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The Effects of Line Construction, Exposure Time, and Stroke Width

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July 1963

B. Botha D. Shurtleff

Prepared for

OPERATIONAL APPLICATIONS LABORATORY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

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THE MITRE CORPORATION
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ABSTRACT

The purpose of this study was to determine the effects on the legibility of capital alphabetic letters of: (a) two simulated TV rasters with horizontal, linear scan constructions of 11 and 5 lines per letter height and a solid (continuous) construction of infinite lines per letter height, (b) two visual exposure times of 0.03 and 0.003 second, and (c) two letter stroke-widths of 16% and 28% of letter height. Four subjects identified the letters presented singly in a tachistoscope under all combinations of these conditions. Legibility was measured three ways: by information transmitted (in bits), by errors in identification, and by verbal reaction time. The results showed that for the 0.03-second exposure time, the letters constructed with 11 lines were as legible as solid (continuous stroke) letters, but the line construction was less legible at 0.003-second exposure. At both exposure times, the 5-line construction was less legible than the solid construction. With 5-line construction and 0.003-second exposure, the wide stroke-width gave better legibility than the narrow width. Confusion between specific letters varied for both line constructions and stroke-widths. The possible effects on legibility of changes in brightness, contrast and letter geometry introduced by the experimental conditions are discussed. It was concluded that the legibility of letters generated by a horizontal linear scan construction is highly dependent upon apparently minor differences in letter geometry.

INTRODUCTION

The current proliferation of display systems in government and industry has renewed and intensified interest in the legibility of alphanumeric symbols. Part of the research activity engendered by this interest has centered on an organization and extension of knowledge of the effects on legibility of such classical variables as stroke-width, brightness, contrast, etc. The remaining research activity has as its goal the determination of the effects on legibility of factors introduced by electrical and/or mechanical devices in modern display systems; these would be blur, noise, vibration, repetition rate, etc. These two kinds of research activities are not completely distinct because the two types of variables are often studied simultaneously in order to determine interaction effects (3, 6).

The study to be reported in this paper also investigated the individual and combined effects on legibility of both types of variables. The electronics variables were those introduced by a horizontal, linear scan (television raster) method of constructing display symbols. Because of its versatility, ease of signal transmission, and reliability of image reproduction, television (TV) would be in many cases a desirable display mechanism. Part of the evaluation of the usefulness of TV in display systems must be based upon a detailed knowledge of the ways in which symbol legibility is affected by variables introduced by this medium. Previous studies of TV have indicated the effect on word legibility of viewing angles, size of symbols, and viewing distances (7, 9, 10). However, these studies have neglected to determine how the legibility of individual symbols that are constructed by horizontal, linear scan methods compares with those generated by more conventional display methods, such as the solid (continuous) symbols displayed on a shaped beam or slewed beam cathode ray tube. Also, there was no indication in the literature of how legibility was affected by changes in the number of linear scans per symbol height. Both of these factors were investigated in this study. While the number of linear scans per symbol height might be of limited importance for the commercial use of TV, it is directly relevant to the use of TV rasters in display systems where good legibility of small alphanumeric symbols is mandatory. In display systems the emphasis is on the legibility of abstract symbols (the recognition of individual symbols) while, in contrast, the major emphasis in most commercial uses of TV is on the legibility of words and text where both serve as cues in the recognition of individual letters. An illegible lower case letter may be accurately guessed on the basis of the words in which it appears, and the identity of a word may be guessed on the basis of the context in which it appears. Legibility of individual letters in display systems, however, must be achieved without the added benefit of contextual cues. This more stringent requirement for high symbol fidelity might present a particularly difficult problem for linear scan construction methods because there is some evidence that deletion of even small parts of symbols affects their legibility (2).

The classical variables investigated in this study were symbol exposure time, and letter stroke-width. Exposure time was included because it yields an estimate of the minimum time required for an observer to make accurate identifications of individual symbols; a process that is a major determiner of the time required by an observer to detect relevant material shown on display consoles.

A standard style of highly legible letters similar to those already in use in display systems was selected to provide a test of the effects on legibility of TV raster methods of symbol construction. Two different alphabets of the same style were used. Letters of the two alphabets differed only in width and stroke-width. It seemed reasonable to predict that the effect of a horizontal, linear scan construction method, as well as variations in the number of linear scans per symbol height, would depend particularly on variations in the stroke-width of the letters since increased stroke-width results in an increase in the horizontal components of the letters. Variations in the width of the letters themselves, on the other hand, might be expected to be more important in maintaining symbol legibility if a vertical, linear scan method is used to construct symbols.

PROCEDURE

Four MITRE employees were shown white, capital letters presented singly on a dull black background in a standard tachistoscope for durations of .03 and .003 seconds. The horizontal, linear scan constructions were simulated by overlaying letters with photographic negatives of 11 lines (fine-grid) or 5 lines (coarse-grid) per symbol height. Each grid consisted of transparent strips which were alternated with opaque strips. The solid letter construction (no-grid) involved direct viewing of letters without obstruction by a photographic negative. The no-grid letters simulated continuous stroke symbols of conventional cathode ray tube displays. The letters of one alphabet (Alphabet A) had a narrower width and stroke-width than did letters of a second alphabet (Alphabet B). The exposure time, grid, and stroke-width variations were incorporated in a factorial design (3x2x2). Each S made letter identifications under all twelve conditions. S was instructed to identify each letter as fast and as accurately as possible. Three measures of the S's response were used to assess letter legibility. These were transmitted information (bits), errors of identification, and verbal reaction times. Specific confusions between letters were determined also.

RESULTS

The results showed that legibility, when measured by number of bits transmitted and errors in letter identifications, was not impaired by the fine-grid provided that exposure time was .03 seconds. Reaction time, however, was significantly slower for the fine-grid than for the no-grid.

A reduction in exposure time to .003 seconds was associated with a marked decrease in legibility, as assessed by all response measures, for the fine-grid. Legibility, as assessed by all response measures, was reduced by the coarse-grid. Exposure time as short as .003 seconds can be tolerated without loss of legibility for the no-grid. However, legibility at this short exposure was impaired for both the fine-grid and coarse-grid. The thicker stroke-width of letters of Alphabet B was only partially effective in ameliorating the adverse effects caused by the short exposure time and fine-grid and coarse-grid. The coarse-grid not only produced a greater number of letter confusions than either the fine-grid or the no-grid, but also changed the letter pairs confused most often with each other. The greatest source of letter confusion was the "O" with the "Q", and the next biggest source was the "Q" with the "O", and these confusions occurred for all experimental conditions.

RECOMMENDATIONS AND CONCLUSIONS

If a TV raster is used to display symbols a horizontal linear scan construction of at least 11 lines per symbol height is recommended. A horizontal, linear construction of 5 lines per symbol height is not suitable for use because it impairs letter recognition, reduces bits transmitted, and increases verbal reaction time. It may be that exposure times of longer duration than those used in this study might compensate for the adverse effects of this letter construction on legibility. However, even if this were the case, this 5-line construction might greatly increase the time needed by an observer to determine the content of a given display

The effects on legibility of a TV raster can be counteracted to some degree by increasing letter stroke-width. While the maximum stroke-width of 26% of letter height used in the present study was not completely effective in ameliorating the effects of the linear scan constructions, particularly under the short exposure time, it may be that further increase in letter stroke-width would have a more pronounced effect.

