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A HUMAN ENGINEERING SPECIFICATION FOR LEGIBILITY OF ALPHANUMERIC SYMBOLOGY ON VIDEO MONITOR DISPLAYS \(REVISED\)

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A Human Engineering Specification for Legibility of Alphanumeric Symbology on Video Monitor Displays (Revised)

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ABSTRACT

Conventional human engineering legibility specifications for alphanumeric symbology displayed on video monitors consist of predictors of user performance derived from legibility research studies. Typical legibility predictors are symbol size, symbol luminance, contrast ratio, font, dot matrix dimensions, and pixel active area. This report discusses a number of significant problems associated with the development and application of conventional legibility specifications. In addition, it presents a detailed specification for comparative and objective evaluation of video monitor legibility performance based upon legibility tests developed for the USAF. This specification consists of criteria for subject selection, visual environment design, display monitor setup, test material design and presentation, legibility task scores, and legibility test performance. It is to be noted that this report is a revision of an earlier report under the same title (DCIEM Tech. Report No. 79X01) published in January 1979. While the specification for the Legibility Test has not undergone any major change, the proposed Minimum Conventional Legibility Criteria have been reduced in number. The revised report also includes a new appendix describing in detail a standardized procedure for measuring CRT symbol luminance and calculating contrast ratios.

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INTRODUCTION

This report is a revision of an earlier report under the same title (DCIEM Technical Report No. 79X01) published in January 1979. While the specification for the Legibility Test has not undergone any major change, the proposed Minimum Conventional Legibility Criteria have been reduced in number. The revised report also includes a new Appendix describing in detail a standardized procedure for measuring CRT symbol luminance and calculating contrast ratios.

DCIEM was tasked by DCSEM (Directorate Computer Systems Engineering and Maintenance) to undertake the development of a legibility specification, based on human engineering criteria, for display of alphanumeric symbology on video monitors to be implemented in Base Automated Data Processing Systems (BADPS). In addition, DCSEM requested the development of a methodology by which DCIEM could assist the BADPS Design Authority in a comparative evaluation of candidate video monitors according to specification requirements.

The BADPS display requirement is for a KVDU (Keyboard Video Display Unit) having a monochromatic video monitor capable of displaying the 94 alphanumeric and special symbols of the ASCII 96 code set in an approximate 80 symbols per row by 25 row format common to the majority of commercially available CRT KVDUs. BADPS display applications utilize a variety of alphanumeric page formats, including menus, fill-in forms, and tabular data displays , and implement features such as dual level luminance, blinking, and inverse video to facilitate user discrimination of selected data fields.

DCSEM expressed concern that conventional human engineering specifications for electronic displays are either too general, resulting in acceptance of displays that are inadequate for the user in terms of, for example, symbol definition or contrast ratio, or too restrictive, thereby rejecting displays which are in fact suitable for the proposed application. It is necessary, therefore, to implement an approach to specification development that eliminates this problem. DCSEM suggested also that the display specification be independent of both display technology (e.g., CRT, liquid crystal) and vendor implementation (e.g., screen area and symbol size) (1).

The specification proposed in this report is based upon an examination of human engineering research data relevant to the design of electronic (i.e., CRT and matrix) display systems. Current electronic display design criteria are derived primarily from studies involving CRT displays. For this reason, particular emphasis was placed upon review of matrix (i.e., plasma, electroluminescence and liquid crystal technologies) display research.

The proposed specification is also based upon literature pertinent to legibility testing of electronic displays. This literature indicates a trend away from the conventional practice of specifying characteristics of display units which are known to have effects on legibility and which are technology-dependent, and toward a method of determining legibility based upon user performance under various testing conditions as described in the specification document.

While the specification proposed herein relies heavily upon performance criteria and methodologies derived from the surveyed legibility research studies, this report presents them in a clear and organized format that can be directly implemented by the display systems engineer.

CONVENTIONAL HUMAN ENGINEERING SPECIFICATIONS FOR ELECTRONIC DISPLAYS

In general, conventional display specifications contain a set of design criteria based upon human engineering research, the majority of which relate to display legibility, quantity of displayed information, and perceived flicker. A study of relevant literature demonstrates that most studies have involved the use of CRT rather than matrix displays (2,3,4,5,6). Although a number of matrix display technologies are potentially available today, including plasma, electroluminescent, and liquid crystal panels, CRT technology dominates the electronic display market by virtue of its relatively low cost, high reliability, high degree of software support, availability of application programs, and wealth of design experience (7). However, the applicability of CRT research data to matrix display design is questionable in many instances due to the inherent differences in symbol generation technique. This together with the lack of human engineering data for matrix displays suggests that a specification for electronic displays which is independent of technology will not likely be based solely upon existing research data.

