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W-07450

STUDIES OF DISPLAY SYMBOL LEGIBILITY

Part V. The Effects of Television Transmission on the Legibility of Common Five-Letter Words

MAY 1966

G. Kosmider

Prepared for

DEPUTY FOR ENGINEERING AND TECHNOLOGY
DECISION SCIENCES LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

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Project 7030
Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract AF19(628)-5165

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FOREWORD

This report is one of a series describing symbol legibility for television display. Additional information on this topic may be found in the following reports: "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963; "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Width of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," by B. Botha and D. Shurtleff, The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963; "Studies of Display Symbol Legibility, III: Line Scan Orientation Effects," by B. Botha, D. Shurtleff, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-138, May 1966; and "Studies of Display Symbol Legibility, IV: The Effects of Brightness, Letter Spacing, Symbol Background Relation and Surround Brightness on the Legibility of Capital Letters," by D. Shurtleff, B. Botha, and M. Young, The MITRE Corp., Bedford, Mass., ESD-TR-65-134, May 1966.

REVIEW AND APPROVAL

This Technical Report has been reviewed and is approved.

James D. Baker
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ABSTRACT

The legibility of common five-letter words was studied under four conditions: with solid-stroke letters, and with 10, 7, and 5 horizontal scan lines per character height on a television monitor. Twelve subjects were shown 100 words, one at a time, under controlled conditions. The subject's task was to recite each word as quickly and as accurately as possible. Analysis of the errors and reaction times showed that the legibility of the words significantly decreased as the number of lines decreased. Using the mean reaction time of the solid condition as a base, there is a 32-percent increase in mean reaction time for the 10-line television presentation, 40 percent using 7 lines and 89 percent using 5 lines.

TABLE OF CONTENTS

SECTION I

INTRODUCTION

The present study is a continuation of earlier evaluations of the symbol legibility effects on television displays. [1, 2, 3, 4] In the present investigation, the effects of different numbers of horizontal television scan lines per character height on the legibility of common five-letter words are studied.

Four conditions of display were used: words with solid-stroke letters were projected on a translucent screen, and words with 10, 7, and 5 lines per character height were presented on a television monitor. In all four display conditions, the contrast ratio was maintained at 10 to 1, and the visual angle of the letter height at the subject's eye was held constant at 16 minutes of arc.

SECTION II

PROCEDURE AND APPARATUS

SUBJECT SELECTION

Twelve subjects were tested with a modified Ortho-Rater and accepted if they had 20/20 acuity with no color deficiencies and no marked phoria. Subjects were allowed to wear eyeglasses if the lenses corrected their vision as required.

WORD SELECTION

One hundred common five-letter English words, which had a use frequency of 30 to 49 per 1,000,000 words, were selected from The Teacher's Word Book of 30,000 Words, by Thorndike and Lorge. The words, a sample of which is shown in Figure 1, were photographed with light letters on an opaque background on 35-mm film and projected precisely on a translucent screen. Voice-operated and push-button-operated relay circuits controlled the word presentation.

A 525-line closed-circuit television system was modified to operate with 2:1 interlace. The interlace ratio (the distance from one line to the other two adjacent lines in the interlaced field) was approximately 1:1, and the widths of the inactive lines or dark spaces were approximately equal to the widths of the active lines.

MEASUREMENTS OF BRIGHTNESS

Measurements of brightness were made with a Spectra Brightness Spot Meter. The figure brightness for solid-stroke projection was adjusted by regulating the line voltage to the projector lamp, and the background