The finding that the kinds of letter confusions are changed by variations in the number of lines per symbol height presents a formidable problem for use of TV rasters in display systems. The lack of consistency in letter confusions introduced by different numbers of lines per symbol height indicates that minor changes in the geometry of the letters for general use with TV rasters would not be effective. It appears that the elimination of major letter confusions must be undertaken for each number of lines per symbol height. This finding is tentative until supported by further investigation.

B. Botha

B. Botha

D. Shurtleff

D. Shurtleff

BB:DS/jmp

APPENDIX A

DETAILS OF THE EXPERIMENT

APPARATUS

The subjects (Ss) ranged in age from 22-26 years. Each S had normal acuity and no astigmatism.

A standard tachistoscope with a 31" focal distance was used to present the stimuli to S. (See Fig. 1) The height and width dimension of the tachistoscope were 6.6" and 4.1" respectively. The tachistoscope was mounted on legs 14" high. Two ends of the tachistoscope were fitted with hinged doors that could be pulled down for access to 3"x5" card holders located on the inside of each door. One of the card holders was used to contain the pre-exposure field which consisted of a card painted flat gray with a small, black fixation spot of .25" in diameter located at its center. The brightness of the card was .20 ft. Lamberts. The other card holder held the stimulus material which was illuminated during exposure by a Sylvania, standard, cool white, 4-watt fluorescent tube. The tube was mounted in the top of the tachistoscope 2" from the stimulus material. A pulsing circuit* controlled the on-time of the fluorescent tube, and permitted variations in exposure duration from .120 to .0009 sec. (Fig. 2).

The front end of the tachistoscope was the S's station. A contoured head rest fitted the upper part of S's face and held it in viewing position. A microphone was mounted directly below the head rest approximately 1/2" from S's mouth. A single key operated by the Experimenter (E) activated the pulsing circuit and the voice key circuit simultaneously. Activation of the voice key circuit started a Standard Electric Timer (calibrated in .01 sec.) which was stopped by S's verbal response. Thus, reaction time could be recorded to the nearest .01 sec.

The symbols were white, capital letters made by the Letraset Company, called Instant Lettering (Fig. 3). The style of these letters, encoded B27 and B28, was of standard design similar to Airport Gothic and Futura Medium. The symbols of one alphabet (Alphabet A) had a stroke width 16% of height, and an average symbol width of 77% of height. Symbols in Alphabet B had a stroke width 28% of height, and their average width was 86% of height. Both alphabets were of the same style and height (.116").

*The pulsing circuit was designed by Jonathan Mitchell, Staff member, The MITRE Corporation, Bedford, Mass.

Each letter appeared on a 3" x 5" card which was painted flat black. The letter was indexed on the card so that it appeared within the area circumscribed by the fixation circle on the pre-exposure card when the stimulus card was placed in viewing position.

The brightness* of the symbol was 28 ft. Lamberts, while the brightness of the flat black background was 1.5 ft. Lamberts. The contrast ratio was .96 as determined by the formula:**

$$C \text{ (contrast)} = \frac{B_1 \text{ (Brighter)} - B_2 \text{ (Dimmer)}}{B_1}$$

A TV raster was simulated by constructing a grid which consisted of alternate light and dark horizontal lines of equal width. The grid was reduced photographically to two negatives containing 11 and 5 horizontal transparencies per symbol. (100 transparencies and 40 transparencies per inch, respectively.) The eleven-line film (fine-grid) was made up of alternate transparencies of .005" in width separated by opaque strips of the same width. The five-line film (coarse-grid) was made up of transparencies of .010" in width separated by opaque strips of .016". (Small inequalities introduced by photo technique were the primary causes of differences in widths.) The fine-grid deleted 56% of the letter, while the coarse-grid deleted 60% of the letter.

A metal film holder was located in the test end of the tachistoscope to hold the photographic negative flush against the stimulus card so that the grid transparencies overlaid the letters. The first line of the transparency was indexed to reveal the bottom most part of each letter.

PROCEDURE

The main variables in this study were: (a) two horizontal linear scans (fine-grid and coarse-grid) and no-grid (unobstructed viewing), (b) two letter stroke widths (Alphabet A - 16% of height, Alphabet B - 28% of height); and (c) two exposure times (.03 and .003 seconds). These variables yield a factorial design (3x2x2) with a total of twelve experimental conditions. Each S made letter identifications under all twelve experimental conditions. The order in which conditions were presented to S was determined randomly.

*Brightness was determined by a Spectra Brightness Spot Meter, manufactured by the Photo Research Corporation, Hollywood, California.

**This brightness formula was proposed by R. T. Mitchell of Lincoln Laboratory.

A total of 130 identifications were made by each S in each condition. (Five replications of each letter of each alphabet.) The experimental conditions were repeated a second time so that a separate analysis of S's performance with or without extensive practice was possible. Therefore, each S completed each experimental condition twice. The second set of twelve conditions were presented in the reverse order. If a large amount of practice was needed for stable performance on this task, the analysis of the results could be confined to the second replication of the experimental conditions where learning would be expected to be at an asymptotic level. The use of a small number of Ss in this study made it impossible to control for practice effects through conventional techniques. Such techniques allow for the counterbalancing of experimental conditions so that practice effects, if present, have an equal influence on performance under each experimental condition.

The S's task was to call out the name of the letter as quickly as possible after it appeared at the center of the fixation spot of the pre-exposure field. The instructions gave equal emphasis to speed and accuracy in the identification of letters. At the beginning of the first experimental session, S was handed the 52 stimulus cards, and was told to study each letter and to observe any distinguishing features. S practiced using the voice key by repeating the names of each of the 26 letters ten times. He was instructed always to speak in a firm, clear voice of normal loudness.

S was told that the letters would appear one at a time in the center of the fixation circle. When S was properly focussed on the circle and not blinking, he was instructed to depress a ready button to indicate his readiness to E. E then depressed a switch which started the standard timer, activated the voice key circuit, and turned the light on the test card simultaneously.

There was a delay of approximately ten seconds between successive trials during which time E recorded the response and changed cards.

RESULTS*

Information Transmitted

Data matrices were constructed for each S for each of the twelve experimental conditions. The rows of the matrix were made up of S's correct or incorrect identifications of the 26 letters of Alphabet A or B and the columns consisted of the 26 letters of the alphabet. A measure of transmitted information (in bits) was obtained for each of the forty-eight matrices.

*All results are based upon data from both replications of the conditions since practice effects were negligible.

In the formula:

$$H\ (s) + H\ (r) - H\ (s,r) = T\ (s,r)$$

H (s) equals stimulus information; H (r) equals response information; H (s,r) equals stimulus and response equivocation; and T (s,r) equals transmitted information (bits). T (s,r) is a measure of the correspondence between the stimulus set (letters) and the response set (identification of letters) (5).

The median values of transmitted information obtained for the twelve different experimental conditions are shown in Fig. 4. As Fig. 4 indicates, exposure time affected the number of bits transmitted only for the fine-grid and coarse-grid (Fig. 4b and 4c): A greater reduction in bits transmitted occurred for the short exposure time than for the long exposure time.

A greater reduction in bits transmitted was noted for the coarse-grid than for the fine-grid. The medians of bits transmitted were: 4.62 for no-grid, 4.21 for fine-grid, and 4.02 for coarse-grid. Alphabet B was effective in increasing bits transmitted for the .003 exposure time for the fine-grid and for both exposure times for the coarse-grid.