Several excellent human engineering reviews pertaining to electronic display of alphanumeric symbology are available (Scanlan and Carel, 1976; Gould, 1968; Buckler, 1977; Vanderkolk et al, 1975). They provide a reasonably complete summary of the many variables from which the design criteria of conventional specifications have been derived. These include the following:

a. CRT symbol generation variables;
- font
- dot size
- definition (i.e., dot matrix dimensions)
- subtense
- aspect ratio
- spacing
- luminance and contrast

b. CRT raster variables;
- refresh rate
- resolution
- interlace structure

c. CRT phosphor variables;
- persistence
- spectral response

d. Matrix symbol generation variables;
- font
- definition

- subtense
- edge luminance gradient
- luminance and contrast
- emitter size
- emitter spacing
- emitter shape
- emitter chromaticity
- percent active area
  (i.e., emitter diameter/emitter spacing)

Other factors in conventional specifications include:

- symbol set
- symbol format (i.e., symbols/row x rows)
- anti-reflective display surface treatment
- screen size
- screen orientation relative to viewing angle
- highlighting (i.e., inverse video, blinking, and dual level luminance)

One of the major problems encountered by the specification designer is deciding which of these variables should be included in the specification and what values each should take. A number of design criteria are not difficult to specify because either the data are conclusive or the effects on user performance are well understood. For example, a simple method of reducing specular glare on the display surface and thereby increasing symbol contrast ratio is to specify that the display device be provided with an anti-reflective surface (4). Similarly, screen size can be specified for alphanumeric displays if symbol format is known because symbol dimensions and spacing are also part of the specification. Another example of a factor that is relatively easy to specify is refresh rate for CRT displays. Research data derived from temporal modulation transfer functions for the human visual system strongly indicate to the display designer that generation of a standard , non-interlaced raster on a short persistence phosphor such as P31 or P4, for example, for display of symbology in ambient illumination conditions of, say, 100 fc, will require a refresh rate of about 60 Hz (2,8).

However, other criteria are more difficult to specify because different studies appear to provide conflicting data. For example, Gould (1968) suggested that symbols defined by 5x7 dot matrices are marginally acceptable because a number of studies had demonstrated the need for 10 scan lines per symbol height on television displays. Vanderkolk et al (1975) and Scanlan and Carel (1976) concluded, however, that for static upright symbols a 5x7 matrix with a relatively high percent active area is sufficient for good legibility performance. Another example of data which appear to conflict across studies are those relating to symbol subtense. Some studies recommend a minimum symbol subtense of 12′-15′ of visual arc for operational viewing distances while another study recommends a minimum subtense of 22′-26′ (3). This is a difference of almost one hundred percent. Contrast ratio is yet another example. Gould (1968) specifies a minimum acceptable contrast ratio of 15:1 for CRT symbology while Buckler (1977) accepts a minimum contrast ratio of 8.5:1.

Not only is there some uncertainty about criterion levels to be stated in the specification, but there is uncertainty regarding the relative importance of the conventional predictors of display performance. For example, experimental research by Vanderkolk et al (1975) determined that four variables account for over 50 percent of the legibility of matrix displays. In descending order of importance they are percent active area, symbol subtense, symbol contrast, and surround illumination. Scanlan and Carel (1976) argue, however, that although reducing percent active area to a low level tends to reduce the legibility of alphanumeric symbols, its relative importance may have been overestimated in the study by Vanderkolk er al.

Kinney (1966) presents a succinct discussion of the problems associated with the development of conventional display specifications. In summary, they are:

1. Definitions of legibility vary from study to study with the result that different investigators use different performance measures. Thus, the data cannot be meaningfully compared across studies with much confidence.

2. Criteria in a conventional specification are predictors of display performance. It is predicted that the display will have high legibility if its symbols satisfy the specified criteria. 'Everyone's attention is directed away from human performance and towards the details of its predictors.'

3. 'The relationship between the usually listed predictors and the eventual human performance (in terms of legibility) is not technically sound enough to warrant placing one's faith entirely on the prediction process'.

4. The process of deciding whether or not a particular display complies with the specification depends on measurements of such variables as dot size, symbol height, and contrast ratio. These measurements are not only difficult to make but are usually quite imprecise.

5. Different display technologies require different specifications because symbol generation techique is technology-dependent. Thus, the quest for a standard display specification is made very difficult.

