# Reading Electronic Text

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# Reading Electronic Text

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**Abstract**

A review of empirical studies examining factors affecting the reading of electronic text was conducted in order to provide recommendations and guidelines for the design of electronic text displays where the reading of continuous text needs to be optimized. Significant differences were found between reading performance of paper text when compared to the same text read from electronic displays due to a variety if interacting variables. Among the most important of these variables were the spatial resolution and contrast modulation of the electronic display, display flicker, image polarity, and typography. Studies examining different methods of electronic display, such as Rapid Serial Visual Presentations (RSVP), were also reviewed. Conclusions and recommendations for the design and use of electronic displays in facilitating the reading of electronic text are provided.

## Introduction

The explosive growth of computer technology and our increasing reliance on it for the processing and display of information means that most of us will be reading textual information from electronic displays on a routine basis. Unfortunately, electronic display technology are far from the optimal medium for reading. Developed originally for instrumentation and radar display and later for television broadcasts, display technology has only recently begun to achieve the necessary resolution and image quality needed to compete effectively with paper medium. Nonetheless, there is considerable evidence both empirical and anecdotal, which suggests that substantial losses in reading performance are being incurred when textual information is displayed electronically as compared to performance when the same information is provided in paper form. Clearly, the importance of such a finding for user productivity in the age of information and the Internet should be self-evident. Furthermore, substantial benefits could accrue if a means could be found to minimize or eliminate this difference through technology enhancements, interface design or other means.

Evidence also exists to suggest that electronic text display may a more efficient means (and sometimes the only means) of displaying textual information under certain conditions. For example, where display space is severely restricted, electronic displays may allow the successive display of individual words, sentences or parts of sentences. The use of successive or serial presentation provides an opportunity to provide the needed information to the user under conditions where the fixed presentation size of paper medium is not practical. Additionally, electronic text is the only choice where real-time remote update is desired and immediate display is needed. Optimization of the new modes of presenting textual information, made possible only by electronic displays, is also important to user productivity and to technological improvements as well.

This report examines the factors affecting the reading of electronic text. The findings are particularly relevant to the office and home environments, where desktop, laptop, and related computer devices have become common in the processing and display of textual information. Studies of instrumentation displays, such as those used in vehicle and process control, will not be addressed in this report. While display factors, such as resolution and image quality, are important contributors to reading performance, additional factors such as typography, image color, and presentation modes will be all be addressed this report. Recommendations for image display, typography, presentation modes, and other design alternatives for displaying electronic text will presented at the end of the report.

**Display Technology and Reading Behavior**

While a comprehensive review of electronic display technology and the processes of reading behavior are beyond the scope of this report, a brief review of the fundamentals of display technology and of perceptual processes of reading behavior is necessary in order to understand the contents of this report.

*Display technology*. Virtually all computer desktop and workstation monitors rely on Cathode Ray Tube (CRT) technology to display images to the user. Fundamentally, the CRT in computer monitors is very similar to most television tubes with the exception that additional digital processing and control technology is required. Images are formed on the CRT by the scanning of phosphor elements on the rear of tube with one or more scanning electronic beams. For computer monitors, the entire screen is scanned (or refreshed) at a minimum of 60 Hz (twice that of television tubes), although more advanced displays may have much higher refresh rates. Individual picture elements (pixels or dots) composed of phosphors activated by the scanning beam are used to construct the images (including text images) that users ultimately see displayed. In high resolution displays, millions of such pixels may displayed at a any one time.

In contrast to CRTs, the low power and smaller size of the Liquid Crystal Displays (LCDs), introduced by RCA in 1968, make them the display of choice for portable computers and other devices. Unlike CRTs which vary the light *emitted* from the display, LCD's vary the details of the image by controlling reflected light from *outside* the display. The control of the LCD image is achieved by passing a very low level electric current through selected areas of a liquid crystal sandwiched between two layers of conductive material. The non-activated areas of the LCD display allow incoming light to be reflected from a mirrored surface behind the sandwich. It is this reflected light that the user sees on the display as electronic text. While the conventional LCD does not suffer from the CRT's potential image instability (e.g., flicker), it's reliance on a reflected ambient light source means that the intensity and direction of the light within the users environment can have a significant effect on image clarity.