An analysis of variance of bits transmitted yielded results which are shown in Table I. The only significant main effects, other than that for Ss, was for grid variations. A test* for comparison among means revealed that significantly fewer bits were transmitted for the coarse-grid than for the no-grid. However, there were no significant differences between bits transmitted for the no-grid vs. fine-grid, or for the fine-grid vs. the coarse-grid.

The interaction between exposure times and grid variations, as indicated in Fig. 4b or 4c, was significant. The short exposure time when combined with grid variations produced significantly fewer bits transmitted. The short exposure time had no effect on bits transmitted for the no-grid. The interaction noted between alphabets and exposure times failed to reach significance.

*All tests of this nature were based upon Duncan's procedure for performing multiple t tests after the analysis of variance. (4).

Error Scores

The percentage of error (based upon the incorrect letter identifications made by all Ss) for each of the twelve experimental conditions have been plotted in Fig. 5. Error percentages are inversely related to bits transmitted. When errors increase there is a decrease in bits transmitted, and conversely when error percentages decrease there is an increase in bits transmitted (Figs. 4 and 5).

The error scores were transformed logarithmically and submitted to and analysis of variance (Table II). Significant main effects, other than that for S's, included exposure time as well as grid variations. Duncan's test indicated that errors were significantly less for the no-grid than for either of the other two grid variations, and that errors were significantly less for the fine-grid than for the coarse-grid.

Significant interactions occurred between exposure time and grid variations as well as between alphabets and grid variations. The short exposure time increased the error level for the fine-grid and coarse-grid, but not for the no-grid. Fewer errors occurred in identifications of Alphabet B letters (wide width, wide stroke) than of Alphabet A for the fine-grid and coarse-grid but not for the no-grid.

Reaction Time (RT)

Voice reaction times have been plotted in Fig. 6. Each point represents the median RT for the four Ss. RT was positively correlated with percentage of errors, and negatively correlated with bits transmitted.

The results of the analysis of variance of these data are shown in Table III. All main effects, including that for alphabets, were a significant source of variance. RT for no-grid was significantly lower than RT for the fine-grid and the coarse-grid. RT for the fine-grid and coarse-grid did not differ significantly from each other. The interaction noted in Fig. 6 between alphabets and exposure times was significant, as was that between grid variations and exposure times. The first interaction indicates that for each grid variation, RT for the short exposure time was faster to the letters of Alphabet B than to Alphabet A; while for the long exposure time, RT was similar for both alphabets. The significant interaction between exposure times and grid variations indicated that RT was slower for the short exposure time than for the long exposure time for fine-grid and coarse-grid but RT was the same for each exposure time under the no-grid.

Confusion Matrices

Specific letter confusions for each of the four main effects have been summarized in Tables IVa, IVb, Va, Vb, VIa, VIb, VIc, VIIa, VIIb, VIIc VIId, and VIII. Only consistent errors (those letter confusions which contributed one percent or more to the total number of error) are included in order to highlight the major source of error.

Table IVa, IVb shows the letter confusions obtained for each of the two alphabets when responses were pooled over the other experimental conditions. More consistent errors occurred in the identifications of Alphabet A than of Alphabet B. Confusion of the "O" with the "Q" was common to both alphabets and also, was the biggest single source of error.

Table Va, Vb presents the confusions obtained when exposure time was varied. Ten times as many consistent errors occurred with the short exposure time than with the long exposure time. The "O" was confused with the "Q" for both exposure times and was again the greatest single source of error.

Table VIa, VIb, VIc indicates the letter confusions for the grid variations. There were more specific confusions between the letters for the fine-grid and coarse-grid than for the no-grid. However, the "O" continued to be confused with the "Q" even for the no-grid.

Table VIIa, VIIb, VIIc, VIId shows letter confusions of the individual Ss. There was little agreement among Ss as to specific letter confusions. Three of the four Ss consistently confused the "O" with the "Q". Two of the four had the reverse confusion of the "Q" with the "O". All of the other confusions were specific to the individual S.

Table VIII represents a confusion matrix based on total judgments made by all Ss in this study.

DISCUSSION OF RESULTS

It was apparent that legibility as assessed by all three response measures was better for the letters of Alphabet B than for those of Alphabet A for the fine-grid under the short exposure time and for the coarse-grid under both exposure times. It was hypothesized in the introduction that variations in the width of letter stroke would have a greater influence on legibility than variations in letter width since the former would increase the width of horizontal components of the letters while the latter would not. However, since both stroke-width and letter width varied together it was not possible on the basis of this data alone to attribute the increased legibility of letters of Alphabet B to variations within a single dimension. One might speculate with greater confidence that increased width of stroke was more important than increased letter width if additional evidence were available. A search of the literature indicated that reports on the effect of variation in letter width on legibility were conflicting. In a study by Brown, et.al. (1) increases in letter width from 50-100% of height lead to consistent improvement in letter legibility. However, for the two letter width variations which approximate those used in the current study, the larger width produced only a slight increase in legibility. Crook (2), on the other hand, reported a decrease in legibility when the width of letters was increased from 57% to 67% or 80% of height.

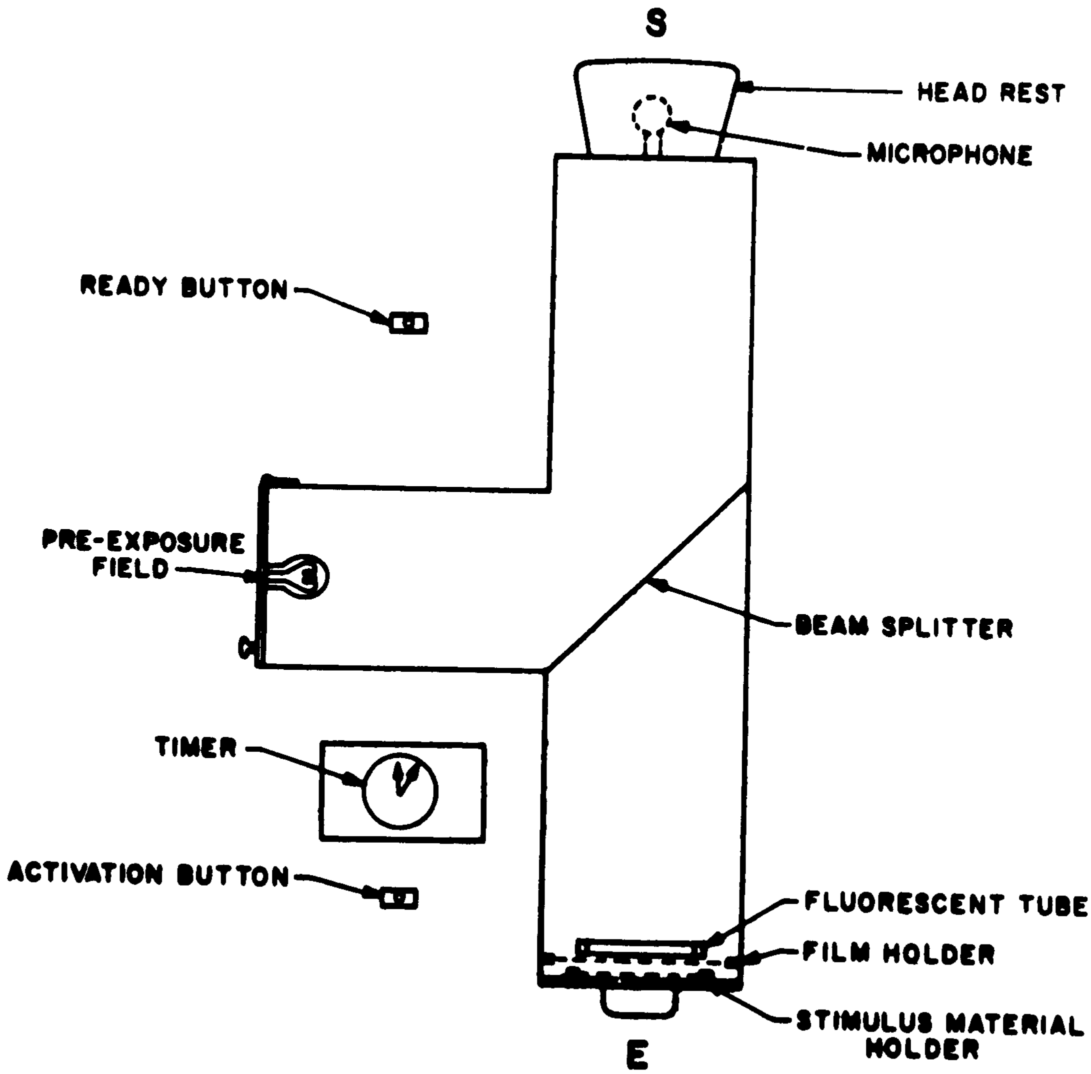
There is, therefore, no consistent evidence that an increase in width especially from an average of 77% to 86% of height would result in greater letter legibility. There was, however, general agreement in the literature that legibility increased regularly with stroke width up to a maximum value which is similar to that of Alphabet B (2, 10). Therefore, it is likely that of the two factors, stroke-width was the one responsible for increased legibility for letters of Alphabet B.