6. Lastly, the display may be accepted before legibility is tested because the Design Authority often places unwarranted faith in the vendor to provide a display which meets the specification. However, as is the case with most commercially available computer terminals, the technical specification provided by the vendor pertaining to symbol features may be somewhat suspect. It is necessary, therefore, to develop other methods for specifying electronic display interfaces which are less dependent upon the interpretation of human engineering data relevent to predictors of user performance and more directly related to user performance per se.

LEGIBILITY TESTING

The use of a conventional display specification consisting of a minimum set of well validated criteria is potentially useful as a screening medium to eliminate video monitors that are clearly unacceptable for alphanumeric symbol display. However, problems inherent in conventional specifications that were discussed in the previous section can be overcome by implementing another form of specification based upon legibility test and performance criteria.

A legibility test is a formal test in which each of a small number of potential users is required to detect and identify symbols presented on a display surface under rigorously controlled test conditions. A set of candidate video monitors can be comparatively evaluated using a legibility test approach because each subject in the test performs with each monitor under identical and highly controlled conditions.

The literature on legibility testing demonstrates that the technique is an extremely useful one and that it can be easily applied to any display technology (5,9,10,11). The emphasis is directly upon user performance as measured with the actual display and not upon the predictors of user performance which comprise conventional specifications for electronic displays. Thus the problems of validity of specification and measurement of display characteristics such as emitter size and luminance are eliminated.

There are three types of user tasks commonly used in legibility testing; namely, tachistoscopic recognition, visual search, and reading tasks.

Tachistoscopic recognition tasks have been used by several investigators and consist of sequential presentation of single symbols to the subject for recognition, usually under conditions that significantly degrade symbol legibility (3,5). Each symbol is randomly selected from a symbol set and displayed for a brief period of time, of the order of tens of milliseconds, at a fixed location on the display surface. The subject's task is to call out the name of the symbol as quickly as possible. Recognition times and naming errors are assumed to be directly related to symbol legibility. Subjects are presumed to quickly and accurately recognize symbols that are legible.

Visual search tasks have also been utilized in legibility testing (12). The subject is presented with a target symbol or word followed by an array of symbols or words on the display surface. It is common practice to use small nonsense words such as WBZ or SQB rather than meaningful words such as DOG or BAT in order to ensure that the subject is searching each symbol. The subject's task is to find the target symbol or word amongst the displayed array as quickly as possible. Again, search time is taken to be a measure of symbol legibility.

Reading tasks are the most common among established legibility tests for the simple reason that subject behaviour (i.e., verbal responses) is readily apparent and relatively easy to control and measure (10,12,13). For these reasons the reading task has been selected as the type of legibility task to be implemented in the BADPS display monitor specification.

In legibility testing, the onus is upon the Design Authority to specify the test criteria and test conditions. Thus it is necessary to discuss the main components of legibility test and performance specifications. They can be categorized as follows:

1. Subject selection criteria;
2. Environmental criteria;
3. Display device setup criteria;
4. Test material criteria;
5. Array presentation criteria;
6. Legibility task criteria;
7. Legibility scores and performance criteria.

1. Subject Selection Criteria

Each subject must be screened for visual abnormalities in near and far acuity, phoria (i.e., balance of the extra-ocular muscles of the eye), colour vision, and depth perception using a standard vision tester. Those subjects with corrected vision would be expected to wear their eye glasses or contact lens during the vision tests.

Subjects should, if at all possible, be randomly selected from amongst the population of potential users of the display system.

2. Environmental Criteria

The display devices should be evaluated under environmental conditions similar to those in the operational environment in which they will be used. For BADPS applications, it is suggested that ambient illumination levels approximate those levels found in modern office environments. (i.e., 50-100 fc.)

The display surface of the monitor should be shielded from direct sources of illumination in order to minimize specular glare.

The auditory environment should be strictly controlled such that it is free of any potentially distracting sources of noise. Overall sound pressure levels should be no higher than 55 dbA.

It is essential that each display device be tested under identical environmental conditions.

3. Display Device Setup Criteria

For comparative evaluation of BADPS candidate video monitors it will be necessary to standardize the setting up of each monitor. The setup procedure must address the problems of symbol and background luminance.

4. Test Material Criteria

The legibility test specification must include a description of the symbol set, symbol display format, and symbol selection criteria. With reading tasks, it is common to divide the 94 ASCII symbols into the 62 alphanumeric symbols (i.e., A-Z, a-z, 0-9) and the 32 special symbols (i.e., !"#$%& etc.). Symbols are randomly selected such that each symbol has an equiprobable chance of display.

