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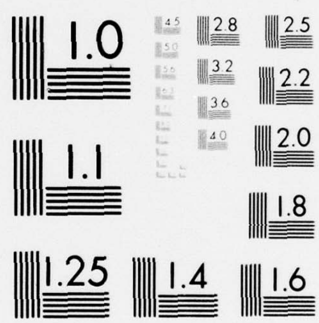

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

DELET-TR-78-11

THE EFFECT OF ACTIVE AREA ON THE LEGIBILITY OF DOT MATRIX DISPLAYS

Isidore H. Stein

Electronics Technology & Devices Laboratory

June 1978

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US ARMY ELECTRONICS RESEARCH & DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY 07703

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The dependence of legibility on active area for dot matrix displays was studied in an experimental program with human subjects. Under normal conditions, such dependence appears to be minimal. Under stressed conditions, there is a threshold at the 30 percent active area region, above which dependence again appears to be minimal.

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THE EFFECT OF ACTIVE AREA ON THE LEGIBILITY OF DOT MATRIX DISPLAYS

INTRODUCTION

There is a trade-off between reduced constraints in construction design and degree of legibility for dot matrix displays. Although construction constraints may be greatly relieved and legibility greatly changed by reducing display active area, the actual effect on legibility is unknown. The supposition that reduced active area would decrease legibility should not be accepted without quantitative evidence.

An experimental study to quantitatively ascertain the functional relationship between active area and legibility for dot matrix flat panel displays was conducted. Error rate and reading rate were the criteria used in experiments with human subjects. These were determined as a function of the percentage of active area of dot matrix alphanumerics with other variables such as contrast and letter size held constant. With this information available, designers of display devices will better understand the trade-offs, and hopefully can minimize production costs and power dissipation without sacrificing legibility.[1]

EXPERIMENTAL DESCRIPTION

Randomized alphanumeric assemblies, as in Figure 1, were prepared for experimental tests with human subjects. It was decided that custom drawn characters, photographically reduced, were preferable to electronically generated characters for reasons of stability,practicality,and exactness in determining the actual active area. The following characteristics were selected for the dot matrix alphanumerics:

Type - 5 x 7 elements

Font - Lincoln/Mitre

Size - 0.2 inch height

Active Area Percentage - 4,9,16,25,36,49,64,81

The 5 x 7 dot matrix was chosen as having the least number of dot elements consistent with good legibility.[2] Although there is no standardization on dot matrix fonts in the display field, the Lincoln/Mitre font was chosen because it is relatively well-known.[3]

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1. R. J. Vanderkolk, J. A. Herman, and M. L. Hershberger, "Dot Matrix Display Symbology Study," Wright-Patterson AFB, Ohio; Air Force Flight Dynamics Laboratory, USAF-AFFDL-TR-75-72, (AD-016-470), July 1975.

2. D. A. Shurtleff, "Legibility Research," Proceedings of the S.I.D., Volume 15, Second Quarter, 1974.

3. G. C. Kinney and D. J. Showman, "Studies in Display Symbol Legibility: XI The Relative Legibility of Selected Alphanumerics in Two Fonts," Mitre Technical Report MTR 205, AF 19(628)5165, 7 April 1966.

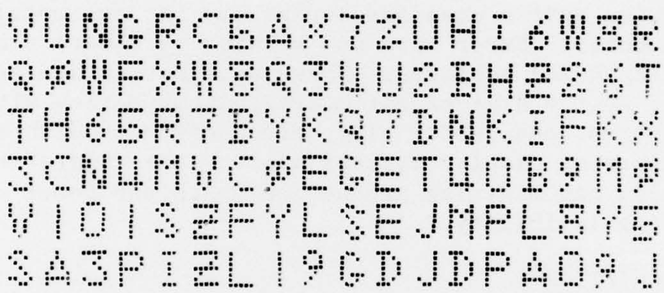


Figure 1. Lincoln/Mitre Font Dot Matrix
Alphanumerics, 0.20 Inch Height,
58.7 Percent Active Area

Eight sets of master drawings (one for each active area percentage) for the 36 alphanumerics (26 letters and 10 digits) were made. These master drawings with 7-inch high characters were photo-reduced to 1 3/4 inch characters. The 1 3/4 inch characters were assembled for each active area in a random order, utilizing a pseudo-random number generator. Each character appeared three times on the matte white painted metal base used for these assemblies. Eight assemblies of 108 characters, one for each active area percentage (numbered from 1 to 8), were made available for final photo reduction. These were photo reduced from the 1 3/4 inch high characters to 0.2 inch, the desired size for the legibility experiments. Active area assemblies, number 2 and number 6,were randomized again for use in subject training.