It might be argued that the effects of the horizontal, linear scan construction, the variations in the number of linear constructions per symbol height, and the exposure time could be attributed to changes in brightness and/or contrast. The effects of brief exposure of light on apparent brightness have been investigated by others (8). In general, the finding is that the apparent brightness of a light source is directly related to its duration -- the briefer the duration of the light the dimmer it appears. Also, the grid variations were found to change the apparent brightness, of the letters, and to reduce contrast. It seems unlikely however that either factor alone (reduced brightness or contrast) was responsible for the loss of legibility under the short exposure time or grid variations. That decreased brightness was not the only factor seems plausible since there were no differences between the two exposure times for the no-grid. Also, previous work has shown that a reduction in contrast of the order involved in this study has negligible effects on legibility (2). However, it could be that the decreased brightness combined with the reduced contrast to impair legibility for short exposure times for the fine-grid and coarse-grid. Part of this assertion is supported by the greater legibility of letters of Alphabet B. Previous studies have indicated that wide letter strokes lead to greater legibility <u>only</u> under low levels of illumination (2, 11). Whether the effect of stroke width on legibility is also related in the same way to contrast level is not clear from the literature. One would suspect however that stroke-width of letters would have a similar effect at low values of contrast. One additional question to be answered is whether the loss of legibility for the coarse-grid for both exposure times could be attributed to an additional reduction in contrast caused by the wider grid lines. This seems unlikely since approximately the same amount of the letter was deleted by both the fine and coarse-grid and therefore contrast was about the same for the fine-grid and coarse-grid. An alternative explanation is that a greater change was introduced in the geometry of some of the letters by the coarse-grid than by the fine-grid. This gains some support from a consideration of the facts that the grids differed in the percentage of letters deleted by individual lines and also in the particular parts of the letter obstructed by each line. Therefore, it is reasonable to conclude that the loss in legibility for the fine-grid was due mainly to the combined effects of reduced apparent brightness and contrast while both these factors plus the change in the geometry of the symbols reduced legibility for the coarse-grid.

The change in letter geometry introduced by the grid lines undoubtedly was the major factor responsible for the changes in the number as well as the kind of letter confusions that occurred between fine-grid and coarse-grid. What data there is available indicates that not only will the number of confusions increase with a decreased number of linear constructions per symbol height, but also there will be a change in the kinds of letters confused as well. There were only two major sources of error common to both fine-grid and coarse-grid, the "V" with the "Y", and the "Y" with the "T". Changes in the geometry of these letters would probably reduce confusion under both linear construction methods. All other major confusions were specific to each grid variation. Therefore, the prediction is that changes in the geometry of letters which eliminate confusions under one ratio of linear construction per symbol height will not be effective when the ratio is changed.

One of the few exceptions to be specificity of letter confusion was the "O" with the "Q" which occurred under all conditions. The confusion of the "O" with the "Q" and the "Q" with the "O" contributed 8% of the total error. Also, if one considers the number of times other letters were confused with the "O" or "Q", the error level would increase to 14% of the total. A change in the configuration of these letters would result in a general increase in legibility.

Table VIII may be used to select letters that are most legible under the conditions of this experiment. The rank order of letters, based upon the number of errors of identification, from the least to the most, is as follows: W, M, A, U, P, N, S, H, X, V, L, J, K, I, Y, Z, Q, R, T, F, D, G, B, E, O. This rank order had a low, positive, non-significant correlation with a similar ranking of letters based upon a study by Howell (6). Differences between studies in ranking of symbols is typical, and they indicate that the legibility of letters is highly dependent upon the conditions under which they are viewed. Specification of optimally legible letters will depend upon a detailed consideration of the viewing conditions.