The evolution of the LCD display has been given a tremendous boost by the advent of Thin Film Transistor (TFT) technology. The TFT technology allowed the possibility of the much higher quality "active matrix' displays in LCD devices such as portable computer. The LCD/TFT active matrix provides a transistor at each of the pixels allowing the storage of a charge at pixel location. This active matrix technology results in much higher image resolution and faster image refresh than was possible with conventional LCDs. However, most LCD/TFT display resolutions are still well below those of CRTs. As a result, studies reviewed here have focused on CRT technology in evaluating electronic text.

*Image resolution*. All digital monitors, whatever the underlying technology, are characterized by two resolution measures: addressable resolution and spatial resolution. Addressable resolution refers to the number of pixels which can be addressed on the monitor and are usually expressed in horizontal and vertical values (e.g., 640 X 480). A more important measure of a display's imaging capability is spatial resolution. Spatial resolution of a display is calculated by dividing the active scan area of a display by the addressable resolution. (The active scan area is the total area of the screen capable of displaying an image). Thus, a display which has an addressable resolution of 640 pixels horizontally and has an active scan area 10 in. (25.4 cm) wide has a spatial resolution of 64 pixels or dots per inch (dpi) or 25 dots per cm (dpcm). Digital monitors usually have symmetrical spatial resolution so a similar value would be derived for the vertical dimension of the monitor. As the active scan area is independent of the addressable resolution of the monitor, it is generally the case that the same addressable resolution on a small monitor will result in a lower spatial resolution on a larger monitor. In other words, a 15 in. monitor with a 640 X 480 addressable resolution will have a spatial less than a 13 in. monitor with the same addressable resolution. As spatial resolution affects the amount of image detail available per unit area, it is one of the major determinants of the readability of a display.

The image quality of a display is also a function of what is called "luminance or contrast modulation frequency" measured by a unit called the Modulation Transfer Function (MTF). The MTF is a means of indexing the physical ability of the display to deliver these contrast modulations over a range of frequencies. Below a certain frequency, the contrast sensitivity threshold, the human eye responds to these modulations as perceivable patterns of dark and light (rather than continuous shade) frequency. Above this threshold, the human eye cannot resolve the pattern. This contrast sensitivity curve can be used in conjunction with MTF to yield a single value of image quality, the Modulation Transfer Function Area (MTFA). Standards have been developed and published in ANSI/HFES 100-1988 (Human Factors Society, 1988) which allow engineers to quantify the image quality of any display using the MTFA value. As MTFA is linked to actual human visual processing, this measure has a become valuable tool in quantifying what users often describe as the "clarity" of a display. As we will see, image quality as measured by MTFA is also a major determinant of the readability of electronic text.

*Reading and human visual processing*. It is important to any discussion of the readability of electronic text display that there be some understanding of the visual processes involved in reading. The perceptual processes involved in reading behavior are complex and can only be summarized here (see Rayner & Pollatsek, 1989 for a detailed discussion). While reading for comprehension and proof-reading involve different task elements, the studies reviewed here will include both types of reading activities.

 

Reading as a visual process is composed of a set of eye movements as well visual pattern recognition processes. Four main eye movement behaviors affect reading performance for continuous text: fixation duration, saccadic length, regression, and return sweep. In order to process textual information, the reader must visually fixate on the text at the beginning and at various points during the reading process. Typical fixation durations range from 150 to 500 msec. depending on variety of factors. All visual information processing occurs during these brief periods of fixation. Fixations are followed by saccadic (or jumping) movements in which the eyes move some 7 to 9 character spaces where them come to rest again for another fixation. Provided the reader is close enough so that characters of the text are legible, the size of the saccadic movements are always about the same length. Regression of these saccades (returning to earlier segments of the text), occur unconsciously every 1 to 2 secs. during the reading process. The regressions appear to aid additional visual or comprehension processes. Finally, where the text consists of multiple lines, return eye movement sweeps will occur to bring the fixation from the end of one line to the beginning of the next.

