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STUDIES IN DISPLAY SYMBOL LEGIBILITY

PART VIII: Legibility of Common Five-Letter Words

MAY 1966

G. Kosmider
M. Young
G. Kinney

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

Project 7030
Prepared by
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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 Corporation, Bedford, Massachusetts, 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 Corporation, Bedford, Massachusetts, 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 Corporation, Bedford, Massachusetts, ESD-TR-65-138, May 1966; "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 Corporation, Bedford, Massachusetts, ESD-TR-65-134, May 1966; "Studies of Display Symbol Legibility, V: The Effects of Television Transmission on Legibility of the Common Five-Letter Words," by G. Kosmider, The MITRE Corporation, Bedford, Massachusetts, ESD-TR-65-135, May 1966; "Studies of Display Symbol Legibility, VI: Leroy and Courtney Symbols," by D. Shurtleff and D. Owen, The MITRE Corporation, Bedford, Massachusetts, ESD-TR-65-136, May 1966; and "Studies of Display Symbol Legibility, VII: Comparison of Displays at 945- and 525-Line Resolutions," by D. Shurtleff and D. Owen, The MITRE Corporation, Bedford, Massachusetts, ESD-TR-65-137, May 1966.

ABSTRACT

This report describes the findings of a study in symbol legibility which investigated the reading time and errors for common five-letter words when they are projected by a solid stroke and when they are shown by a broken stroke. The latter was produced on a 945-line TV monitor at 10, 7, and 5 active lines per symbol height. This study is similar to an earlier report on the readability of common five-letter words in which a 525-line TV system was employed. With visual size, brightness, contrast, and other viewing conditions controlled, the best reading performance resulted from solid-stroke letters. Broken-stroke letters constructed by resolution of 10, 7, and 5 lines resulted in progressively poorer performances.

REVIEW AND APPROVAL

This Technical Report has been reviewed and is approved.

JAMES D. BAKER
703 Project Officer
Decision Sciences Laboratory

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Colonel, USAF
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SECTION I

INTRODUCTION

RESOLUTION AND LINE STRUCTURE

In the use of television for the display of numerals and upper case letters, one of the factors influencing the display's legibility is the number of horizontal TV lines used to resolve the letter strokes. For instance, previous studies have shown that for symbols viewed one at a time, reading performance becomes rapidly poorer as the number of active lines per symbol height drops below 10.[1, 2, 3, 4, 5] An earlier study found that the same held true for common five-letter words.[6] The results for single symbols were found when the TV line structure was simulated on photographic film, and when the symbols appeared on either a low-cost, closed-circuit TV monitor (a 525-line system) or on a higher quality, more expensive monitor (a 945-line system).[7] The same result holds for more than one letter font.[5] It appears that a vertical resolution of approximately 10 lines per symbol height is the lowest limit in TV displays, if large losses in legibility are to be avoided.

LETTER AND WORD DISPLAYS

Yet, there are reasons for believing that the better TV system may allow a lower resolution for word display than was found with the poorer TV system, even though both systems give the same result for the display of single symbols. One reason is that the redundancy among letters in familiar words may make the words equally readable even though each letter, when seen alone, is less readable. Since there are some features of the better TV system which might reasonably be expected to produce a slight

improvement in letter legibility,[7] it is possible that the benefits of such small improvement would appear when words are read, but not when letters are seen one at a time.

READING TIMES AND ERRORS FOR WORDS

Accordingly, the earlier study with five-letter words was repeated using the better TV system and a smaller group of subjects. The reading time and errors for common five-letter words were studied under four experimental conditions. First, the words were optically back-projected from 35-mm film, which gave the letters in unbroken, white strokes against a darker background. The legibility of the words is very good for the brightness contrast, and visual size chosen for the study. This first condition is a reasonable basis for determining the relative legibilities of the words under the other three conditions, which are the presentation of the words on the TV monitor with 10, 7, and 5 lines per symbol height. In this way, the minimum resolution of upper case letters for the TV display of either redundant or non-redundant materials can be examined under one more set of conditions that is likely to be encountered in systems applications.

SECTION II

APPARATUS AND PROCEDURE

DETAILS OF APPARATUS AND EXPERIMENTAL SETTING

The details of the apparatus and the experimental setting are given in the report of the earlier study.[6] Briefly, a 945-line closed-circuit TV system was arranged to pick up the words to be read and to show them on a TV monitor. The subject could be seated so that he could view the words directly on the screen or on the monitor. In either case, the subject fixed his eyes on the place where the word would appear, and depressed a switch causing the word to appear and at the same time starting an electric timer. When the subject spoke the word aloud, a microphone circuit stopped the timer and turned off the word display. All of the five subjects were instructed to respond as quickly and accurately as possible.

MEASUREMENT CRITERIA

Each subject was shown 100 words in a scrambled order under each of the four experimental conditions. The sequence in which the conditions were given was chosen randomly for each subject. In some cases, an equipment malfunction or an error of procedure resulted in loss of the data for a word or two; but in all cases, the subjects average reaction time was based on the number of words successfully shown. The different methods of word presentation were associated with different time lags in the equipment. These lags were separately measured, and the measured reaction times appropriately corrected before analysis.