1A-10,359

FIG. 1
DIAGRAM OF THE TACHISTOSCOPE

IA-10,360

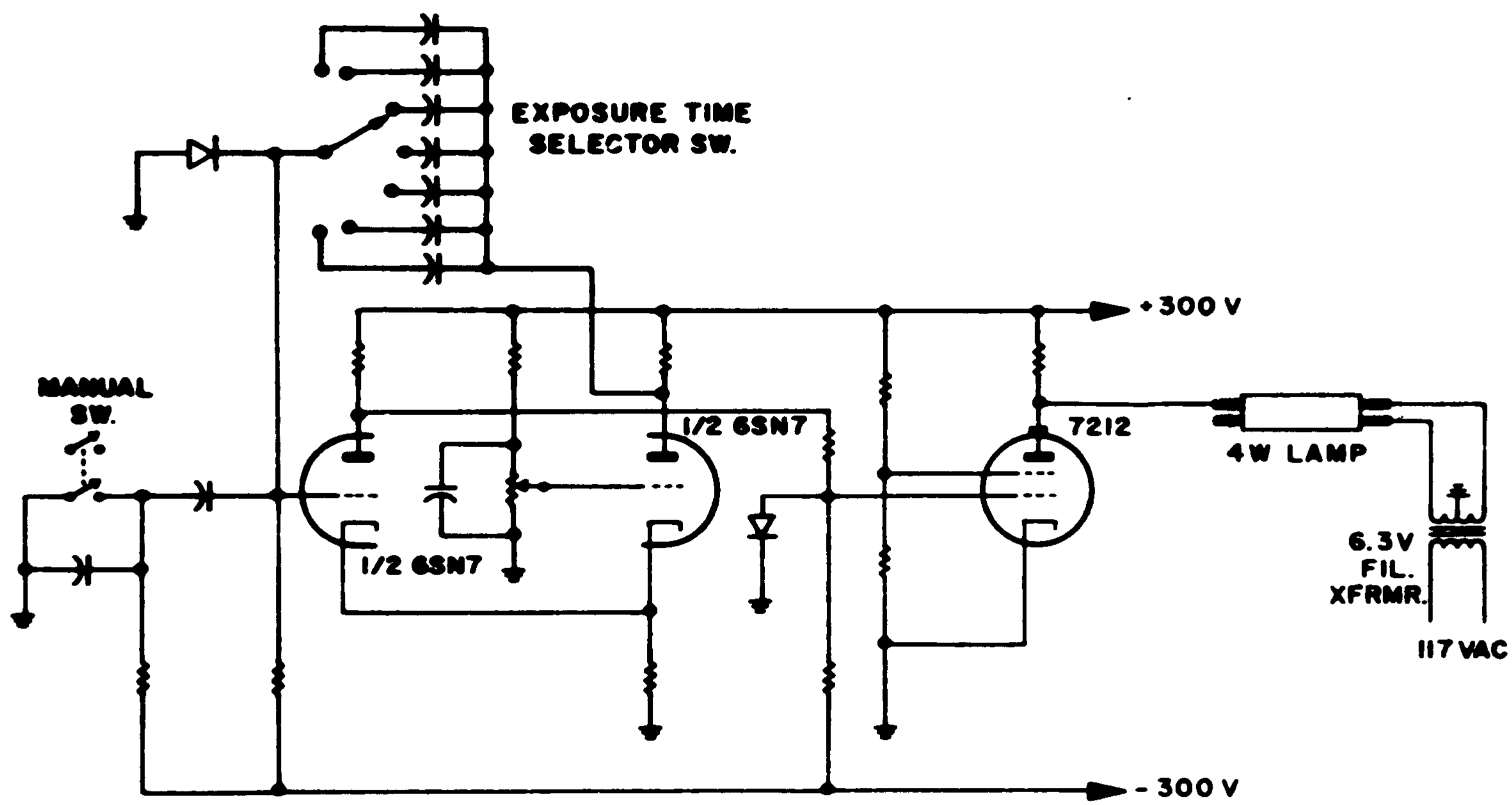


FIG. 2
CIRCUIT DIAGRAM OF PULSER AND LAMP POWER SUPPLY

FIG. 3
ALPHABET A (TOP). ALPHABET B (BOTTOM).

Figure 4. The number of bits transmitted for grid variations: (a) no-grid, (b) fine-grid, (c) coarse-grid, plotted with alphabets as a parameter. Each point represents the median number of the transmitted bits for the four Ss.

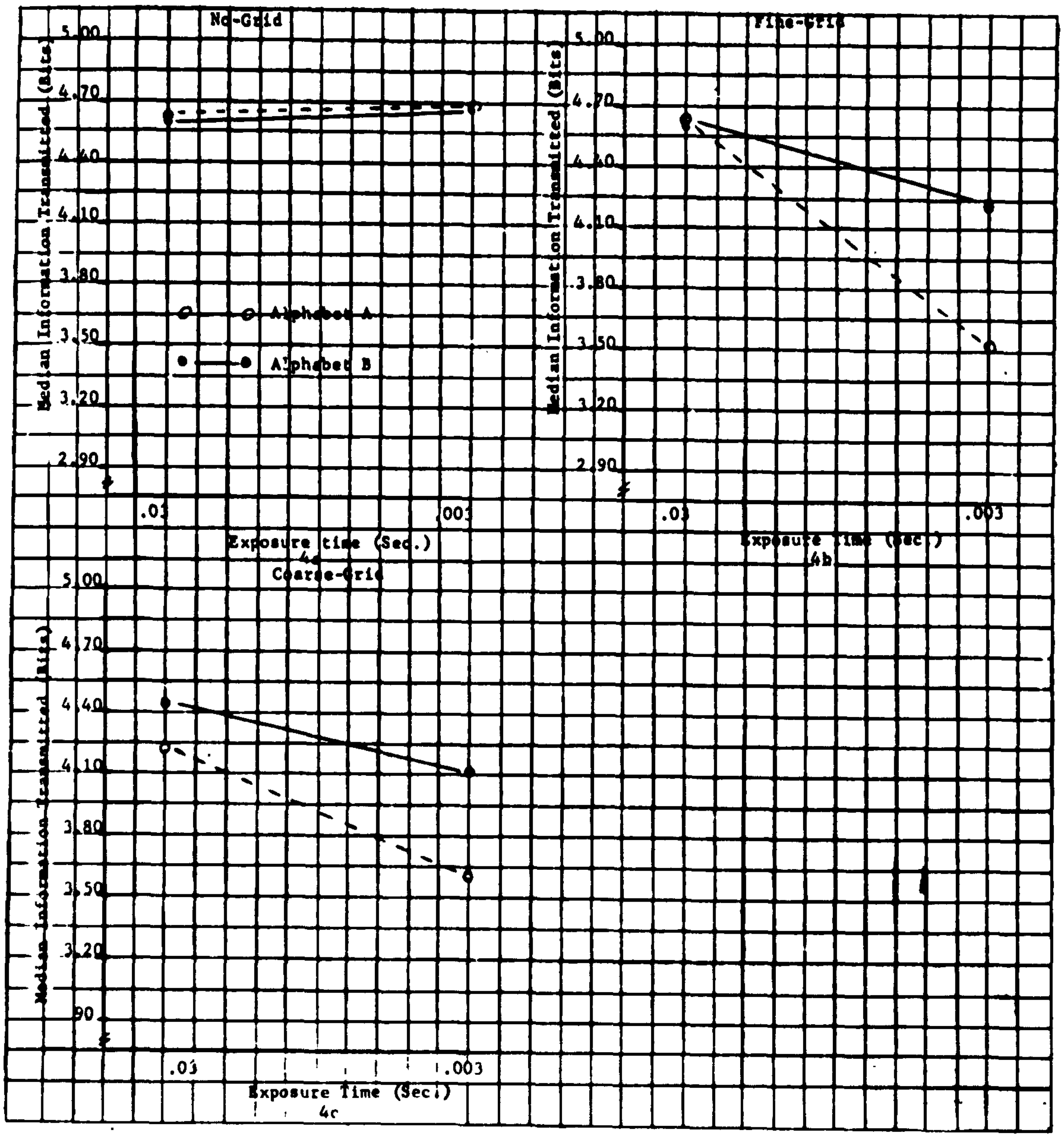


Figure 5. Percent errors made for the grid variations: (a) no-grid, (b) fine-grid, (c) coarse-grid, plotted with alphabets as a parameter.

