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ABSTRACT

This report reviews the available literature concerning the readability of electronic displays. The dominant human factor parameters that affect display readability are discussed, and optimum values for the various parameters are presented. Since there is interaction between many parameters, the value of any one depends upon the value of the others.

The final section of this report briefly points out the advantages and disadvantages associated with the use of cathode ray tubes, light emitting diodes, and gas discharge panels.

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READABILITY OF ELECTRONIC DISPLAYS

by

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M.A. Webster College, 1978

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INTRODUCTION

The technological advances in the field of electro-optics over the past twenty years has led to the expanded use of electronic displays for the presentation of a wide variety of information. Cathode Ray Tubes (CRT), Light Emitting Diodes (LED), Liquid Crystals (LCD), Gas Discharge Panels, and other types of light emitting displays are being used for information displays varying from single character displays to those with 40 or more lines of data to maps and pictures.

For any display to be useful, the information that it displays must be readable. This paper discusses the more important human factor parameters affecting the readability of electronic displays. The dominant parameters are divided into catagories of display design, man-machine interface, and the environmental factors. The last section of this paper briefly discusses the advantages and disadvantages of the different types of displays.

It will be emphasized that the parameters are not independent of one another. Altering one parameter may have an effect on one or more other parameters (i.e., decreasing character size may decrease resolution also). Conversely, if one parameter cannot be changed, one or more of the others may be altered to get the same resultant readability (i.e., if character size is fixed, increasing resolution or decreasing viewing distance will improve readability).

Since the bulk of displayed information is alphanumeric, the discussion will be restricted to alphanumeric displays.

DISPLAY DESIGN CHARACTERISTICS

Many of the factors which can affect readability of a display are intrinsic to the display machinery. Factors such as character size, resolution, and font are designed into the display; once the equipment is installed, these factors generally cannot be altered. The best time to consider these very important human factors is while designing the display or when shopping for a display.

<u>Symbol size</u>

The size of the displayed character is probably the most important readability factor. Symbol size may be measured by subtended angle (α). Subtended angle allows for differences in viewing distance[1] by measuring character height (H) relative to viewing distance (D).

$$\tan\alpha\text{, min of arc} = \frac{H}{D}$$

By knowing the viewing distance and the appropriate subtended angle, the appropriate character size may be selected.

Considerable research has been conducted to determine the optimum subtended angle. Results vary, but there is a general consistancy. See Table 1 for values of subtended angle for "near error free" reading.

These findings agree generally with the current design standards of 10-15 min. of arc.[2] Note that the more recent research has emphasized the effects of other parameters such as illumination, blur, resolution, and glare on the optimum subtended angle. Under good conditions 15 minutes of arc will be readable, but as the conditions worsen, the subtended angle must increase upwards to as much as 35 minutes.

<u>Resolution</u>

Resolution is the number of dots per character height (for dot matrix displays) or the number of lines per character height (for raster type CRT's). For CRT's the minimum recommended resolution is 10

Table 1

Some Recommendations of Displayed Alphanumeric Characters*

Reference	Subtended Angle, minutes of arc
Minimum Normal acuity (Snellen E Chart)	5
"Reasonable" size (Murrell, 1965; Fletcher, 1972)	10
Electronic Displays (Shurtleff, 1967; Gould, 1968)	12-15
"Image size" (H.E.G.; 1972)	12-20
"Preferred" size (Duncan and Konz; 1974)	17
MIL-STD-1742 (1974)	
General Labels, good viewing	16+
Non-critical Data	6-24
Critical Data	
high luminance	12-25
low luminance	25-37
"Minimum recommended" (Buckler, 1977)	
Good Conditions	15
Degraded Conditions	21-25

*(Portions of this Table adapted from Smith, 1978)[2]

lines per symbol height.[3] For dot matrix displays a 7 x 9 matrix (7 wide and 9 high) is superior to a 5 x 7 matrix.[4] A 3 x 5 matrix has too little resolution and cannot be read easily.[3]