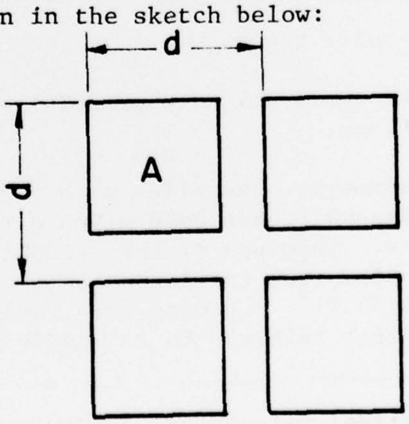
Before any testing could be done, the percentage of active area and the contrast of the photographic prints with 0.2 inch high alphanumerics had to be ascertained.

The contrast for the black dots on the white background of the photographic prints had to be uniform for all alphanumerics on any one assembly and the same for all assemblies. A Spectra brightness spotmeter, model UB 1/4, was used to measure brightness of the light and dark areas. The contrast ratio was defined as follows:

$$\frac{\text{White Background Illuminance} - \text{Black Dot Illuminance}}{\text{Black Dot Illuminance}}$$

A satisfactory set of photographic prints was made using vacuum suction in the contact printing process. All prints of this set had a uniform contrast ratio of 7.5.

The prints were then measured for meeting the design values for percentage of active area as shown in the sketch below:



Microphotographs of a few adjacent elements on a dot matrix alphanumeric for each percentage of active area were made. The active area percentage was computed as follows: active area percentage = $\frac{A}{d^2}$, where A is the dot matrix element area, and d is the distance between equivalent locations on two adjacent dot matrix elements.

With these measurements taken, the design active area percentages compared with the measured active area percentages as shown in Table 1. (For simplicity, the measured active areas will be identified as active areas Number 1 to 8).

TABLE 1

Design and Measured Percentage of Active Area

Active Area Number	Dot Matrix Design % Active Area	Dot Matrix Measured % Active Area	Difference (|Design %- Measured %|)	% Difference (Difference/ Design %)
8	81.0	71.6	9.4	11.6
7	64.0	58.7	5.3	8.3
6	49.0	46.8	2.2	4.5
5	36.0	38.5	2.5	6.9
4	25.0	33.0	8.0	32.0
3	16.0	23.9	7.9	49.4
2	9.0	15.0	6.0	66.6
1	4.0	11.9	7.9	198

As can be seen above, the photographic process changed the drawn active area; however, the important thing for this study is that the actual percentage of active area is accurately known.

Physical requirements for the test subject were as follows:

(1) Vision of 20/20 Snellen in both eyes, either uncorrected or corrected with glasses

(2) normal color vision

(3) subjects shall not have or require bifocal corrections.

The various alphanumeric assemblies with a different percentage of active area for each assembly have been given a randomized order for presentation to test subjects. This use of the randomized order of presentation was intended to avoid bias from continued learning and from avoidable fatigue due to repetition.[4,5] Subjects were tested under four groups of test conditions, hereafter referred to as Condition A, B, C, and D

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4. T. N. Cornsweet, Visual Perception, Academic Press, New York, 1970.

5. D. Y. Cornog and F. C. Rose, Legibility of Alphanumeric Characters and Other Symbols, A Reference Handbook, US Government Printing Office, Washington, DC, 1967

as follows:

	A	B	C	D
Contrast	7.5	7.5	7.5	3.2
Reading Distance	18"	18"	24"	24"
Character Viewing Angle	34.2'	34.2'	28.6'	28.6'
Background Illuminance	1.2 fc	0.12 fc	0.12 fc	0.97 fc

Condition A is considered an unstressed situation with regard to reading distance and illuminance. Condition B is an increased constraint upon Condition A by decreasing illuminance by a factor of ten. Condition C is a constraint upon Condition A where both the reading distance has been increased and illuminance has been reduced by a factor of ten. In Condition D the contrast has been changed by a combination of front and back lighting of the alphanumeric assembly photographs and the background illuminance is greater than in Condition C.

The alphanumeric assemblies were presented to the test subject in a light-tight chamber with a viewing port (Figures 2 and 3). The ambient light level in the chamber was controlled with a filtered daylight fluorescent light source for front lighting and back lighted with a second controlled incandescent source. A tape recorder and an electric timer were used for measurement of the correctness and reading time metrics.