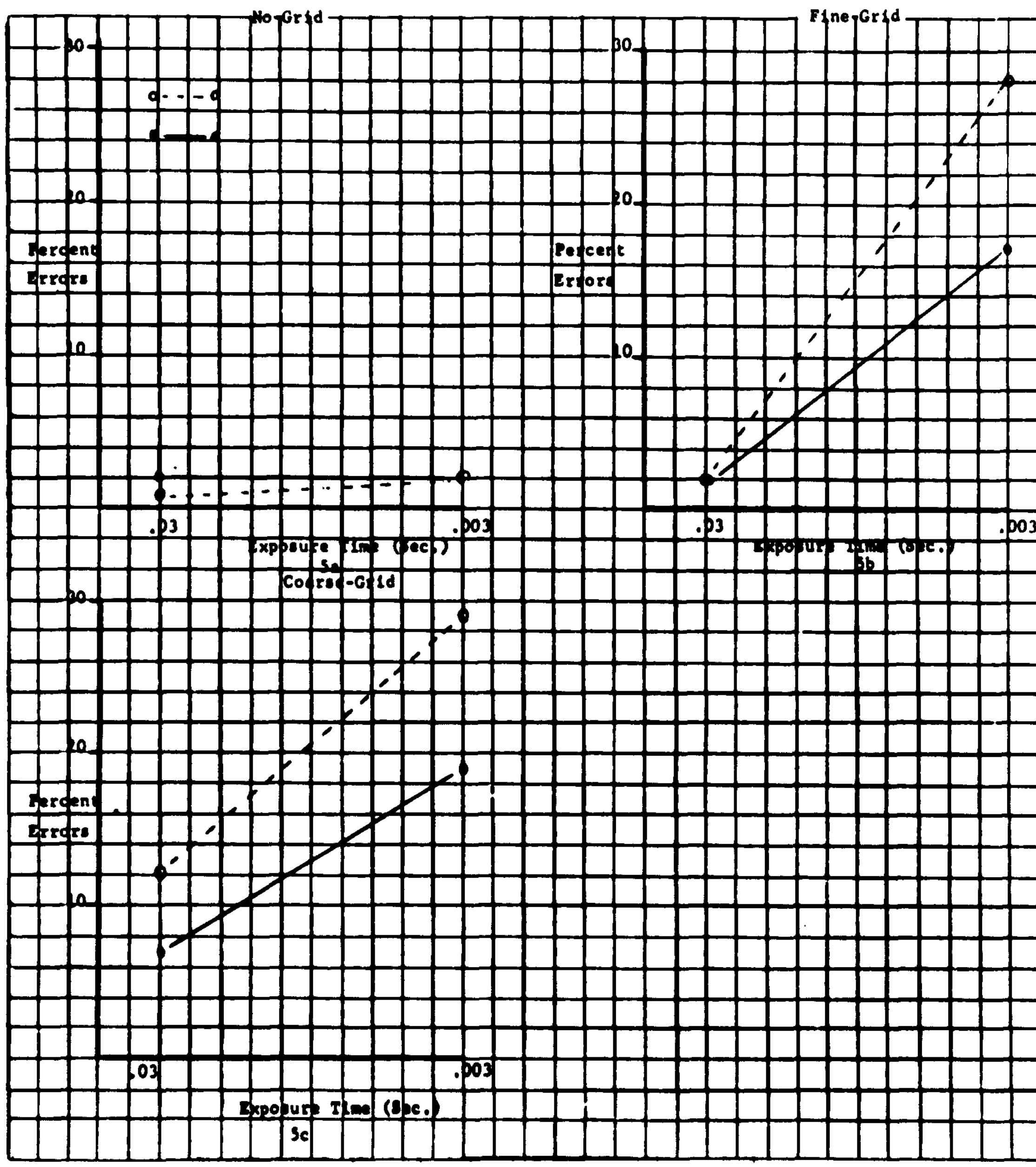


Figure 6. Reaction time obtained for the grid variations: (a) no-grid, (b) fine-grid, (c) coarse-grid, plotted with alphabets as a parameter. Each point represents the median RT for the four Ss.

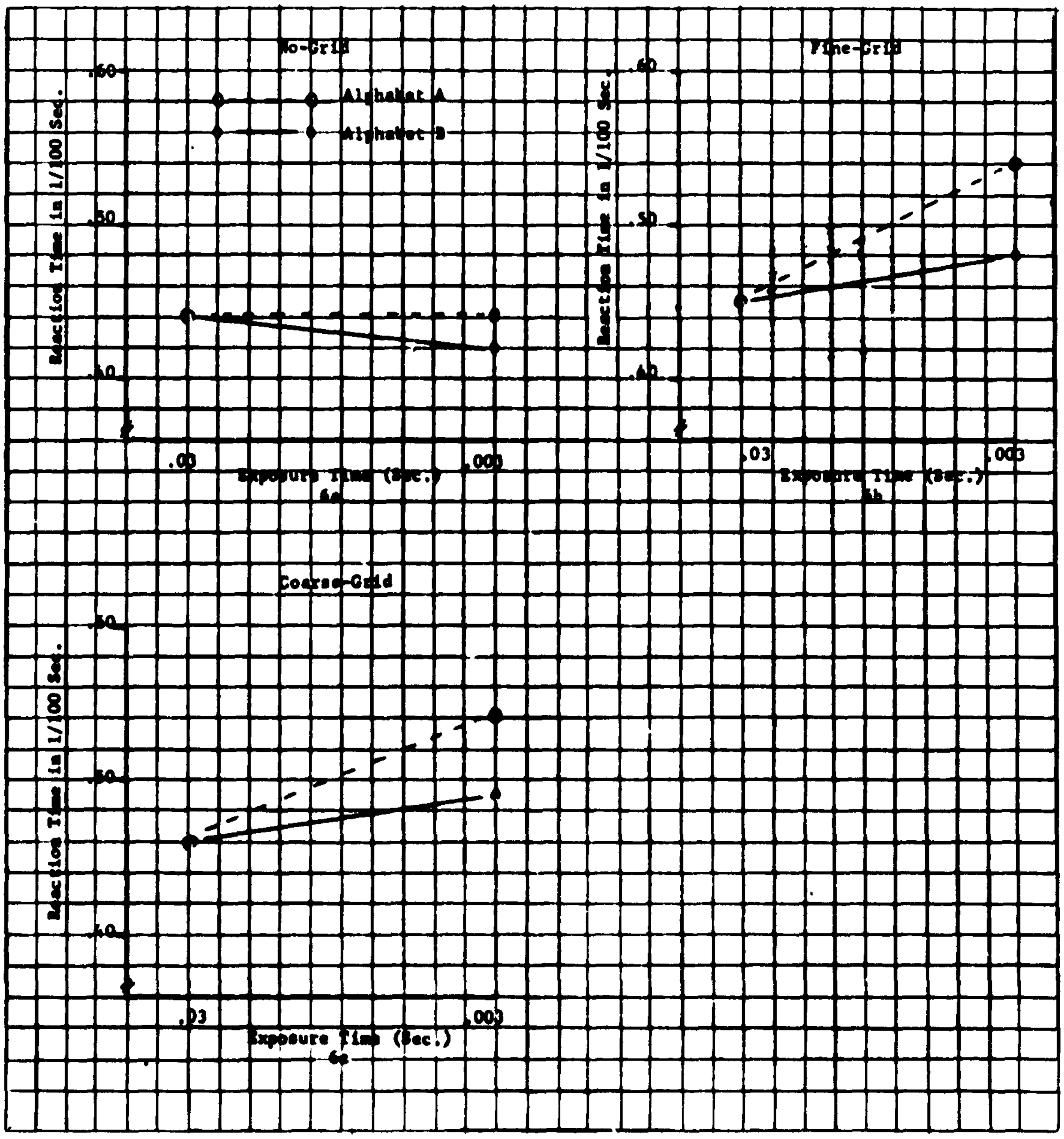


Table I. Summary of the analysis of variance for bits transmitted.