Symbol size and resolution are closely related. As the resolution increases, the symbol size required to maintain good readability decreases.[3] Thus, optimum resolution may be described best in combination with symbol size. Under good viewing conditions the greater of 10 lines/character or 15 minutes of arc is recommended; but with poor viewing conditions use 16 lines or 21-25 minutes.[3]

<u>Percent active area</u>

Percent active area is that portion of the symbol that is actually emitting light. It is defined[3] by $\left(\frac{\text{Emitter size}}{\text{Emitter spacing}}\right)^2 \times 100$. Increase the active area by increasing emitter size or decreasing the spacing between emitters. Decrease dot spacing by increasing resolution or by decreasing character size.

Large dimmer emitters are more legible than small bright ones.[3] Dot elongation adversely affects readability so round or square dots are more effective than rectangular or elongated dots.[4]

To make the dots run together and appear as a continuous line, the spacing between the dots should subtend no more than 1 min. of arc.[5] One minute of arc is the minimum spacing that the normal human eye can perceive so anything less will be imperceptible.

<u>Character generation</u>

There are essentially three methods for generating alphanumeric characters in electronic displays. These methods are the following:

1. raster type CRT's

2. dot matrix

3. segmented bar matrix.

For readability, raster generally is the best method because it provides the greatest resolution at a reasonable price. In a dot matrix as the number of dots in the matrix increases, the readability improves. However, as more dots are added, the character size increases, and the number of characters being displayed must decrease, or the display size must increase.

For readability, dot matrix symbols are superior to segmented bar generated symbols.[4] A reasonably priced segmented bar matrix cannot closely approximate the alphanumeric characters. This problem diminishes as the number of segments increases, but the character size also increases with the addition of more segments. The number of segments used generally is limited by cost and display size.

Font

Font is the shape and geometry of the alphanumeric characters. For electronic displays the font must be simple, without serifs and italics. Only upper case letters should be used for dot matrix and segmented bar displays.[3] These limitations are imposed because of the limitations of the character generation methods mentioned above.

For electronic displays, the Leroy Font (Fig. 1) is the most widely accepted.[6] Other widely accepted fonts are the Military Specification MIL-M-18012 and Lincoln/Mitre.[3]

Slanting characters are more difficult to read than upright characters.[4]

Stroke width-to-height

Stroke width-to-height also is dictated by symbol generation technique and resolution. For example a 7 x 9 dot matrix will have a stroke width-to-height ratio of 1:7 (i.e., 14%). It is important that the ratio not become too small or the character stroke will blur or run together. Sherr recommends 14% as a minimum [6] and Buckler recommends a range of 10-17%.[3] Note that as the stroke width-to-height ratio increases, so must resolution.

Symbol spacing

Symbol spacing is the distance between the beginning of a character and the end of the preceeding character. A wide range of acceptable spacing values have been reported (from 25% to 200% of symbol width). Konz and Duncan recommend 75% as a maximum because legibility decreases beyond this.[1] Buckler recommends a range of 26-63%.[3]

Color

For economic reasons most displays are monochromatic. Combination of colors may be used effectively for color coding data and to enable more information to be displayed at once. When using multicolor displays, care must be taken to provide good contrast between all colors and between the symbols and the background.

Contrast

Generally, the higher the contrast between symbols and the background, the better the readability. Direction of contrast (light on dark or dark on light) is insignificant in most cases.[3]

Luminance modulation, M, is a mean of defining contrast:

$$M = \frac{L-D}{L+D}$$

where L = brightest luminance (i.e., symbol)

D = dimmest luminance (i.e., background)

This equation may be modified to allow for the effects of ambient luminance. The modified equation is as follows:[7]

$$M = \frac{(L_i + L_e) - (D_i + L_e)}{(L_i + L_e) + (D_i + L_e)} = \frac{L_i - D_i}{L_i + D_i + 2 L_e}$$

where L_i = internally produced symbol luminance

D_i = internally produced background luminance

L_e = reflected ambient luminance

Howell and Kraft, cited by Snyder,[7] recommended a modulation of .94 with .88 acceptable for character sizes less than 16 min. of arc. Snyder[7] concluded that readability would be good as long as the symbol subtends at least 10.8 min. of arc if modulation was at least .78.