The procedure used with each test subject was as follows:

1. The subject was given an enlarged copy of the Lincoln/Mitre 5 x 7 dot matrix alphanumerics to study until the subject felt that he was sufficiently familiar with the font.

2. The subject was seated at the light tight box for training in viewing the alphanumeric assemblies. Two randomized dot matrix assemblies were presented to the subject in a practice session.

3. The subject was then presented with active area assemblies No. 1 to No. 8 in a random order, and the subject's reading timed and tape recorded for future analysis.

RESULTS

The error rate and reading time for the unstressed condition A, for the stressed condition B (decreased illumination), for further stressed condition C (decreased illumination and increased reading distance), and for condition D, with contrast ratio decreased to 3.2, are presented in Table 2. All data are plotted in Figures 4 and 5.

Figure 2. Experimental Setup for Test Subjects

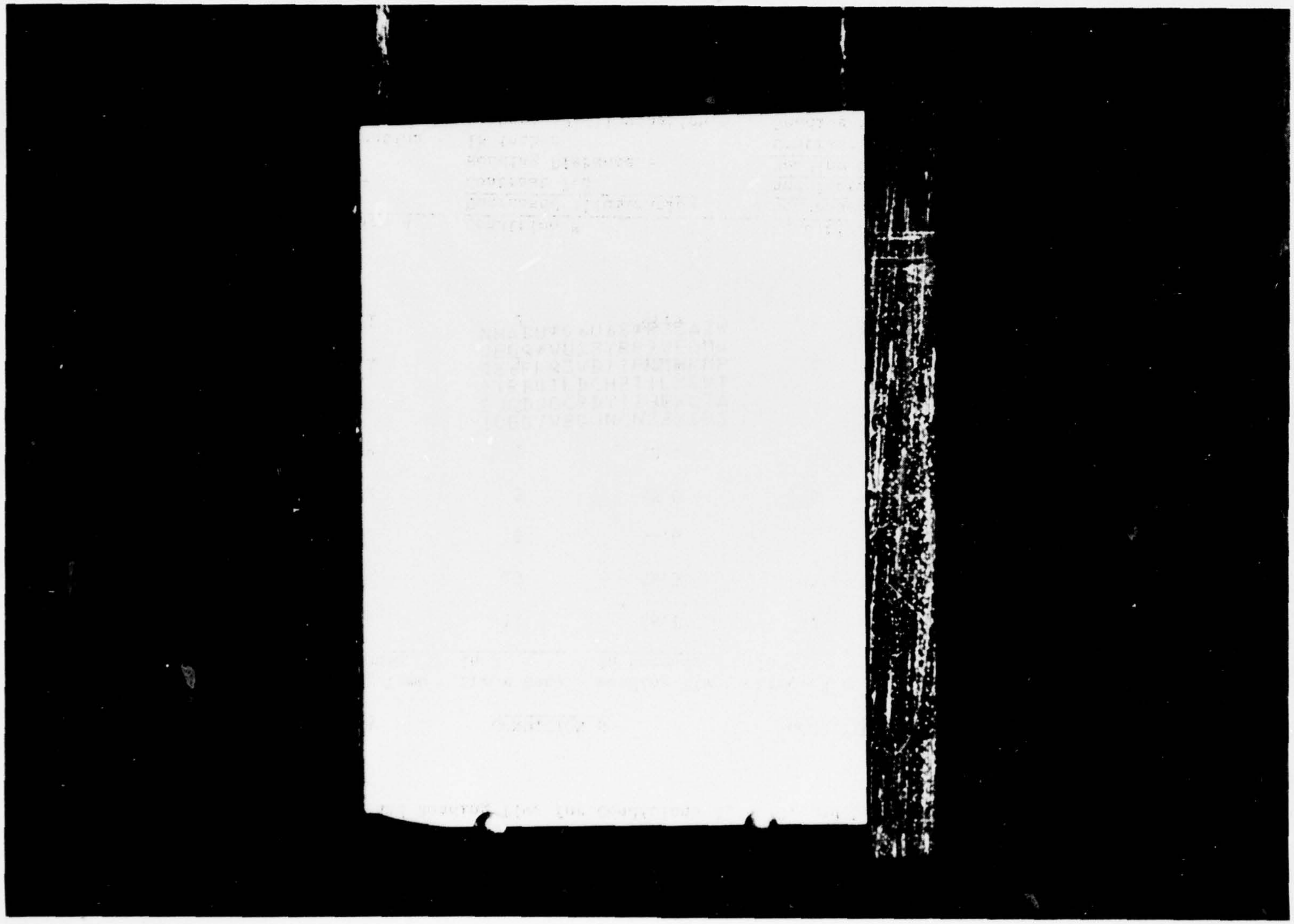


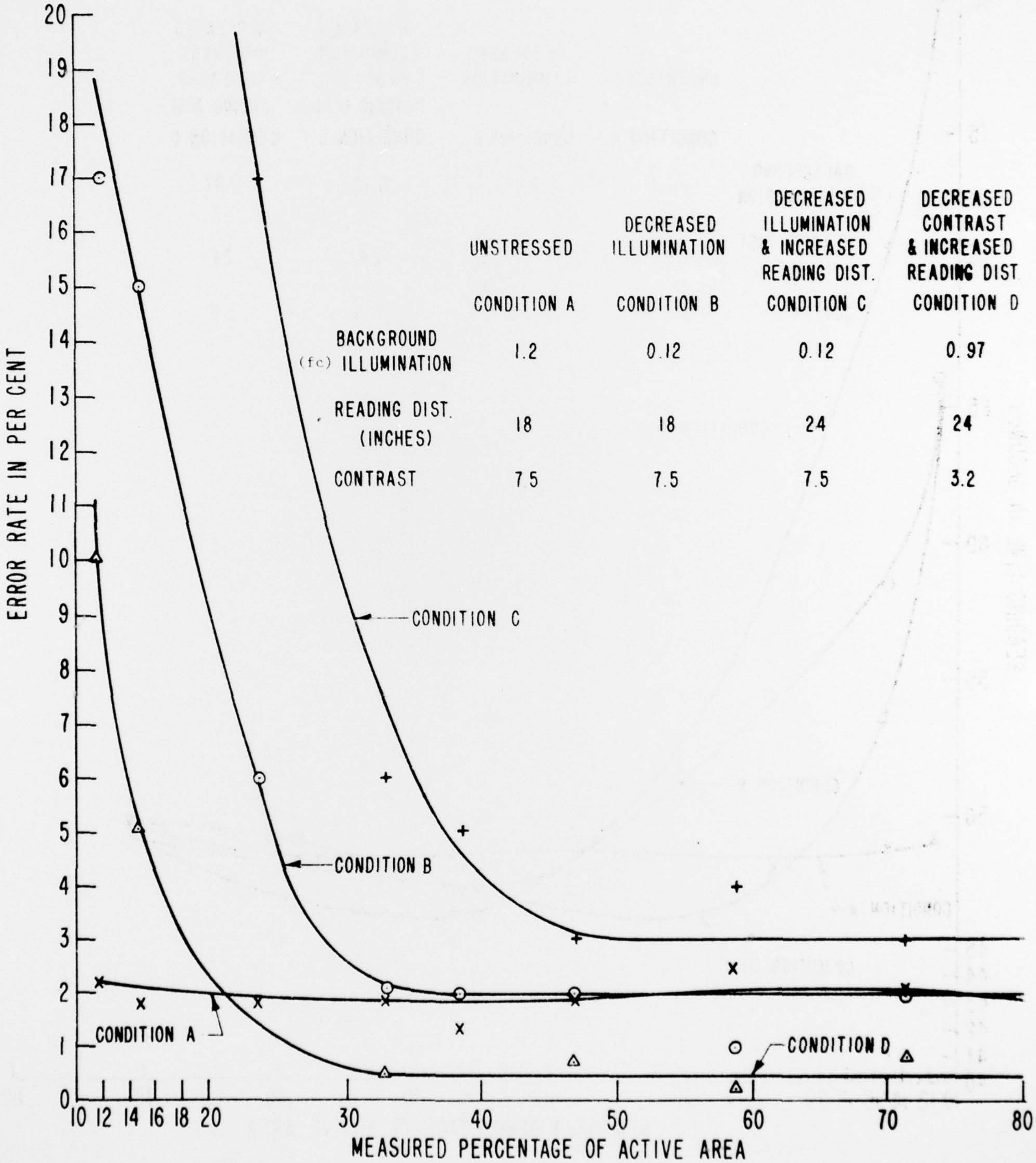
Figure 3. Alphanumeric Assembly in Light Tight Box