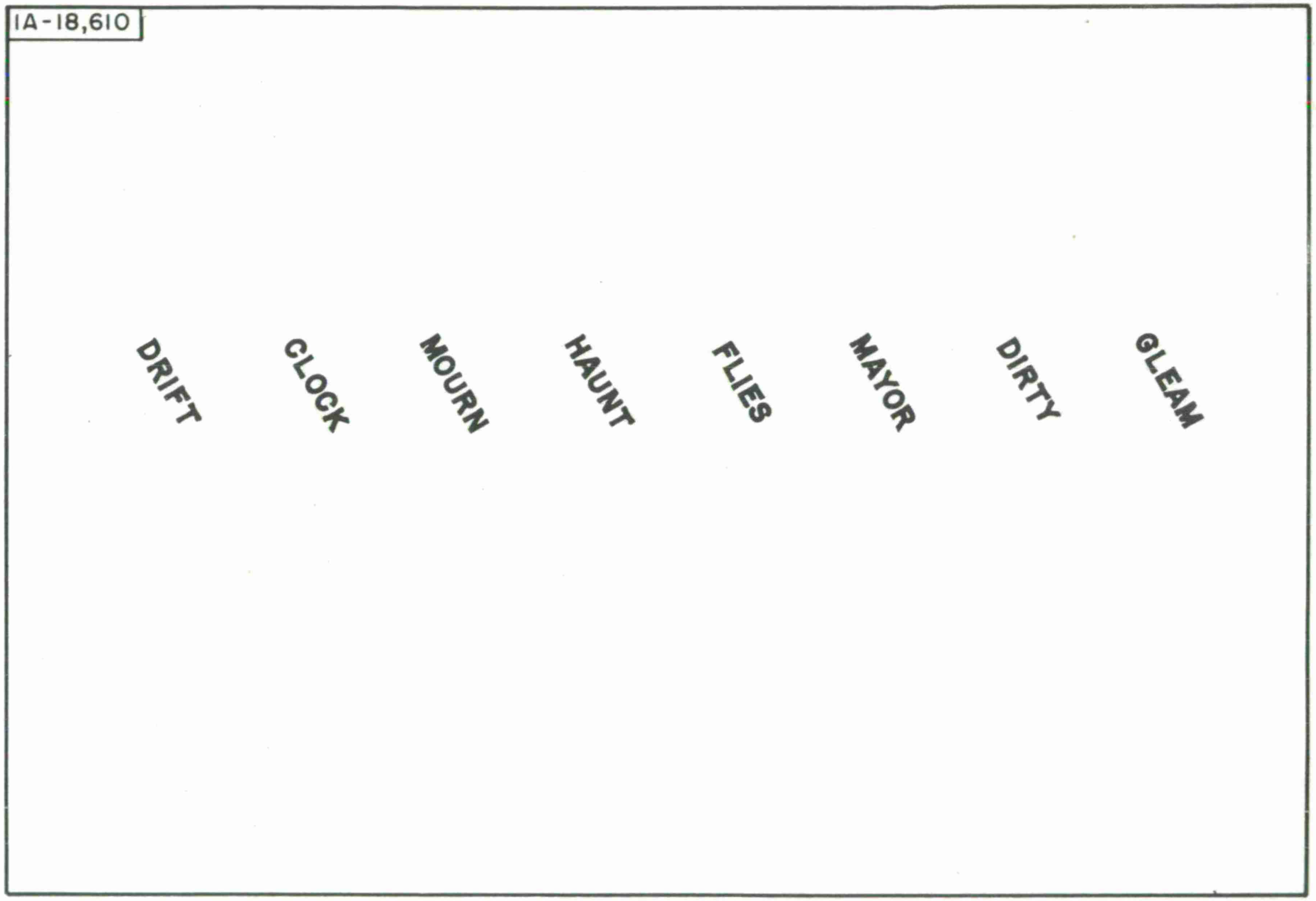

Figure 1. Example of the Section of Film Used in the Study

brightness was achieved by rheostat-controlled overhead lights. In the case of the television monitor, a brightness reading half that of the image on the projection screen was used as a best guess of image brightness on the monitor. Half as much apparent brightness was used on the monitor as on the projection screen because the image on the monitor consisted of alternate bright (active) lines and dark lines. The brightness spot meter read the total light over a specific area. Therefore, the active scan lines were approximately twice as bright as the meter indicated and of the same brightness as the projected letters. The background brightness of the projection screen on the monitor was regulated by adjusting the overhead lights.

WORD PRESENTATION

Each subject was shown the words in three conditions: solid stroke, and 10 and 7 lines. In addition, six subjects were shown the 5-line condition. Each experimental session consisted of 100 randomly determined word presentations under one condition of viewing. Both accuracy and reaction time for word identification were recorded.

The subject presented the word to himself by depressing a push-button which activated a relay circuit and started the clock and projection lamp which presented the word on the screen. The subject's vocal response activated a voice-operated relay circuit which shut the display off and automatically stopped the clock. The experimenter then recorded the reaction time on the subject's score sheet and advanced the film the number of frames required to position the next word for viewing.

The subject was seated at different distances from the screen or monitor for each viewing condition to satisfy the requirement for a constant visual arc. His task was to call out the word as quickly as possible, with equal emphasis on speed and accuracy in the identification of the words. A schematic diagram of the seating arrangements for each viewing condition is shown in Figure 2.

REACTION TIMES

The data showed the subjects' reaction times for the solid condition were very high (by an unknown amount) because the projection lamp reached its peak brightness gradually. In order to determine the mean increase in reaction time due to the method of operating the lamp, a separate study was performed in which seven subjects were presented words by two methods. In one method, the lamp was turned on and off as in the original study. In the second method, the lamp remained on, and the light source was controlled by a high-speed shutter. The mean reaction time was 0.05 seconds greater when the lamp was turned on and off than when the lamp was left on and the shutter was used. This correction was made on all data before analysis.