5. Array Presentation Criteria

These criteria describe the temporal and spatial aspects of symbol presentation. Spatial criteria specify viewing distances and screen locations at which the symbol arrays are to be displayed. Temporal criteria specify display schedules for arrays within a single testing trial and specify subject rest periods. Symbols are displayed in an array format (e.g., 3 rows x 4 symbols per row) for most reading tasks in legibility testing.

6. Legibility Task Criteria

These criteria specify the control and verbal responses required of the subject during the running of the legibility test. Criteria for design of the instructions and practice trials which are given to the subject may also be specified.

Implementation of the legibility task requires the use of a host computer and medium speed (e.g., 2400 Baud) data link with the video monitor under test.

The computer performs the functions of:

- displaying instructions to the subject;
- selecting and displaying alphanumeric test arrays;
- timing control responses given by the subject;
- computing and storing session performance statistics.

Three additional pieces of hardware required for a reading type of legibility test are a tape recorder for recording the subject's verbal responses, a microphone, and a small handheld pushbutton control with which the subject controls the display of each array.

7. Legibility Scores and Performance Criteria

The raw data from tachistoscopic and reading types of legibility tests consist of recognition times and recognition errors. Inherent in the concept of 'recognition time' is the time required to translate the output of the perceptual processes to the appropriate motor response and,hence, recognition time is called reading time.

The raw data from reading tasks consist of the following:

- symbol array reading times as monitored by the host computer; and

- tape recordings of the subject's verbal responses.

From these data are computed symbol reading rates and reading errors.

Uncorrected reading rate is defined as the number of correct and incorrect naming responses per minute.

Corrected reading rate is defined as the number of correct naming responses per minute.

A reading error is defined to occur whenever the subject incorrectly names a displayed symbol (i.e., error of commission) or neglects to name a displayed symbol (i.e., error of omission).

Reading error is defined as the percentage of displayed symbols that are read in error.

Reading errors can be arranged in what is called a 'confusion' matrix (5,9,11). Suppose, for example, that a symbol set consists of four symbols, A, B, 2, and 8, and that each symbol was presented to each of five subjects 10 times for a given monitor. Thus each symbol was presented 50 times during the course of the legibility test. Further, assume that all the As and 2s were correctly named and that the B was confused with the 8 five times and with the A five times. Assume also that the 8 was confused with the A six times and with the B four times. The confusion matrix representing these data would appear as shown in Figure 1.

SYMBOL DISPLAYED

SYMBOL NAMED		A	B	2	8
	A	50	5	0	6
	B	0	40	0	4
	2	0	0	50	0
	8	0	5	0	40

Fig. 1. Raw data from a legibility test arranged in a confusion matrix.

The confusion matrix for each video monitor is used to compute five legibility scores. These scores have been adapted from the legibility test literature (5,10) and are defined as follows:

1. Corrected Reading Rate:

$$CRR = \left[\frac{\text{total correctly named symbols}}{\text{total reading time}}\right] \times 60 \text{ symbols/min}$$

2. Reading Error:

$$RE = \left[\frac{\text{total incorrectly read symbols}}{\text{total symbols displayed}}\right] \times 100\ \%$$

3. Reading Error per Symbol: (This score is computed for the symbol having the greatest number of reading errors.)

$$RES = \left[\frac{\text{total number of times symbol incorrectly read}}{\text{total symbols displayed}}\right] \times 100\ \%$$

4. Confusion Error per Symbol: (This score is computed for the symbol having the greatest number of errors in a single cell of the confusion matrix.)

$$CES = \left[\frac{\text{total number of times symbol confused (i.e., single cell score)}}{\text{total symbols displayed}}\right] \times 100\ \%$$

For example, from Fig. 1:

RE = (20/200) x 100 % = 10.0 %

RES = (10/200) x 100 % = 5.0 % (Both 'B' and '8' have 10 errors.)

CES = (6/200) x 100 % = 3.0 % (The symbol '8' has the greatest number of errors (6) in a single cell of the confusion matrix.)

If the total reading time had been 90 seconds, then

CRR = (180/90) x 60 = 120 symbols per min

5. Information Transfer Rate:

Information Transfer Rate is a composite measure of legibility performance derived from information theory concepts as they have been applied in the discipline of mathematical psychology. (Garner, 1962) Its composite nature permits one to measure the actual amount of information which the display transmits to the user by combining both rate and error scores.

$$ITR = \left[\log_2 N - \sum p(y).\log_2 p(y) + \sum\sum p(x,y).\log_2 p(x,y)\right]$$

$$\times \left[\frac{\text{total symbols displayed}}{\text{total reading time}}\right] \quad \text{bits/second}$$

where N = size of symbol set

p(y) = probability of yth symbol being named

p(x,y) = probability associated with row y and column x in the confusion matrix

ITR can be computed from the data presented in Fig. 1 as follows:

Step 1.