TABLE 2

r Rate and Reading Time for Conditions A, B, C, and D

		ITION A		CONDITION B		CONDITION C		CONDITION D	
Active Area Number	Measured % Active Area	Error Rat in %	Reading Time in Seconds	Error Rate in %	Reading Time in Seconds	Error Rate in %	Reading Time in Seconds	Error Rate in %	Reading Time in Sec
1	11.9	2.2	48.4	17	66.1	47	79.9	10.0	65.8
2	15.0	1.8	47.5	15	58.5	33	70.7	5.1	53.6
3	23.9	1.8	46.2	6	54.6	17	58.7	1.4	47.9
4	33.0	1.8	47.2	2	47.0	6	50.7	0.5	46.0
5	38.5	1.5	42.9	2	48.4	5	47.9	1.4	47.0
6	46.8	1.9	47.2	2	45.4	3	46.3	0.7	47.1
7	58.7	2.5	48.4	1	48.3	4	49.2	0.2	48.9
8	71.6	2.1	49.1	2	47.9	3	48.3	0.7	50.0

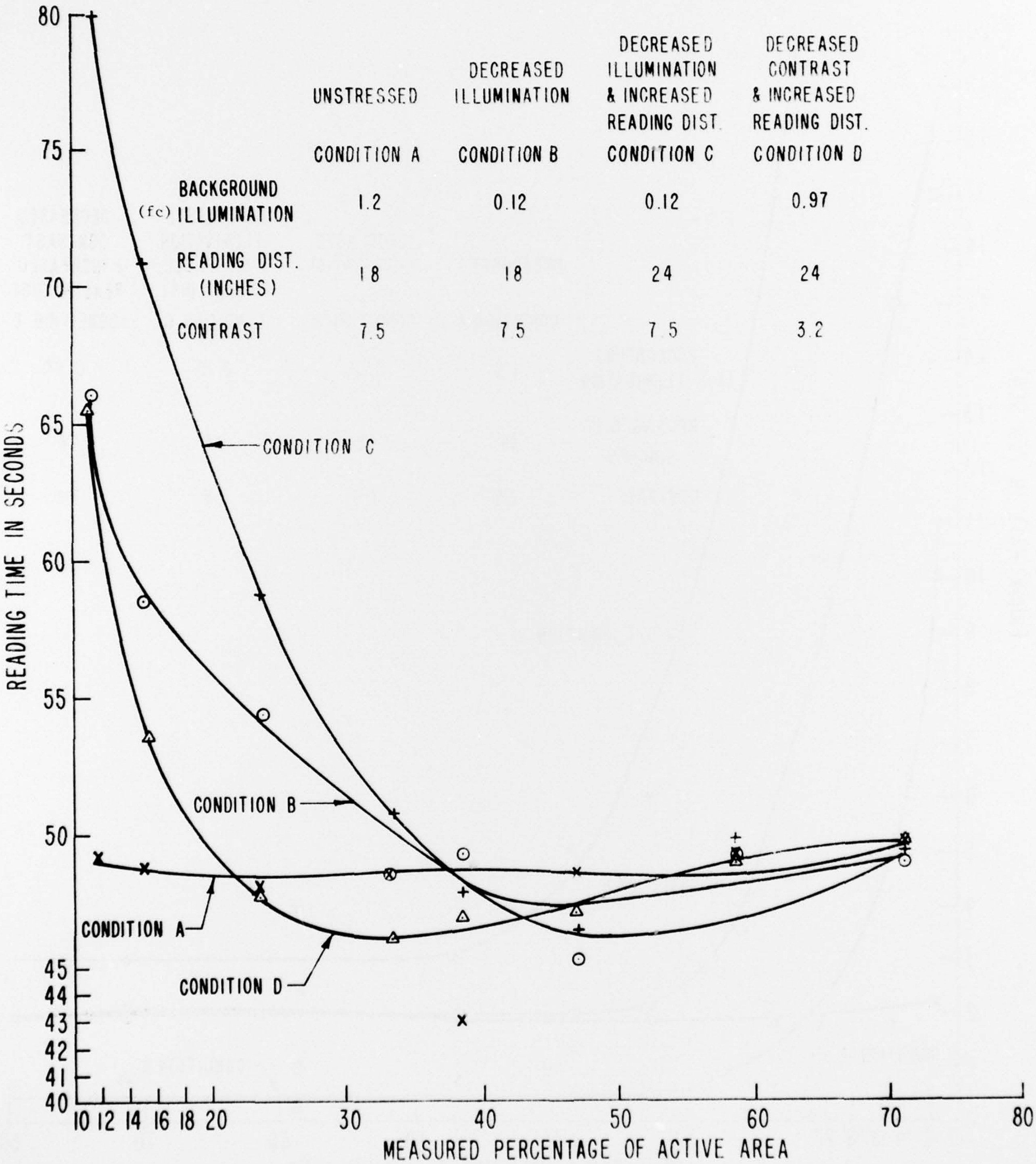
Unstressed ondition A	Condition B	Condition C	Condition D
Contrast 7. Reading Di ance - 18 inches Background llumination - 1.2 fc.	Decreased Illumination Contrast 7.5 Reading Distance - 18 inches Background Illumination - 0.12 fc.	Decreased Illumination and Increased Reading Distance Contrast 7.5 Reading Distance - 24 inches Background Illumination- 0.12 fc.	Reduced Contrast Contrast 3.2 Reading Distance - 24 inches Background Illumination - 0.97 fc.