Source of Variance	df	Mean Square	F	P
ALPHABET (A)	1	0.01159	2.00	NS
EXPOSURE TIME (T)	1	0.24015	3.67	NS
LINE SCAN (L)	2	0.09873	17.08	<.01
SUBJECTS (S)	3	0.06590	11.40	<.01
A x T	1	0.00716	---	
A x L	2	0.00523	---	
A x S	3	0.00551	---	
T x L	2	0.05989	10.36	<.05
T x S	3	0.06535*	11.31	<.01
L x S	6	0.01455	2.52	NS
A x T x L	2	0.00649	---	
A x T x S	3	0.00653	---	
A x L x S	6	0.00480	---	
T x L x S	6	0.01332	2.30	NS
A x T x L x S	6	0.00578		
TOTAL	47			

*This was used as an error term to test the significance of the main effect for the exposure time. All other tests of significance were computed with the residual (A x T x L x S) as the error term.

TABLE II. Summary of the analysis of variance of error scores

Source of Variance	df	Mean Square	F	P
ALPHABET (A)	1	0.11025	4.78	NS
EXPOSURE TIME (T)	1	1.84676	7.92	<.05
LINE SCAN (L)	2	3.55322	154.02	<.01
SUBJECTS (S)	3	0.35602	15.43	<.01
A x T	1	0.05054	2.19	NS
A x L	2	0.16328	7.08	<.05
A x S	3	0.00429	---	
T x L	2	1.32022	57.23	<.01
T x S	3	0.23331*	10.11	<.01
L x S	6	0.04347	1.88	NS
A x T x L	2	0.01445	---	
A x T x S	3	0.04174	1.81	NS
A x L x S	6	0.06476	2.81	NS
T x L x S	6	0.03267	1.42	NS
A x T x L x S	6	0.02307		
TOTAL	47			

*This was used as the error term to test for the significance of the main effect for exposure time. All other tests of significance were computed with (A x T x L x S) as the error term.

Table III. Summary of the analysis of variance of reaction time

Source of Variance	df	Mean Square	F	P
ALPHABET (A)	1	50.02083	13.2	<.01
EXPOSURE TIME (T)	1	136.68750	36.0	<.01
LINE SCAN (L)	2	143.68750	37.8	<.01
SUBJECTS (S)	3	278.02083	73.19	<.01
A x T	1	50.02083	13.17	<.01
A x L	2	10.39583	2.74	NS
A x S	3	7.57639	1.99	NS
T x L	2	64.31250	16.93	<.01
T x S	3	14.24305	3.75	NS
L x S	6	14.35417	3.78	NS
A x T x L	2	4.52084	----	
A x T x S	3	11.79861	3.10	NS
A x L x S	6	7.95139	2.09	NS
T x L x S	6	9.70139	2.55	NS
A x T x L x S	6	3.79861*		
TOTAL	47			

*All tests of significance were made with this error term.

Table IVa. The confusion matrix for responses made to letters of Alphabet B

STIMULI	RESPONSES 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	0/0 CORRECT
A	231																										96.26
B		203																									84.59
C			222																								92.51
D				207																							86.26
E					206																						85.84
F						214																					89.17
G							210								13												89.17
H								222																			92.51
I									214																		89.17
J										228																	95.01
K											217																90.42
L												226															94.17
M													234														97.51
N														225													93.76
O							14								184		37										76.67
P																230											95.84
Q																	222										92.57
R																		216									90.01
S																			226								94.17
T																				219							91.26
U																					235						97.92
V																						220					91.67
W																							240				100.00
X																								227			90.42
Y																									221		92.09
Z																										231	96.26

Table IVb. The confusion matrix for responses made to letters of Alphabet A

RESPONSES

STIMULI	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	O/O CORRECT
A	230																										95.84
B		201																									83.76
C			231																								96.26
D				203																							84.59
E					197																						82.09
F						200										16											83.34
G			18				195																				81.67
H								219																			91.26
I									214																		89.17
J									24	203																	84.59
K											213																88.76
L									23			203															84.59
M													230														96.26
N														225													93.76
O							13								176		32										73.34
P																225											93.76
Q															30		199										82.92
R																		199									82.92
S																			217								90.42
T									25											197							82.09
U																					225						93.76
V																						214			15		89.17
W																							236				98.34
X											18													206			85.84
Y																				20					205		85.42
Z																										195	81.26

Table Va. The confusion matrix for responses made under .03 sec. exposure.

RESPONSES

STIMULI	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	0/0 CORRECT
A	236																										98.34
B		219																									91.26
C			237																								98.76
D				233																							97.09
E					221																						92.09
F						228																					95.01
G							220																				91.67
H								229																			95.42
I									231																		96.26
J										231																	96.26
K											225																93.76
L												230															95.84
M													234														97.51
N														235													97.92
O															202		22										84.17
P																237											98.76
Q																	225										93.76
R																		225									93.17
S																			236								98.34
T									13											223							92.92
U																					240						100.00
V																						236					98.34
W																							240				100.00
X																								233			97.09
Y																									231		96.26
Z																										230	95.84

Table Vb. The confusion matrix for responses made under .003 sec. exposure

RESPONSES

STIMULI	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	0/0 CORRECT
A	225																										93.76
B		185																19									77.09
C			216																								90.01
D		16		180											17												75.00
E			13		182																						75.84
F						186										22											77.51
G							185								13		17										77.09
H								212																			88.34
I									197			14															82.09
J									22	200																	83.34
K											205							17									85.42
L									20			204															85.01
M													230														95.58
N														215													89.59
O							18								158		47										65.84
P						14										218											90.84
Q															25		196										81.67
R																		190									79.17
S																			207								86.26
T									14											193							80.42
U																					220						91.67
V																						198			24		82:50
W																							236				98.34
X											19													200			83.34
Y																				23					195		81.26
Z																										196	81.67

Table VIa. The confusion matrix for responses made under no-grid.

RESPONSES

STIMULI	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	0/0 CORRECT
A	160																										100.00
B		156																									97.50
C			159																								99.38
D				154																							96.25
E					154																						96.25
F						157																					98.12
G							154																				96.25
H								156																			97.50
I									153																		95.62
J										158																	98.75
K											160																100.00
L												160															100.00
M													160														100.00
N														159													99.38
O															142		13										88.75
P																159											99.38
Q																	159										99.38
R																		156									97.50
S																			158								98.75
T																				157							98.12
U																					160						100.00
V																						157					98.12
W																							160				100.00
X																								158			98.75
Y																									159		99.38
Z																										159	99.38

Table VIb. The confusion matrix for responses made under fine-grid

RESPONSES

STIMULI	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	0/0 CORRECT
A	155																										96.88
B		130																14									81.25
C			144																								90.00
D				132																							82.50
E					128																						80.00
F						135																					84.38
G							137																				85.62
H								148																			92.50
I									140																		87.50
J										144																	90.00
K											145																90.62
L												147															91.88
M													151														94.88
N														144													90.00
O															111		24										69.38
P																149											93.12
Q															14		136										85.00
R																		136									85.00
S																			148								92.50
T									16											128							80.00
U																					151						94.38
V																						137			13		85.62
W																							156				97.50
X																								140			87.50
Y																				13					137		85.62
Z																										144	90.00

Table VIc. The confusion matrix for responses made under coarse-grid.