BRIGHTNESS LEVELS

The brightness of the letter strokes on the screen for the first condition was approximately 20 foot-lamberts, and the screen background brightness was 2 foot-lambert. The brightness of the TV line on the monitor of the letter stroke was approximately 18 to 20 foot-lamberts, and the background brightness of the TV monitor screen was 2 foot-lamberts. For all conditions, the letter height subtended an arc of 16 minutes at the subject's eyes.

SECTION III

RESULTS

REACTION TIME DIFFERENCES

A subject's corrected reaction time for the first condition (solid-stroke letters) was subtracted from his reaction time for the 10-line condition. The average difference for each subject is shown in the first column of Table I. Similarly, the average difference for "7 lines minus 10 lines" and "5 lines minus 7 lines" are in columns two and three of Table I. This table also shows the average difference for all subjects for the three comparisons between conditions. The hypothesis that this average difference is zero was tested in each case with the "t" test. The difference between the solid-stroke and the 10-line conditon is statistically significant at the 0.05 level of confidence but the other two differences are not.

Table I

Mean Differences in Reaction Time

Subject	Conditions Compared: 10 Lines Minus Solid-Stroke	7 Lines Minus 10 Lines	5 Lines Minus 7 Lines
1	-0.014	0.029	0.087
2	0.004	0.207	0.209
3	0.298	-0.141	0.025
4	-0.011	0.037	-0.003
5	0.211	0.201	-0.034
Mean	0.098	0.031	0.057
t*	3.161	2.214	2.192

*The "t" values at the 0.05 level of confidence for the two-tailed and one-tailed tests are 2.78 and 2.13, respectively.

The hypothesis that the average difference between conditions compared successively (as in Table I) is equal to or greater than zero (the "one-tailed t test," discussed below) was tested by the same test. All three mean differences are statistically significant at the 0.05 level of confidence.

TOTAL ERRORS

The total errors for each subject in each condition are shown in Table II. No statistical analysis of the errors was made; the table is shown for purposes of inspection and discussion.

Table II

Total Errors

Subject	Solid-Stroke	10 Lines	7 Lines	5 Lines
1	0	0	0	1
2	0	0	2	6
3	0	2	2	3
4	0	0	1	3
5	0	3	5	3
Sum	0	5	10	16

SECTION IV

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Printed matter, composed of numerals and capital letters of a block style font, becomes noticeably harder to read or recognize when the character strokes are 10 pairs or less of alternate light and dark bands. These results appear to confirm earlier findings concerning readability. When a curve is plotted of the reading times and of the number of errors, or both, against the number of lines per symbol height, a value of 10 active TV lines per symbol height has consistently appeared to be at or near to the break in the curve. The interpretation of the results of this experiment follows rather clearly in view of two main considerations.

First, the results agree in direction with earlier results of greater statistical reliability. That the data in this experiment did not provide averages which are statistically significant in two of the three cases is probably attributable to the small number of subjects.

Second, the earlier results may be taken as evidence that the hypothesis to be tested statistically is that reductions in symbol resolution will not increase the reading time (that is, will either not change it or will decrease it). In other words, a "one-tailed t" test seems appropriate in view of previous results. Instead of testing the usual null hypothesis, which allows for differences between means in either direction, it seems unrisky to test a hypothesis that does not account for improvements in legibility as resolution decreases. The results, as mentioned earlier, yielded a statistically significant value of "t" for all three mean differences in subject reaction time.

The errors shown in Table II add more evidence that the subjects' reading performance grew steadily worse as resolution decreased. Therefore, it is concluded that the relationship between reading performance and TV line resolution of upper case letters used in this study is as shown in Table II, and that relationship holds for both single symbols and common five-letter words of the same visual size. It is apparent, in view of all findings to date, that this conclusion holds for TV systems of both low and high quality.

It is recommended that television displays of alphanumeric symbology devote at least 10 active lines per symbol height if marked losses in the legibility of the displayed materials are to be avoided in either short-term or more prolonged reading tasks.

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.

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6. G. Kosmider, "Studies of Display Symbol Legibility, V: The Effects of Television Transmission on the Legibility of Common Five-Letter Words," The MITRE Corp., Bedford, Mass., ESD-TR-65-135, May 1966.

7. D. Shurtleff and D. Owen, "Studies of Display Symbol Legibility, VII: Comparison of Displays at 945- and 525-Line Resolutions," The MITRE Corp., Bedford, Mass., ESD-TR-65-137, May 1966.

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This report describes the findings of a study in symbol legibility which investigated the reading time and errors for common five-letter words when they are projected by a solid stroke and when they are shown by a broken stroke. The latter was produced on a 945-line TV monitor at 10, 7, and 5 active lines per symbol height. This study is similar to an earlier report on the readability of five-letter common words in which a 525-line TV system was employed. With visual size, brightness, contrast, and other viewing conditions controlled, the best reading performance resulted from solid-stroke letters. Broken-stroke letters constructed by resolution of 10, 7, and 5 lines resulted in progressively poorer performances.

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