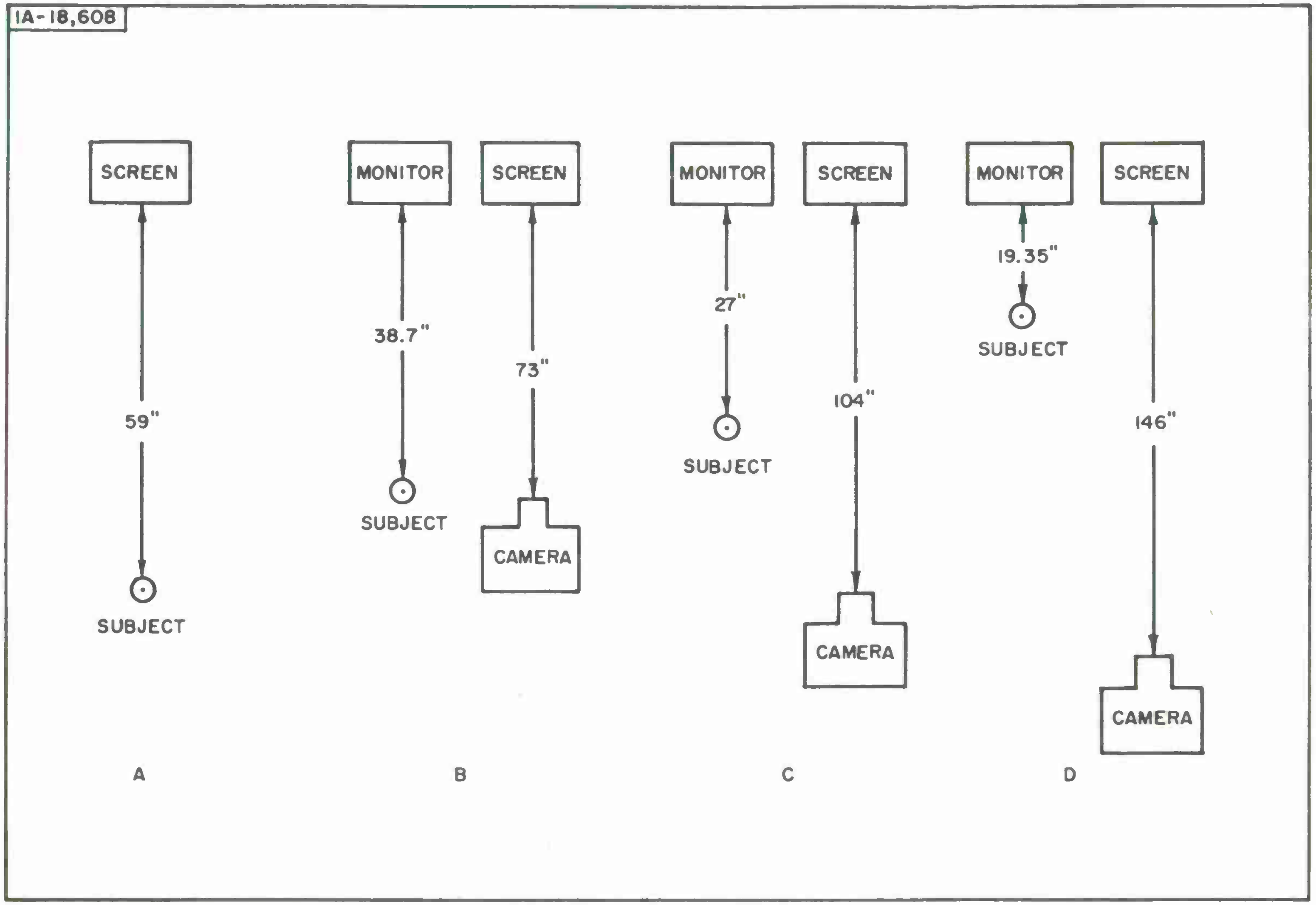

Figure 2. Distance of Subject to Image and Camera to Screen Under the Four Test Conditions (A is Solid Stroke, B is Ten Lines Per Character Height, C is Seven Lines, and D is Five Lines.)

SECTION III

RESULTS

COMPARISON OF DATA

The means of the four sets of data were then compared two at a time: 10 lines minus solid stroke, 7 lines minus 10 lines, and 5 lines minus 7 lines. These mean differences, shown in Table I in hundredths of a second, provided three sets of data for three correlated t tests. Positive entries in the table indicate that the condition of higher resolution, or the condition having more lines per character height of the two conditions being compared, had the faster mean reaction time. Negative entries indicate that, of the two conditions compared, the condition of poorer resolution or the fewest lines per character height had the faster mean reaction time. Blank entries indicate that the subject was not tested in the 5-line condition.