RESPONSES

STIMULI	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	0/0 CORRECT
A	146																										91.25
B		118																									73.75
C			150																								93.75
D				124																							77.50
E					121																						75.62
F						122										14											76.25
G			18				114																				71.25
H								137																			85.62
I									135																		84.38
J									18	129																	80.62
K											125							14									78.12
L									21			127															79.38
M													153														95.62
N														147													91.88
O															107		32										66.88
P																147											91.88
Q															22		126										78.88
R																		123									76.88
S																			137								85.62
T																				131							81.88
U																					149						93.12
V																						140			14		87.50
W																							160				100.00
X											14													135			84.38
Y																				18					130		81.25
Z																										123	76.88

Table VIIa. The confusion matrix for responses made by Subject R.B.

RESPONSES

STIMULI	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	0/0 CORRECT
A	119																										99.13
B		106																									88.30
C			119																								99.13
D				115																							95.80
E					106																						88.30
F						109																					90.80
G							106																				88.30
H								113																			94.13
I									102																		84.97
J										110																	91.63
K											112																93.30
L												115															95.80
M													116														96.63
N														113													94.13
O															97		13										80.80
P																114											94.96
Q																	107										89.13
R																		111									92.46
S																			117								97.46
T																				111							92.46
U																					120						100.00
V																						115					95.80
W																							120				100.00
X																								116			96.63
Y																									112		93.30
Z																										112	93.30

Table VIIb. The confusion matrix for responses made by Subject P.C.

RESPONSES

STIMULI	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	0/0 CORRECT
A	111																										92.46
B		98																									81.63
C			117																								97.46
D				99																							82.47
E					105																						87.46
F						103																					85.80
G							103																				85.80
H								115																			95.80
I									111																		92.46
J										109																	90.80
K											101																84.13
L												104															86.63
M													112														93.30
N														114													94.96
O															97												80.80
P																116											96.63
Q																	106										88.30
R																		99									82.47
S																			110								91.63
T																				111							92.46
U																					115						95.80
V																						113					94.13
W																							118				98.29
X																								107			89.96
Y																				19					95		79.14
Z																										104	86.63

Table VIIc. The confusion matrix for responses made by J.K.

RESPONSES

STIMULI	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	0/0 CORRECT
A	111																										92.46
B		92																									76.64
C			101																								84.13
D				86																							71.64
E					81																						67.47
F						92																					76.64
G							98																				81.63
H								96																			79.97
I									102																		84.97
J									13	98																	81.63
K											103																85.80
L												103															85.80
M													118														98.29
N														105													87.46
O							17								66		30										55.81
P																112											93.30
Q																	103										85.80
R																		102									84.97
S																			103								85.80
T																				87							72.47
U																					108						89.96
V																						96			14		79.97
W																							120				100.00
X																								98			81.63
Y																									108		89.96
Z																										102	84.97

Table VIId. The confusion matrix for responses made by Subject D.K.

RESPONSES

STIMULI	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	0/0 CORRECT
A	120																										100.00
B		108																									89.96
C			116																								96.63
D				110																							91.63
E					111																						92.46
F						110																					91.63
G							98																				81.63
H								117																			97.46
I									113																		94.13
J										114																	94.96
K											114																94.96
L												112															93.30
M													118														98.29
N														118													98.29
O															100		17										83.30
P																113											94.13
Q																	105										87.46
R																		103									85.80
S																			113								94.13
T																				107							89.30
U																					117						97.46
V																						110					91.63
W																							118				98.29
X																								112			93.80
Y																									111		92.46
Z																										104	86.63

Table VIII. The confusion matrix for total responses made. Those confucions encircled contribute 1% or more to the total number of errors.

RESPONSES

STIMULI	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	Σ Errors	%Correct
A	461	1			2				1	1	1	1	1	2		1		5						3			19	96.04
B	6	404		4	7		3	3		1	5		1	1		5		21	15				1			3	76	84.17
C	2		453		8	1	2				2	7				1		3	1								27	94.38
D	1	18	1	410			3								19	12	4	3	1	1	6	1					70	85.42
E	2	2	14		403	12			4		4	5		1		8		11	6	2	1	1				4	77	83.96
F	2	1			4	414		2	8		3			2		25		3		13					3		66	86.25
G	1	2	19	3	1		405					1	1		22		18	3			3					1	75	84.38
H	1							441			2		11	15	1			4					5				39	91.88
I		1	1	1	4	5			428	7	3	20	1					1		5	1				2		52	89.17
J	5				1	1			28	431	2	4				2			2	1				1	2		49	89.79
K	3				6	1		1	2	1	430	1		2				23					1	6	2	1	50	89.58
L	4	1	1		2				29	3	2	434						1	1							2	46	90.42
M	1	1			1			3					464	8					1				1				16	96.67
N	1							8	1	1	1		9	450		1		4					3			1	30	93.75
O	1	1	3	8			27	1							360	1	69				6	1	2				120	75.00
P	2				1	17		1					1			455						1		1	1		25	94.79
Q	1		1	1			10						1		36	1	421	3	1		3	1					59	87.71
R	5	7	1	1	15	3	1	5			12			2		4	1	415	3		1	1		3			65	86.46
S	3	12			2		1		1		1	3	1	3	1	2		4	443				1		2		37	92.29
T	2				1	10		1	27		1	2				2	1	1		416		1		2	13		64	86.67
U				2				2					1	3			3				460	3	6				20	95.83
V	3													1				2	1		1	434	8	3	27		46	90.42
W													2	1		1							476				4	99.17
X	4			1	1				2		23				1	2		7		1		1		433		4	47	90.21
Y	1					2			4		3									31		4	2	7	426		54	88.75
Z	3	1	1		3	7		2	10	7	6	4						3				1		4	2	426	54	88.75
Σ Errors	54	48	42	21	59	59	47	29	117	21	71	48	30	41	80	68	96	102	32	54	22	16	30	30	54	16	1287	

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letters of: (a) two simulated TV rasters with horizontal, linear scan constructions of 11 and 5 lines per letter height and a solid (continuous) construction of infinite lines per letter height; (b) two visual exposure times of 0.03 and 0.003 seconds; (c) two letter stroke widths of 16 and 28 percent of letter height.

VII. In DDC collection

letters of: (a) two simulated TV rasters with horizontal, linear scan constructions of 11 and 5 lines per letter height and a solid (continuous) construction of infinite lines per letter height; (b) two visual exposure times of 0.03 and 0.003 seconds; (c) two letter stroke widths of 16 and 28 percent of letter height.

VII. In DDC collection

letters of: (a) two simulated TV rasters with horizontal, linear scan constructions of 11 and 5 lines per letter height and a solid (continuous) construction of infinite lines per letter height; (b) two visual exposure times of 0.03 and 0.003 seconds; (c) two letter stroke widths of 16 and 28 percent of letter height.

VII. In DDC collection

letters of: (a) two simulated TV rasters with horizontal, linear scan constructions of 11 and 5 lines per letter height and a solid (continuous) construction of infinite lines per letter height; (b) two visual exposure times of 0.03 and 0.003 seconds; (c) two letter stroke widths of 16 and 28 percent of letter height.

VII. In DDC collection

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Rpt. No. ESD-TDR-63-249. STUDIES OF DISPLAY SYMBOL LEGIBILITY: THE EFFECTS OF LINE CONSTRUCTION, EXPOSURE TIME, AND STROKE WIDTH. Preliminary report, July 1963, 40p., incl. illus., tables, 11 refs.

Unclassified Report

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2. Experimental data
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