1		1											2
J																																					
K																																					
L																																					
M								9																													9
N								4					4																								8
O																																				5	5
P																																					
Q																																					
R																																					
S																															1						1
T																																					
U																						1															1
V																					8																8
W	1												5	2				4																			12
X													3	1																1							5
Y																																					
Ƶ																																					
1									1																												1
2																																					
3																										1											1
4																																					
5																			1																		1
6																																					
7																																					
8																										2											2
9																																					
Ø															2																						2
Σ	1		6					13	1				14	5	3			4	1		8	1		1		4				1	1	2				5	71

Table X b. 3x5 intersymbol confusions for second session for Group B.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Ƶ	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B				5																																	5
C																																					
D																																					
E																																					
F																																					
G																																				1	1
H													3																								3
I																																					
J																																					
K																																					
L																																					
M								7																													7
N																																					
O				1																																	1
P																																					
Q																																			1		1
R																																					
S																																					
T																																					
U																						1								1							2
V																																					
W																						9												1			10
X																																					
Y																						1															1
Ƶ																												4									4
1									3																												3
2																										1											1
3																			1															1			2
4																					1																1
5																																5					5
6																																					
7																																					
8																																					
9																																				1	1
Ø																																					
Σ				6				7	3				3						1		1	11				1		4		1		5		2	1	2	48

Table XI a. 5x7 intersymbol confusions for first session for Group B.

Character Called

Character Shown

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B																																					
C																																					
D																																					
E																																					
F																																					
G																																					
H																																					
I																																					
J																																					
K																																					
L																																					
M								2																													2
N																																					
O																																					
P																																					
Q																																					
R																																					
S																												1									1
T																																					
U																																					
V																																					
W		1																				5												3			9
X																																					
Y																																					
Z																												3									3
1									1																												1
2																																					
3																																					
4																					2																2
5																																4					4
6																																					
7																																					
8																																					
9																																					
Ø																																					
Σ		1						2	1												2	5						4				4		3			22

Table XI b. 5x7 intersymbol confusions for second session for Group B.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B				3																									3								6
C																																					
D																																					
E																																					
F																1																					1
G																																3					3
H													3																								3
I																				1																	1
J																																					
K																																					
L																																					
M								6																													6
N																																					
O																																					
P																																					
Q																														1							1
R																																					
S																																1					1
T																																					
U																																					
V																																					
W														2	1			4																			7
X																																					
Y																						1															1
Z																												8									8
1									3																												3
2																										1											1
3																																					
4																																					
5																																					
6																																					
7																																					
8																				1						1											2
9																																					
Ø																																			1		1
Σ				3				6	3				3	2	1	1		4		2		1				2		8	3	1		4			1		45

Table XII a. 7x11 intersymbol confusions for first session for Group B.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B				1																																	1
C																																					
D																																					
E																																					
F																1																					1
G																																					
H													2																								2
I																																					
J																																					
K																																					
L																																					
M								6																													6
N																																					
O																																					
P																																					
Q																																					
R																																					
S																																					
T																																					
U																																					
V																																					
W																																					
X																																					
Y																																					
Z																																					
1																																					
2																																					
3																																					
4																																					
5																																					
6																																					
7																																					
8																																					
9																																					
Ø																																					
Σ				1				6					2			1																					10

Table XII b. 7x11 intersymbol confusions for second session for Group B.

Character Called

Character Shown	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B																													4								4
C																																					
D																																					
E																																					
F																1																					1
G			1																													5					6
H													2																								2
I																																					
J																																					
K																																					
L																																					
M								2																													2
N																																					
O				1																																	1
P																																					
Q																																					
R																																					
S																															2						2
T																																					
U																																					
V																							2		1												3
W													1									2															3
X																																					
Y																						3															3
Z																																					
1									3																												3
2																																					
3																																					
4																																					
5																			1																		1
6	1																													1							2
7																												1									1
8																				1				1													2
9																																				1	1
Ø																								1											1		2
Σ	1		1	1				2	3				3			1			1	1		5	2	2	1			1	4	1	2	5			1	1	39

Table XIII a. 9x15 intersymbol confusions for first session for Group B.