CRITICAL VALUES

The critical value of t with 11 degrees of freedom at the 0.01-confidence level is 3.11. Where t is calculated for the 10-line minus solid comparison, its value is 7.849. For the 7-line minus 10-line comparison, the value is 3.470. The critical value of t with 5 degrees of freedom at the 0.01-confidence level is 4.03. The calculated value of t for the 5-line minus 7-line comparison is 4.136.

In Figure 3 the resolution, or number of lines per character height, is plotted against the mean reaction time (for all subjects) for each condition. The curve is broken as a scaling convenience since it is not practical to equate the solid-stroke condition with a finite number of lines. Because of this break, there is no significance to the slope of the curve between the solid-stroke value and the 10-line value.

Table I

Mean Differences of Reaction Times

Subject	Differences (Comparisons/Character Height)		
	10 Lines Minus Solid	7 Line Minus 10 Line	5 Line Minus 7 Line
1	1.49	2.09	---
2	6.93	0.52	15.55
3	4.38	1.34	---
4	3.97	5.50	3.48
5	5.72	-0.95	---
6	2.31	3.21	12.96
7	5.99	2.02	26.03
8	7.78	7.10	---
9	4.36	1.09	---
10	2.88	4.29	23.18
11	6.80	-0.22	31.71
12	3.54	5.05	---
$\underline{t}$ test	7.849*	3.470*	4.136*

* Significant at the 0.01-confidence level

MEAN REACTION TIME

The curve shows an increase in mean reaction time from 0.346 seconds in the solid condition to 0.458 seconds in the 10-line condition,