Transform the data in each cell of the confusion matrix to cell probabilities as shown in Figure 2.

Step 2.

Add the probability data for each row to produce a p(y) for each symbol in the symbol set as shown in Figure 2.

		SYMBOL DISPLAYED				
		A	B	2	8	p(y)
SYMBOL NAMED	A	.250	.025	0	.030	.305
	B	0	.200	0	.020	.220
	2	0	0	.250	0	.250
	8	0	.025	0	.200	.225

Fig. 2. Raw data from fig. 1 transformed to probability data in a confusion matrix.

Step 3.

Compute $\log_2 N$. For the example given, N = 4. Therefore, $\log_2 N = 2$.

Step 4.

Compute $p(y).\log_2 p(y)$ for each p(y) and $p(x,y).\log_2 p(x,y)$ for each p(x,y). Note that each computation yields a negative number.

For the example given, the following data result. They were generated using a table from Ref. 14 (pp. 345-6) and, where necessary, linear interpolation.

p(x,y)	$p(x,y).\log_2 p(x,y)$
0.250	-0.5000
0.025	-0.1324
0.030	-0.1518
0.200	-0.4644
0.020	-0.1129
0.250	-0.5000
0.025	-0.1324
0.200	-0.4644
$\sum\sum$ =	-2.4583

p(y)	$p(y).\log_2 p(y)$
0.305	-0.5225
0.220	-0.4806
0.250	-0.5000
0.225	-0.4842
$\sum$ =	-1.9873

Step 4.

Compute $\left[\log_2 N - \sum p(y).\log_2 p(y) + \sum\sum p(x,y).\log_2 p(x,y).\right]$

For the example given, this value

$$= 2 -(-1.9873) +(-2.4583)$$
$$= 2 + 1.9873 - 2.4583$$
$$= +1.5290 \text{ bits/symbol}$$

Note that this value will always be less than $\log_2 N$.

Step 5.

Compute ITR.

For the example given:

$$\text{ITR} = +1.5290 \text{ bits/symbol} \times (200/90) \text{ symbols/sec}$$

$$= 3.40 \text{ bits/sec}$$

PROPOSED LEGIBILITY SPECIFICATION FOR VIDEO MONITORS

The following legibility specification is divided into three sections:

A. Minimum Conventional Legibility Criteria

B. Legibility Test Performance Criteria

C. Legibility Test Specification

The Minimum Conventional Legibility Criteria are derived from legibility research data applicable to electronic displays. These criteria are provided to enable the quick rejection of candidate video monitors which do not meet what are considered to be minimal human engineering standards for legibility of CRT-displayed, dot matrix symbology.

The Legibility Test Performance Criteria enable the acceptance or rejection of those monitors which satisfy the criteria in Part A of the specification. Those monitors which pass the Legibility Test are then rank-ordered in terms of their ITR scores.

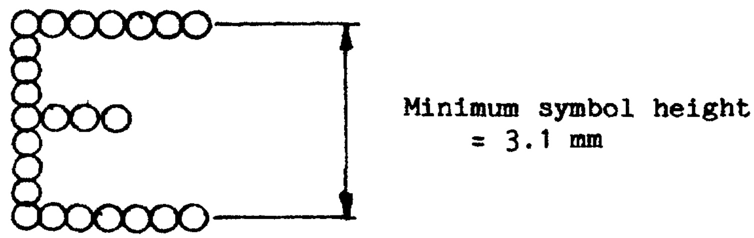
The Legibility Test Specification describes in detail how the legibility test is to be run, controlled and scored.

Part A: MINIMUM CONVENTIONAL LEGIBILITY CRITERIA

1. Minimum Symbol Height:

   3.1 mm (based upon minimum acceptable angular subtense of 18′ and 60 cm viewing distance)

   Symbol height is defined as the centre-to-centre distance between the top and bottom pixels as shown below.



2. Minimum Symbol Matrix Dimensions:

   5 x 7

3. Minimum Symbol Luminance:

   25 ftL (see Appendix A for measurement procedure)

4. Minimum Contrast Ratio:

   4:1 (see Appendix A for calculation procedure)

   with ambient illumination in range 75-100 fc.

5. Minimum Pixel Diameter to Pixel Spacing Ratio:

   0.7

   Pixel diameter can be calculated using the shrinking raster method described in Ref. 15. Pixel spacing can be calculated from the data for symbol height and symbol definition.

6. Minimum Treatment of Screen Surface:

   a diffusing treatment that effectively reduces specular glare from the screen

Part B: LEGIBILITY TEST PERFORMANCE CRITERIA

Note: The following criteria apply only to the set of 62 alphanumeric symbols. They are based upon criteria found in Refs. 5 and 10.