Character Called

Character Shown

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	1	2	3	4	5	6	7	8	9	Ø	Σ
A																																					
B																																					
C																																					
D																																					
E																																					
F																																					
G																																2					2
H														1																							1
I																																					
J																																					
K																																					
L																																					
M								3						1																							4
N																																					
O																																					
P																																					
Q																																					
R																																					
S																																					
T																																					
U																																					
V																									1												1
W																						3															3
X																																					
Y																				1		4															5
Z																																					
1																																					
2																																					
3																																					
4																																					
5																			3																		3
6																																					
7																																					
8																																					
9																																					
Ø																																					
Σ								3						2					3	1		7			1							2					19

Table XIII b. 9x15 intersymbol confusions for second session for Group B.

SUMMARY

A comparison of the results for Group A and B indicates that the relative legibility of the respective matrices depends upon the conditions of viewing. When the visual size of the symbols is large (equivalent of 1/8" high symbols viewed at a distance of 18") and the operator is given practice, he will do better, or his performance will reach a higher level, with each enlargement of the matrix from 3 x 5 to 5 x 7 to 7 x 11. At the same time, when the visual size of the symbol is small (equivalent of 1/32" high symbols viewed at 18"), performance will improve for enlargement of the matrix from 3 x 5 to 5 x 7, but not from 5 x 7 to 7 x 11 even if the operator is given some practice with the symbol fonts.

It is concluded that a 5 x 7 is as legible as the larger size matrices (7 x 11 and 9 x 15) for most of the conditions studied, but that the 7 x 11 is more legible than the 5 x 7 when visual size of the symbol is large (symbol height subtending 22 minutes of arc) and the operator is given practice with the symbol fonts. The 3 x 5 matrix may be adequate for some applications if the visual size of the symbol is large.

SECTION VI

DISCUSSION

SYMBOL QUALITY AND LEGIBILITY

The finding that the larger size matrices (7 x 11 and 9 x 15) are more legible than the smaller size matrices (3 x 5 and 5 x 7) only when the symbol is visually large and not when it is visually small, is somewhat contrary to initial expectations. It was anticipated that, if legibility increased when the matrix was enlarged from 5 x 7 to 7 x 11 or 9 x 15, it would be for the degraded display condition rather than for the non-degraded display condition. Although the latter finding was unexpected, it may not be too surprising when the following is considered.

Figure 1 indicates that one of the advantages of enlarging the dot array is that it is possible to reproduce better the fine detail of conventional, solid-stroke symbols. The findings of the present study are consistent with the notion that operators in the degraded display condition (symbols subtended a small visual size) were not able to resolve very well the greater symbol detail provided by matrices larger than the 5 x 7. Consequently, their symbol identification failed to improve when matrix size was enlarged from 5 x 7 to 7 x 11 or 9 x 15. At the same time, operators for whom the symbols subtended a large visual size were able to resolve better the finer detail provided by the larger matrices and with practice their symbol identification improved as matrix size was enlarged from 5 x 7 to 7 x 11.

While the above account of these results seems logical, the critical reader may question, if the above analysis is true, why in the degraded condition did significant improvement in performance occur when matrix size was enlarged from 3 x 5 to 5 x 7? This is a reasonable question and the answer to it may come from consideration of the amount or relative size of the detail that is added to a symbol as the number of dots in a matrix is enlarged. As Figure 1 shows, in enlarging the matrix from 3 x 5 to 5 x 7, each additional dot in the 5 x 7 is adding extra detail about the geometry of the symbols. That is, the dots of the 5 x 7 do not overlap one another. At the same time, Figure 1 shows also that the new symbol detail added per dot probably becomes less and less as matrix size is increased from 5 x 7 to 7 x 11 and 9 x 15, since there is greater and greater overlapping of dots for the larger size matrices. It may be that the size of the new symbol detail which is provided by additional dots, when the dot matrix is enlarged from 5 x 7 to 7 x 11 or 9 x 15, does not subtend a large enough angle at the observer's eyes to improve his ability to identify symbols made up from a 7 x 11 or 9 x 15 matrix.