Quite apart from eye movements, reading also necessarily requires active visual processing of textual information. All of this processing occurs during the fixation period. It is at this point where the human visual system must convert alternating light and dark patterns of the text characters into meaningful information. As noted earlier, the eye responds to modulations of light and dark patterns, especially to the border transition areas between these light and dark elements. Images, such as text characters, which have strong contrast with their background will tend to enhance the speed of visual processing. Images of characters which tend to blur or distort, tend to increase the fiction duration (as well as increasing the number of regressions). Legibility is the term use to describe the extent to which individual characters are identifiable. As will be seen, a variety of factors in electronic text displays can conspire to reduce legibility. Inevitably, poor legibility serves to crease reading time by increasing the duration of the fixation time need to identify the character

Legibility is also affected by the visual segregation of one character from another. Normally, text will be displayed with a least a single stroke width separating each character and the eye is readily capable of resolving this level of detail and even smaller detail on electronic displays. (The eye can resolve detail up to about 1 min. of visual arc or an image .006 inches in diameter at 20 inches viewing distance). Text displayed electronically on some monitors may eliminate this inter-character segregation due to inadequate spatial resolution. As an example, the text used in this report when displayed on a low resolution (65 dpi) display will result in frequent encroachment of one character into another character's space. This lack of segregation is one of several reasons while spatial resolution of a display is so important to the reading of electronic text.

## Electronic Displays and Reading

Attention to the problem of reading electronic text was first raised by a series of studies comparing paper and electronic text in the early and mid 1980's. A review of many of these early studies was critical of their poor methodology (Helander, Billingsley, and Schurick, 1984), but the differences between reading paper and reading electronic text found in some studies were not so readily dismissed. The studies of Muter and his colleagues (Muter, Latremouille, Treurniet, and Beam, 1982; Kruk and Muter, 1984; Muter and Maurutton, 1991) and Gould and his associates (Gould, J.D. et al., 1987; Gould, J.D., 1984, 1986) as well as others (Harpster, Frievalds, Shulman, and Leibowitz, 1989; Kak, 1981; Kolers, Duchnicky, and Ferguson, 1981; Wright and Lickorish, 1983) were better designed and still revealed reading differences between the two media. In these studies, mean reductions in reading speed for text on paper compared to the same text read from electronic displays usually varied from 20-30%. Individual subject differences in some studies could result in speed reductions of from 5% to in excess of 40%. Clearly, such large differences in reading performance have significant implications for productivity in an age where computer use is ubiquitous. The question remains as to why such differences were found in theses studies and what steps could be taken to mitigate the effects.

In a review of the literature in 1992, Dillon examined the performance differences found in these studies with the goal of identifying those variables most likely to account for the reading differences found. Although he also examined differences in performance measures used in these studies, his discussion of the physical differences between the two media are particularly relevant here. Among these variables are differences in media orientation (text is displayed wide format for display, the reverse for paper), the presence of flicker in CRTs, image polarity (dark text on light background or the reverse), a variety of typographic variables (such as font size and character spacing), and the use of anti-aliasing (to eliminate the jagged edges of characters commonly found in CDT display of text).

*Image polarity*. Of all of these physical variables, only image polarity, flicker, typography, and the interaction of these variables were deemed likely to cause the differences in reading performance found (Dillon, 1992). The first of these variables, image polarity, was often different between the CRT display and the paper document in these studies due to the common use of negative image polarity (light text on dark background) in computer monitors during the 1980's. The use of a dark image background in these was necessitated by the high degree of image flicker that occurred when light backgrounds were used (a consequence of the low refresh rates of the prevalent technology). The use of negative polarity in monitors (typically white, amber or light green text on a black background) was the near opposite of the black text on white background used in paper documentation. While the evidence to support the superiority of positive image polarity for reading text is mixed, the majority of the evidence tends to support the hypothesis that some of the differences seen these studies were due to the fact that the negative image polarity of the CRT screen used in some studies slowed reading performance (Zwahlen and Kothari, 1986; Pawlak, 1986; Cushman, 1986; Snyder, Decker, Lloydd and Dye, 1990).

*Image flicker*. Image instability or flicker was also a potential source of visual fatigue and, indirectly, of reduced reading performance in these studies. As discussed earlier, images of CRTs are raster-scanned at varying rates, though typically at 30 Hz for television CRTs and 50-60 Hz for older computer CRTs. The typical rate for modern computer monitors is 60 Hz or higher. It is still possible that flicker can occur at speeds as high as 60 Hz as has been reported in some studies (Gould, et al., 1986) and in anecdotal reports. Therefore, some of the losses in reading performance, particularly for those studies using positive image polarity, may have been due to the eye fatigue caused by image flicker on the CRT displays used.