MAN-MACHINE INTERFACE

Man-machine interface refers to those factors that must be considered to link together the man and machine. Unlike the design factors, these factors may be changed once the display is installed in order to optimize readability.

Viewing distance

By defining character size in terms of subtended angle, viewing distance has been included. Once the actual character size is determined, optimum viewing distance may be determined from the optimum subtended angle. When viewing display terminals, viewing distances of 35 to 50 cm are preferred.[8]

Optimum subtended angle is not completely independent of viewing distance. Characters being viewed from less than 1 meter require a slightly larger subtended angle than those viewed at a greater distance.[2]

This implies using subtended angles from the upper range of values when viewing distance is less than 1 meter.

<u>Viewing angle</u>

Viewing angle refers to the line of sight relative to a perpendicular to the display screen. The acceptable viewing angle for good readability is affected by other factors such as ambient illumination, screen curvature, use of lenses, contrast, resolution, and character size. Because of the many other factors affecting it, there is a relatively wide range of acceptable viewing angles for good readability, but 30° is the recommended maximum angle.[3] The most comfortable viewing angle is 15° (viewing from above).[9]

<u>Visual acuity</u>

Viewing an electronic display is quite different from reading printed material. Persons who normally do not have an acuity problem may experience some difficulties viewing electronic displays because of the different luminance levels, flicker, contrast, character generation, resolution, etc. If a person is to spend an appreciable amount of time viewing electronic displays, it is advisable that the person's visual acuity be checked under these viewing conditions, and appropriate corrective lenses be provided if necessary. A solution, especially for people viewing electronic displays all day, is to provide them with a pair of "work glasses." These glasses would be ground for the specific focal length used at the viewing task. That is, if the person views the display from 20 inches, the corrective lenses would be designed for a focal length of 20 inches.

Persons who wear bifocals especially should be provided with work glasses. Because of the way bifocals are designed, the viewer must look out of the top or bottom half of the glasses when viewing the display. This causes the viewer to hold his head in an unnatural position for extended periods, resulting in muscle aches and fatigue.[9]

If displays use color coding, then color weakness may be a problem. Color weakness normally occurs only in males and may be detected with a simple test. Avoid using red and green or yellow and blue in pairs.

ENVIRONMENT

The primary environmental parameter affecting readability of electronic displays is lighting (placement, intensity, and type). Walls, floors, ceilings, and other equipment and their location, reflectance, and contrast relative to the work area also are primary considerations. There are many other environmental factors such as temperature, vibration, and obscurations which also may affect the readability of displays. Each work area will have its own unique set of environmental considerations that must be analyzed for that particular display. Only the effects of lighting and surface reflectances will be discussed here.

Lighting

Ambient illumination levels affect how well a display may be read. The contrast between display luminance and ambient luminance is the parameter which must be controlled. This ratio may be defined as follows:[10]

$$F_s = B_s / B_b$$

where F_s = surround factor

B_s = ambient luminance

B_b = display luminance

Readability is best under moderate ambient luminosities when $0.1 <$

$F_s < 1.0$. Readability is poor when $F_s < 0.1$ (where ambient luminosities are low) and when $F_s > 1.0$ (where ambient luminosities are high).[10] Ostberg[7] recommends $0.1 < F_s < 1.0$.

Another problem with ambient lighting is glare and its masking effect. Light reflected from the display will blur, dim, obscure, or otherwise mask the display data making it difficult to read. The best way to control this effect is to control the level and/or direction of ambient luminance.