In summary, when symbols are small (height subtending 6 minutes of arc), the 3 x 5 matrix is also too small to give good performance. Some improvement is obtained by using the 5 x 7 matrix, but further improvement in performance as matrix size is enlarged is prevented by the small visual size.

COMPARISON OF DOT SYMBOLS WITH SOLID-STROKE SYMBOLS

It was noted (Figure 1) that each increase in dot matrix size permitted a better approximation of the geometry of solid-stroke L/M symbols. One may wonder at which matrix size in this progressively better approximation of solid-stroke symbols operator performance matches that possible to attain with solid-stroke symbols. Fortunately, a comparison of operator performance with dot and solid-stroke symbols is possible since a previous, unpublished study determined symbol identification rates for good quality capital typewritten symbols. A comparison of CI/min for these solid-stroke, typewritten symbols with those of the present study indicates that rate of CI/min attained by operators in Group A of the present study (for dot matrices of 7 x 11 and 9 x 15 during their second sessions) were approximately the same as those rates attained by operators identifying good quality solid-stroke symbols. On the basis of the preceding comparison one would conclude that performance with a 7 x 11 dot matrix is equivalent to performance with solid-stroke symbols. However, it should also be pointed out that other size matrices falling between the 5 x 7 and 7 x 11 may also yield performance which is equivalent to performance with solid-stroke symbols. Operator performance for several additional matrices falling between the 5 x 7 and 7 x 11 will be evaluated in a subsequent study in this series of reports on the legibility of dot symbols.

TYPES OF SYMBOL DEGRADATION

It is well known that symbol quality may be degraded in many other ways besides reducing the visual size subtended by the symbols. The display design engineer who is faced with other kinds of possible degradation (e.g., blurring), might well ask if the present findings for these four matrices may be applied when symbols are degraded in these other ways. While an unequivocal yes cannot be given to the preceding question, there is some evidence that a font which is superior in legibility to another font in one kind of degrading situation will retain its superior legibility in other kinds of degrading situations(5).

At the very least, it could be argued that, while a font may not retain its superior legibility in all kinds of degrading situations it probably will not be superior in legibility in one degrading situation and inferior in legibility in a second degrading situation. Therefore, a font that is superior in some degraded viewing conditions is to be preferred in the absence of data on the effects of other types of degradation.

OTHER FACTORS IN DOT SYMBOL LEGIBILITY

Other factors besides number of elements may be expected to affect the legibility dot symbols. For example, it may be that performance of operators with dot symbols might be enhanced if another value of stroke-width is used in place of that of the present study. In fact, following the determination of a minimum number of dots for symbol construction, other features of dot symbols, such as stroke-width, height-to-width ratio, etc., should be investigated to determine optimal design values of these other factors for dot symbol construction.

SECTION VII

RECOMMENDATIONS

The 5 x 7 dot matrix is recommended for situations in which the visual size of the symbols is as small as the smaller size used in the present study. The 5 x 7 is also recommended for situations in which the visual size of the symbol is as large as the larger size used in the present study where the operator is not given much opportunity to familiarize himself with the font. If the symbol size is as large as the larger size used in the present study, and the operator is given some practice with the font, a matrix greater than a 5 x 7, for example a 7 x 11, is recommended when the rate of symbol identification is important. A matrix as small as 3 x 5 is not recommended for display use at this time, although the analyses of intersymbol confusions for the 3 x 5 suggested that it might be possible to use a 3 x 5 matrix if (a) some of the symbols are redesigned, (b) the operator is given practice with the symbol font, and (c) symbol size is as large as the larger size used in the present study.

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13. ABSTRACT

The purpose of this study was to determine the legibility of symbols formed from matrices which contained different numbers of dot elements. A set of alphanumeric symbols was constructed from each of the following dot matrices: 3 x 5, 5 x 7, 7 x 11, and 9 x 15. The four symbol sets were shown for identification to one group of operators under nearly optimal viewing conditions and to a second group under degraded viewing conditions. Both rate and accuracy of identification were recorded. The results indicate that the 5 x 7 symbols are as legible as 7 x 11 and 9 x 15 symbols for most of the conditions studied, but in one condition the 7 x 11 was more legible than the 5 x 7.

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