*Typography*. Typography, or the design of type, is another potential variable which might reduce reading performance for electronic text in these studies. Digital type, unlike analog type, is constructed of a matrix of pixels, each character of given font style and size is composed from a fixed array of pixels. Table 1 shows the pixel array sizes for a variety of fonts used in the popular Microsoft™ Windows 95™ operating system. As can be seen, the number of pixels in a given font can vary significantly. Generally, large font sizes will require a large array, though the relation between font size and array size is not necessarily linear. Moreover, in computer software, font size refers not to the size as *displayed*, but rather to the size as *printed*. While there is a positive correlation between the font size and the size of type displayed on a monitor with a given resolution, there is a negative relationship between font size and the spatial resolution available a monitor. That is, for a given font size (pixel array), monitors with high spatial resolutions (pixel density) will be able to display the same array in a smaller space. As a result, the actual displayed size of a font will be reduced as the spatial resolution increases. As size of the character affects reading speed at a given reading distance (Morrison and Inhoff, 1981), physical size displayed rather than font size, per se, needs to be constant for the two media if reading performance is to be compared. Thus, the lack of comparability between character size on displays and paper documents could have affected the findings in some of these studies. Figure 1 shows how the displayed size of a particular font will change as the spatial resolution of the display changes. Included in this figure are the minimum and maximum recommended character heights for comfortable reading by the ANSI/HFES 100-1988 standard. The recommendations are given in minutes of visual arc in this standard as the size of the character viewed by the human eye will change as a function of viewing distance from the display. For the example calculation in Figure 1, a distance of 20 in. viewing distance was assumed for a range of fonts varying in size from 8 to 14 pixels in height displayed on monitors with spatial resolutions varying from 20 to 50 dpcm (51 to 127 dpi). Note how text with small fonts (e.g., 8 pixels), which may have been comfortably read on a lower resolution display, become unreadable as spatial resolution increases.

An additional factor is the composition of the pixel array of given font family. Early monitors commonly used a 5 x 7 array due to the poor spatial resolution available. In addition to affecting size, the array size affects the amount of detail of each character that can be displayed so that lower array sizes may reduce reading speed (Pastoor, Schwarz, and Beldie, 1983). A minimum array size of 7 x 9 has been recommended by the ANSI/HFES 100-188 standards (Human Factors Society, 1988) to assure adequate detail representation in digital fonts.