As mentioned previously, dim display luminance is preferable to bright displays because brighter symbols have edge blurring and tend to run together. With this in mind, ambient luminance should be kept low also. When the display must be located in an area where luminance levels must be relatively high to permit other types of work, the display and the operator can be shielded from direct light to improve readability. Where displays cannot be shielded effectively (such as displays out of doors), filters may be installed on the screen to reduce the amount of light reflected by the display. By reducing the amount of light reflected, the contrast modulation (M) is increased, which is desirable.

<u>The work area</u>

The color and reflections of all surfaces (both in the immediate work area and the surroundings) will have an effect on glare and the contrast between the display and its surroundings.

Glare may be reduced by assuring low reflectivity of all surfaces and by shielding the display and the operator from the reflective effects.

The colors used in a room will affect the amount of ambient illumination present. Light colors and diffused light will provide more even room illumination and eliminate shadows. Pastels and light grey are recommendations for surface reflectance.[5] All surfaces should be of a color and material so as to reduce specular reflection (i.e., reflected glare).

Table 2 is a general reference for colors to be used to provide appropriate reflectance.[5]

If colored displays are being used, then care must be taken with the selection of the luminaires, since the lamps may produce different color effects.

Much can be done in office layout, landscaping, and luminaire selection and placement to facilitate improved display readability.

TYPES OF DISPLAYS

The discussion here will focus on the relative advantages and disadvantages of the three major types of electronic displays (CRT, LED and LCD, and gas discharge).

CRT's (cathode ray tubes) have an advantage because they have been in use the longest. Research and development through the years has provided a broad base of application for the CRT. The primary advantages of using CRT's are high writing speed, high resolution, simple addressing, full color capabilities, full range of gray scales, storage, large range of screen size, and high luminous efficiency.[11] Disadvantages of CRT use include bulkiness of the equipment, curvature of the screen, high voltage required, relatively delicate equipment (vacuum tube), and limitations of maximum screen size.[11]

The development of CRT flat panels will help alleviate the problems associated with bulk, screen curvature, high voltage requirement, and

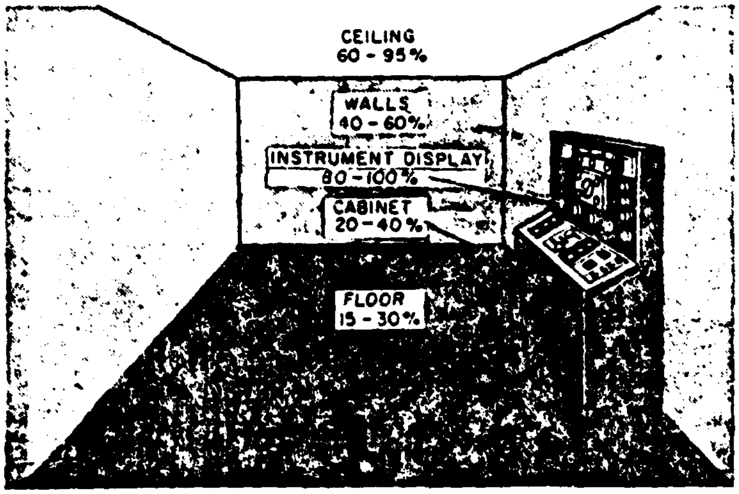

FIGURE 2. General recommendations for workplace reflectances.

TABLE 2. APPROXIMATE REFLECTANCE FACTORS FOR VARIOUS SURFACE COLORS

Color	Reflectance	Color	Reflectance
White	85		
Light:		Dark:	
Cream	75	Gray	30
Gray	75	Red	13
Yellow	75	Brown	10
Buff	70	Blue	8
Green	65	Green	7
Blue	55		
Medium:		Wood Finish:	
Yellow	65	Maple	42
Buff	63	Satinwood	34
Gray	55	English Oak	17
Green	52	Walnut	16
Blue	35	Mahogany	12

ruggedness of the equipment.