1. Minimum Acceptable Corrected Reading Rate

   CRR = 120 symbols per min

2. Maximum Acceptable Reading Error

   RE = 3 %

3. Maximum Acceptable Reading Error per Symbol

   RES = 0.45 % (i.e., 15 % of RE)

4. Maximum Acceptable Confusion Error per Symbol

   CES = 0.30 % (i.e., 10 % of RE)

5. Information Transfer Rate

   ITR is computed only for those monitors that satisfy 1-4.

Part C: LEGIBILITY TEST SPECIFICATION

1. Subject Selection

Six subjects shall be selected for the legibility test. Each of the subjects shall have 20/20 far and normal near visual acuity, normal phoria, normal colour vision, and normal depth perception as tested using a standard vision tester. Subjects who normally wear eye glasses or contact lens shall wear them during vision testing and legibility testing.

Where possible, the subjects shall be randomly selected from the potential user population and, ideally, should not have extensive experience with video terminals.

During the running of the legibility tests, subjects shall wear a black matte smock in order to reduce reflection of external light onto the screen.

2. Environmental Controls

Environmental conditions shall be identical from one testing session to another.

The testing environment shall have an illumination level in the range 75-100 fc. as measured with a properly calibrated photometer. Fluorescent lighting shall be used.

The testing environment shall be free from distracting sources of noise. The overall noise level shall be no greater than 55 dbA.

The testing environment shall be windowless.

3. Video Monitor Setup

A position for placement of monitors shall be selected such that specular and diffuse glare from the display surface is reduced to a reasonable minimum.

The position of the monitor in the testing environment shall be identical for each monitor under evaluation.

For CRT monitors, background raster luminance shall be adjusted to obtain a ′just invisible′ condition.

If the monitor is provided with an external ′contrast′ control, then symbol luminance shall be set to a level considered optimal in a pretest involving 4-6 experienced CRT display users. Background raster luminance shall satisfy the ′just invisible′ condition.

If a CRT monitor is provided with an external focus control, then symbol focus shall be adjusted to an optimal level as per the above paragraph.

4. Test Material

The symbol set for testing purposes shall consist of the 62 alphanumeric symbol set described in Part A of this specification.

The unit of symbol data displayed to the subject shall be an array of dimension 4x3 (i.e., 3 rows of symbols, with 4 symbols in each row). Horizontal and vertical spacing shall be the same as that provided on the operational display.

The symbols for each array shall be preselected by DCIEM such that the following conditions are satisfied:

a. Thirty one arrays shall be presented for each monitor/test condition for a total of 372 (31x3x4) symbols to be named by the subject for each monitor tested;

b. The 62 symbols shall be distributed in an equiprobable manner for each monitor/test condition (i.e., each of the 62 symbols shall appear 6 times in the total 372 symbol presentations for each monitor/subject test condition).

c. No symbol shall be repeated in an array;

d. The arrays shall not contain meaningful combinations of symbols (e.g., LOVE, TRAP).

e. The total number of sets of 31 arrays shall equal 2xN, where N is the number of monitors under evaluation; one set shall be used in practice sessions while the other set shall be used in testing sessions;

f. The order of presentation to the subject of arrays and monitors will be randomized.

5. Array Presentation

The 31 arrays presented in each subject/monitor test condition shall be presented at 5 screen positions as shown in Figure 3. The order of presentation of the arrays shall be as shown in Figure 3. The number of arrays presented at each screen position shall be 6 except for the centre position which shall have 7 arrays (i.e., 6+6+6+6+7=31).

Screen positions are defined as follows:

Position #1
Upper left symbol of the array in the upper left (i.e., home) position of the screen symbol format;

Position #2
Upper right symbol of the array in the upper right position of the screen symbol format;

Position #3
Lower right symbol of the array in the lower right position of the screen symbol format;

Position #4
Lower left symbol of the array in the lower left position of the screen symbol array;

Position #5
Symbol array centred on screen symbol format.