	UNSTRESSED	DECREASED ILLUMINATION	DECREASED ILLUMINATION & INCREASED READING DIST.	DECREASED CONTRAST & INCREASED READING DIST
	CONDITION A	CONDITION B	CONDITION C	CONDITION D
BACKGROUND (fc) ILLUMINATION	1.2	0.12	0.12	0.97
READING DIST. (INCHES)	18	18	24	24
CONTRAST	7.5	7.5	7.5	3.2

READING ERROR RATE FOR 5 x 7 DOT MATRIX ALPHANUMERICS AS A FUNCTION OF ACTIVE AREA

FIGURE 4



READING TIME FOR 5 x 7 DOT MATRIX ALPHANUMERICS AS A FUNCTION OF ACTIVE AREA

FIGURE 5

DISCUSSION

A review of the results in this experimental study indicates that the error rate and reading time remained essentially unchanged for the unstressed conditions (comfortable reading distance and illumination) throughout the variation of percentage of active from 11.9 to 71.6 percent.

For stressed conditions such as decreased illumination, increased reading distance, and decreased contrast, the experimental results for the conditions used in this study indicate a threshold at the 30 percent active area level. Above this, dependence appears to be minimal. Below 30 percent active area, error rate and reading time increase rapidly. It is interesting to note that despite the reduction in contrast from 7.5 to 3.2, error rate and reading time for Condition D (conditions defined on page 5), indicates greater legibility than for Conditions B and C below the 30 percent active area. A greater background illumination was used in Condition D and this appears to have counteracted the effect of reduced contrast upon legibility. Only in Condition A, where the variables of reading distance, background illumination, and contrast are more favorable for legibility, is the legibility greater in the less than 30 percent active area range than for Condition D. These results have been achieved with a specific font (Lincoln/Mitre), under specific uniform test conditions, and with photographs rather than light emitting electronic display devices. Further experimental work is recommended in order to support the results of this study for application to display devices.

However, further support of these results may have important implications to the designer of display devices. A greater freedom in the choice of percentage of active area under unstressed and stressed conditions may give the designer another parameter for lower cost, high reliability display devices without reducing legibility.

CONCLUSIONS

The conclusions below are limited to the specifics used in this experimental study such as 5 x 7 dot matrix alphanumerics, the Lincoln/Mitre font, illuminated photographs as the display device, and the illumination and reading distance levels used. Within these bounds, the following conclusions may be made:

1. It seems clear that at unstressed viewing conditions, that is, conditions in which characters are basically recognizable, the trade-off of increased active area for other parameters does not pay, regardless of impressions by casual observation. Although 75 to 80 percent active area characters would seem to be more legible, in many cases 12 to 25 percent active area will suffice for legibility.

2. The results of this study point to background illumination as an important factor in determining legibility. Trade-offs betweeen contrast and background illumination should be carefully considered in display device design.

3. Further studies should be conducted on percentage of active area effects for other fonts and other types of display, and further study should be made of the dependence of legibility on contrast and illumination. No such studies are planned at present.

ACKNOWLEDGMENT

The suggestions of Dr. Elliott Schlam are gratefully acknowledged.

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2. D. A. Shurtleff, "Legibility Research," Proceedings of the S.I.D., Volume 15, Second Quarter, 1974.

3. G. C. Kinney and D. J. Showman, "Studies in Display Symbol Legibility; XI The Relative Legibility of Selected Alphanumerics in Two Fonts," Mitre Technical Report MTR 205, AF 19(628)5165, 7 April 1966.

4. T. N. Cornsweet, "Visual Perception," Academic Press, New York, 1970.

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