LED (light emitting diode) and LCD (liquid crystal) displays currently dominate the small display markets such as hand held calculators. Advantages of these displays are their long life and very low driving voltage requirements. The number of characters per unit area displayed is limited due to the character size. Because low resolution and character generation limits the readability of LED and LCD displays, the characters must be relatively large, thus limiting the number of characters per unit area being displayed.

Gas discharge displays are relatively new in the field of electronic displays, but they are challenging both the CRT and LED markets. The driving voltage for gas discharge is around 40v as compared to 170v for CRT and 5v for LED.[12] Because of this relatively high voltage requirement, gas discharge displays are not portable. The initial investment for gas discharge is considerably higher than for LED. On the other hand, gas discharge panels can provide better resolution and smaller character size than the LED. Because it is still very difficult to make very small discharge dots, the gas discharge panels must be relatively large compared to a CRT displaying the same amount of information. However, the maximum size of the gas discharge screen is not limited as the CRT is. Finally the gas discharge panel is much thinner and more rugged than the CRT.

In summary, LED and LCD displays, because of low operating cost, ruggedness, and portability, have the advantage when only a small number of characters need be displayed at once. CRT's provide good readability for large amounts of data on relatively small screens. They also provide a wide selection of display types such as color, screen size, memory, drive mechanisms, etc. The gas discharge is a promising new display that challenges the CRT in that it is more rugged, less bulky, and may provide for larger display screens.

Conclusion

Only the more dominant human factor considerations have been discussed here. There are other factors such as vibration, climate, and oral and visual distractions that also may affect readability. When installing, remodeling, or buying an electronic display, attempt to identify the factors that will affect the optimum use of the display. The human factors then must be taken compositely and balanced against other nonhuman factors such as costs (of remodeling, of different display types, power, etc.), management and personnel preferences, and availability of equipment to obtain the best equipment and work area layout that will maximize the benefits of the display.

REFERENCES

1. Duncan, Jerry and Kons, Stephan. "Legibility of LED and Liquid-Crystal Displays," SID Journal, 1976, 17(4), 180-86.

2. Smith, Sidney L. "Letter Size and Legibility" unpublished manuscript, The MITRE Corporation. Sept. 1978, Bedford, Mass.

3. Buckler, Andrew T. "A Review of the Literature on the Legibility of Alphanumerics on Electronic Displays." U.S. Government Report No. ADA 040625, May 1977.

4. Vartabedian, Allen G. "Legibility of Symbols on CRT Displays." Applied Ergonomics, 1971, 2(3), 130-132.

5. Grether, Walter F. and Baker, Charles A. "Visual Presentation of Information." Human Engineering Guide to Equipment Design, Ch. 3, McGraw-Hill, New York, 1963.

6. Sherr, Sol. Fundamentals of Display Systems Design. Wiley-Interscience. New York, 1970, Ch. 1.

7. Snyder, Harry L. "The Sensitivity of Response Measures of Alphanumeric Legibility to Variations in Dot Matrix Display Parameters " Human Factors, 1979, 21(4), 457-471.

8. Bennett, A.G. and others. "Human Factors of Workstations with Display Terminals," International Business Machines Corporation, May 1978, San Jose, Calif. p. 27.

9. Ostberg, Olov. "The Ergonomic Requirements of Microform Reading Design." Reprographics Quarterly, 1977, 10(2), 43-48.

10. Kuehn, Rudolph L. and Luxenberg, H. R. Display Systems Engineering, McGraw-Hill, New York, 1968, p. 107.

11. Considine, Kevin. "CRT Technology." Conference Record of 1976 Biennial Display Conference, Institute of Electrical and Electronic Engineers, 1976, p. 80-87.

12. Soble, Alan. "Gas-Discharge Displays: The State of the Art, " Conference Record of 1976 Biennial Display Conference, Institute of Electrical and Electronic Engineers, 1976, p. 99-103.