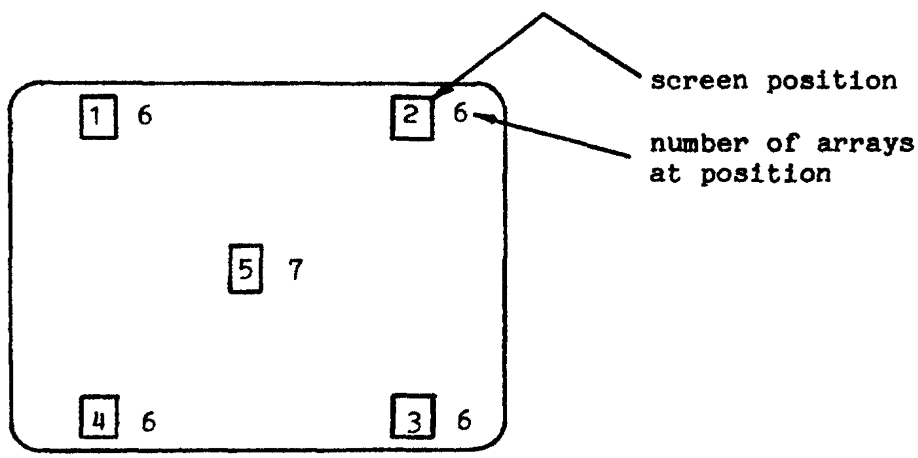


Figure 3. Array presentation protocol for the proposed BADPS legibility test.

For a single testing session in which the subject will name the symbols in 31 arrays, the first 6 arrays will be presented sequentially at screen position #1 followed by 6 arrays at position #2 and so on.

The arrays presented at each screen position shall be presented one after the other with no blanking interval between presentations. The subject shall control the presentation of each array by operating a small handheld pushbuton control.

The subject shall control the onset of presentation of the first array at each screen position. That is to say, the subject will be able to pause between screen positions.

6. Subject's Task

The subject's task shall be an array reading task.

The instructions for the subject's task shall be written by DCIEM and shall meet established criteria for task instruction design.

Each test session shall be preceded by a practice session.

The subject shall be comfortably seated directly in front of the test monitor at a viewing distance of 90 cm from the centre of display screen. A microphone shall be positioned in close proximity to the subject's mouth in order to prevent the subject from leaning towards the screen.

When the subject operates the pushbutton control initially, the word 'START' shall be displayed at screen position #1. When the subject operates the control a second time, the first array shall be displayed at position #1.

The subject shall then attempt to name the symbols in the array. When this task has been completed, the subject shall again operate the PB which shall cause the next array to be displayed and so on.

The subject shall name the symbols in a normal reading fashion, namely, from left to right and top to bottom. The subject's verbal responses shall be recorded on a tape recorder.

After the 6th array at screen position #1 has been named, the word 'STOP' shall be displayed at position #1 and the word 'START' shall be displayed at position #2.

The subject may now pause before operating the PB again. Once the PB is operated, however, the above sequence of events is repeated.

The computer shall log the time of display of the first array and the time at which the last array is erased for each screen position. The reading time for that screen position shall be the difference between the two times.

The subject shall not be informed of the correctness of incorrectness of his/her responses until all the data are collected for that subject.

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APPENDIX

A STANDARDIZED PROCEDURE FOR MEASURING CRT SYMBOL LUMINANCES AND CALCULATING CONTRAST RATIOS

A. Photometric Equipment

1. Components:

   Photometric microscope
   Microscope stand
   Photometer

2. The photometric system components for measuring CRT-displayed dot luminance should have technical and performance specifications at least equivalent to those of the Gamma Scientific 2400 photometer amd model 700-10 photometric microscope. In particular, the area of acceptance of the photometric probe as measured at the screen must be smaller than the CRT dot area as viewed through the photometric microscope in order to achieve valid results.

3. The photometric system shall have been calibrated according to the manufacturer's instructions using an NBS traceable source.

B. Test Environment

1. In order to obtain valid contrast ratios the illumination level in the test environment must approximate that in the operational environment. To ensure constancy of illumination level the test environment must be windowless.

2. In addition, the tester should wear a matte black smock, especially if the luminance measures are to be read from the photometer's display while standing in close proximity (ie., 6 ft or less) to the test screen. The tester should stand at least 6 ft from the screen if at all possible to prevent light energy reflected by the tester from having any significant effect on symbol and background luminances.

C. CRT Video Monitor Setup

1. Orient the screen as it would be oriented in the operational environment. Ensure that specular reflections from the screen are reduced as much as possible given the illumination system in the test environment.

2. Set symbol luminance to a level considered optimal in a pretest involving a small number (3-6) of experienced CRT terminal users. Maintain raster background luminance at a 'just invisible' level.

3. Display a full screen of symbols ('Hs') for at least one-half hour prior to taking any luminance measurements. This will ensure that the display circuitry is warmed up and, therefore, stable.