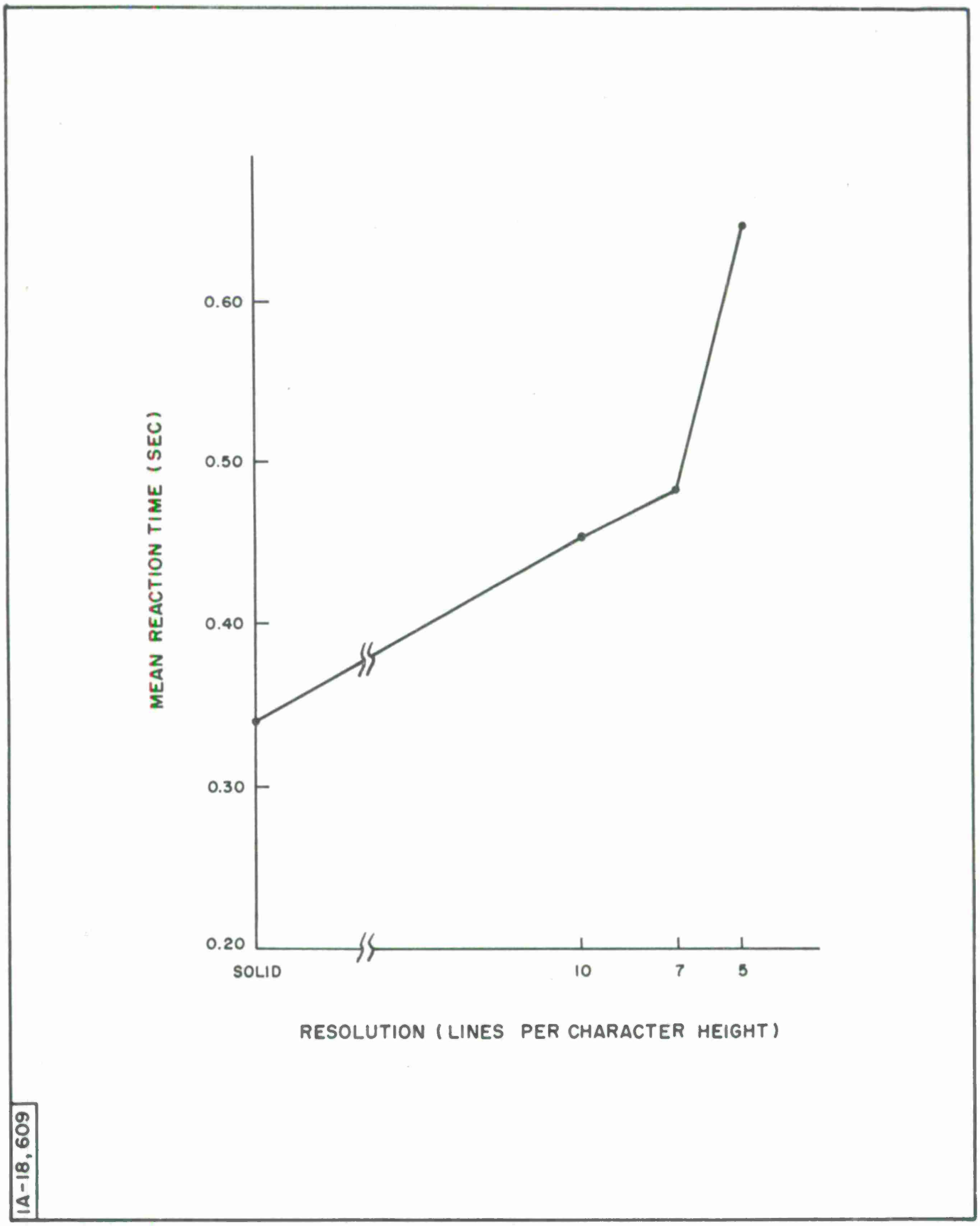

Figure 3. Mean Reaction Time Versus Resolution

a net increase of 0.112 seconds. The increase in mean reaction time from the 10-line condition to the 5-line condition is 0.195 seconds, or almost double the increase between the solid- and 10-line conditions. The increase in mean reaction time between the solid condition and 5 lines is 0.308 seconds, which is more than three times the increase between solid and 10 lines. Stated in yet another way, using the mean reaction time of the solid condition as a base, there is a 32-percent increase in mean reaction time for the 10-line television presentation, 40 percent using 7 lines, and 89 percent using 5 lines. These increases occurred even though the subtended visual angle, the brightness, and the contrast ratio remained constant in all conditions.

The number of errors for each condition is shown in Table II. It appears that, as the number of lines per character height decreased, the number of errors increased, and that the greatest increase in errors occurred between 7 and 5 lines per character height. However, there were too few errors to warrant a more detailed analysis. In all, there were only 31 errors in a total of 4,200 responses.

CONCLUSIONS

The legibility of common words with letters having solid strokes, when projected, is decreased when the words are televised with 10 active lines per symbol height. Legibility is further decreased for words televised with less than 10 lines per symbol height. Indications show that if more than 10 lines per character height were to be used, reading performance would be similar to that observed under the solid-stroke condition.

Table II

Subject Errors

Subject	Viewing Condition (Total Number of Errors/100 Responses)			
	Lines			
	Solid Stroke	10	7	5
1	0	0	0	---*
2	0	0	0	2
3	0	0	0	---
4	0	0	0	2
5	0	0	0	---
6	0	0	1	4
7	2	2	1	8
8	0	0	2	---
9	0	1	3	---
10	0	0	1	2
11	0	0	0	0
12	0	0	0	---

* Dashed lines indicate that the subject was not tested in that condition.

SECTION IV

RECOMMENDATIONS FOR FURTHER STUDY

The method used to compare the legibility of this particular television system with a solid-stroke display can easily be adapted to test the legibility of any television system, whether it be another 525-line system or a high-resolution system of 1,000 lines or more.

The results of this study suggest that it might be worthwhile to conduct similar comparative studies using different contrast, visual angles, interlace ratios, and types of stimuli such as Air Force chart symbols, military map symbols, and weather map symbols. It might also be worthwhile to conduct this same type of study on other 525-line closed-circuit television systems to determine whether or not any generalities can be made on the legibility within classes of equipment.

REFERENCES

1. B. Botha and D. Shurtleff, "Studies of Display Symbol Legibility: The Effects of Line Construction, Exposure Time, and Stroke Width," The MITRE Corp., Bedford, Mass., ESD-TR-63-249, February 1963.

2. B. Botha and D. Shurtleff, "Studies of Display Symbol Legibility, II: The Effects of the Ratio of Widths of Inactive to Active Elements Within a TV Scan Line and the Scan Pattern Used in Symbol Construction," The MITRE Corp., Bedford, Mass., ESD-TR-63-440, July 1963.

3. B. Botha, D. Shurtleff, and M. Young, "Studies of Display Symbol Legibility, III: Line Scan Orientation," The MITRE Corp., Bedford, Mass., ESD-TR-65-138, May 1966.

4. B. Botha, D. Shurtleff, and M. Young, "Studies of Display Symbol Legibility, IV: The Effects of Brightness, Letter Spacing, Symbol Background and Surround Brightness on the Legibility of Capital Letters," The MITRE Corp., Bedford, Mass., ESD-TR-65-134, May 1966.

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