D. Test Procedure

1. Display the '.' symbol in the centre and corner symbol cells on the screen as shown in Fig. 1.

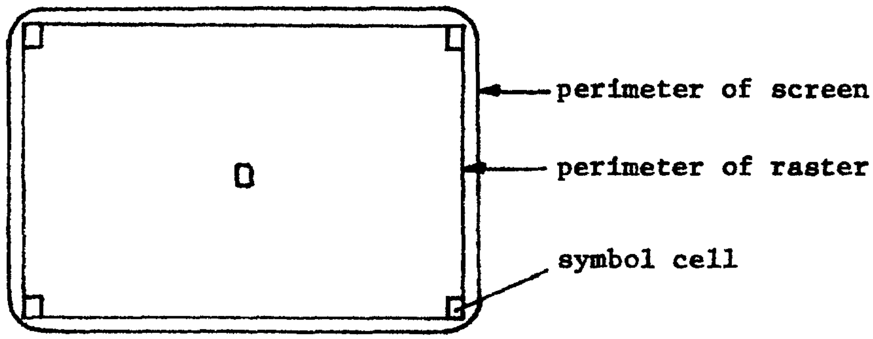

Fig. 1. Symbol cell locations for luminance measurement procedure.

2. Position the photometric microscope over one of the five displayed symbols according to the manufacturer's instructions. Ensure that the microscope's fibre probe is positioned over the centre of the symbol and that the diameter of the area of acceptance of the probe at the screen as viewed through the microscope is significantly smaller than symbol diameter. (see Fig. 2)

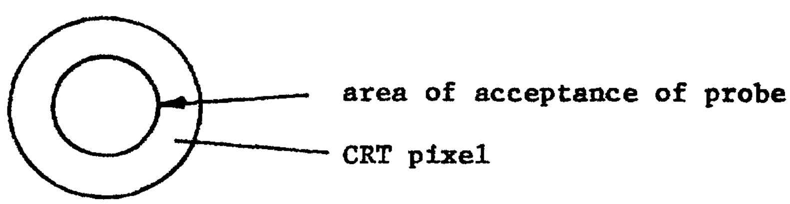

Fig. 2. Size and location of probe area of acceptance relative to area of displayed symbol.

3. Record symbol luminance. (see Fig. 4)

4. Erase the symbol and record background luminance.

5. Position the microscope over one of the remaining symbols and repeat steps 3 and 4.

6. Repeat steps 2-4 until luminance measures for all five '.' symbols have been recorded.

7. Display the 'H' symbol in the five symbol cells shown in Fig. 1.

8. Repeat steps 2-6 until luminance measures for all five 'H' symbols have been recorded. Ensure that the probe is positioned over the 'H' symbol as shown in Fig. 3.

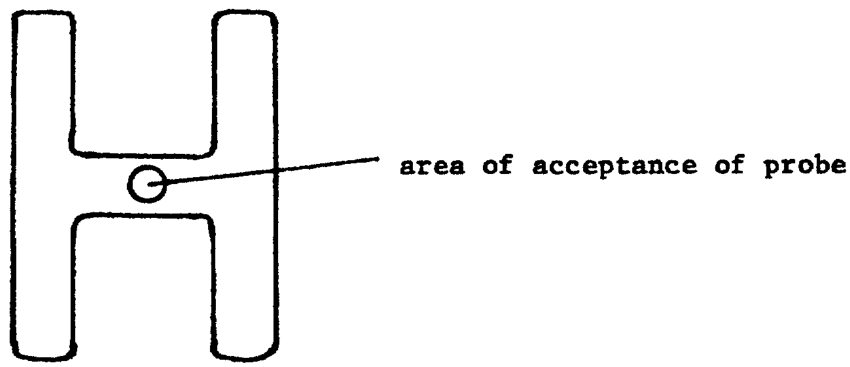

Fig. 3. Size and location of probe area of acceptance relative to area of displayed symbol 'H'.

E. Contrast Ratio Calculation

1. Overall contrast ratio for the monitor is calculated according to the following equation:

$$CR = 0.1 \times \sum_{i=1}^{10} (L_s / L_b)_i$$

where CR = overall contrast ratio

L_s = luminance with symbol displayed

L_b = luminance with symbol erased

i = measurement number

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CRT SYMBOL LUMINANCE-CONTRAST RATIO DATA

Date:____________ Location:________________________

Illumination Level:____________ Tester:____________

Measurement No.	Symbol	Position	L_s	L_b	L_s / L_b
1	.	C			
2	.	ULC			
3	.	URC			
4	.	LLC			
5	.	LRC			
6	H	C			
7	H	ULC			
8	H	URC			
9	H	LLC			
10	H	LRC			
			TOTAL =		

CONTRAST RATIO = 0.1 x TOTAL =

Fig. 4. Table for recording CRT luminance data.