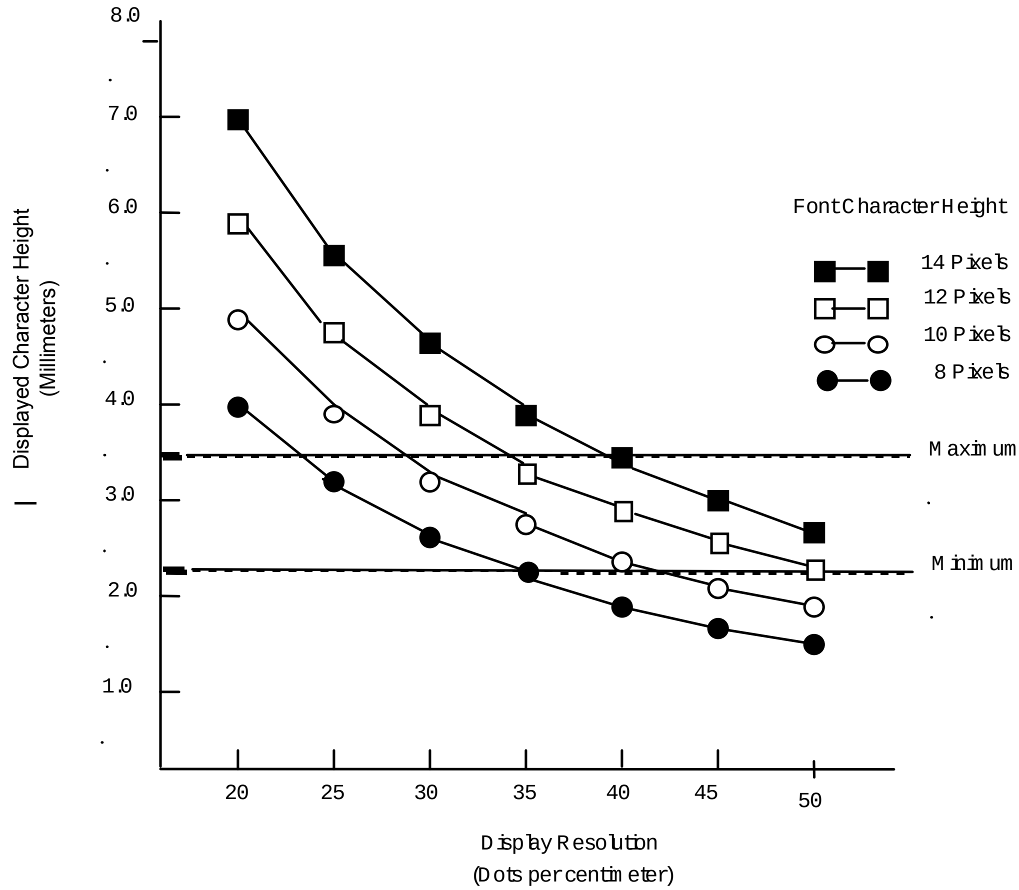


Figure 1. Effects of display resolution and font character height on the height of characters displayed. Dashed lines indicate ANSI minimum and maximum height for readability at a viewing distance of 50.8 cm (20 in).

A more recent study by Tullis, Boyntoon, and Hersh (1995) of digital type fonts reveals the importance of the interaction between display characteristics and type font. In the Tullis, et al. study using a high resolution display (est. 98 dpi), a variety of type fonts of the Windows™ operating system. Reading performance was found to best for 9.75 san serif fonts. Examining Table 1, we can see that the array size for such fonts will be 7 x 10 pixels. The findings are in line with those recommended in the ANSI/HFES standard and suggests that pixel array could be a factor in the differences found between paper and electronic text in past studies.

**Table 1. Commonly used fonts in computers with Microsoft™ Windows 95™ operating system.**

| Typeface | Serifed | Point Size | Weight | Cap Height (Pixels) | Modal Character Width (Pixels) | Character H-W Ratio |
|---|---|---|---|---|---|---|
| Arial | No | 8 | Regular | 8 | 6 | 1:0.75 |
| | | 10 | Regular | 10 | 7 | 1:0.70 |
| | | 12 | Regular | 12 | 9 | 1:0.75 |
| | | 12 | Bold | 12 | 10 | 1:0.83 |
| Courier | Yes | 10 | Regular | 9 | 7 | 1:0.78 |
| | | 12 | Regular | 10 | 7 | 1:0.70 |
| Courier New* | Yes | 10 | Regular | 8 | 7 | 1:0.88 |
| | | 12 | Regular | 9 | 8 | 1:0.88 |
| MS Sans Serif | No | 8 | Regular | 9 | 6 | 1:0.67 |
| | No | 8 | Bold | 8 | 7 | 1:0.88 |
| Garamond | Yes | 8 | Regular | 7 | 7 | 1:1.00 |
| | | 10 | Regular | 8 | 9 | 1:1.25 |
| | | 12 | Regular | 10 | 10 | 1:1.00 |
| System | No | 12 | Regular | 10 | 8 | 1:0.80 |
| Times New Roman | Yes | 8 | Regular | 8 | 7 | 1:0.88 |
| | | 10 | Regular | 9 | 8 | 1:0.88 |
| | | 12 | Regular | 11 | 10 | 1:0.91 |

*Interactions*. It is evident that individual variables affecting the readability of electronic text should not be considered in isolation. The interaction of these variables must be considered when comparing reading performance with paper and electronic text. Indeed, when studies have examined these factors in combination the reading differences are minimized or eliminated entirely. Gould, et al. (1986) compared reading performance of paper and electronic text using a high resolution (91 dpi, 36 dpcm.) display while holding format, font, color, image polarity and character size constant between the two media. Average reading performance was found to be only 5% slower on the CRT than paper. In a more recent study by Jorna and Snyder (1991), the above factors where also held constant but, in addition, the MTFA of both paper and electronic text was systematically varied. When MTFA was the same value for both paper and electronic text display, no reliable differences were found in reading performance. When MTFA differences where introduced between the two media, reading performance declined in proportion to the difference in MTFA between the two media.

## Enhancing Electronic Text Display

It should be evident from the prior discussion that complex interactions among a number of factors are responsible for reading performance. Designers of electronic text displays have added to the list of potential factors affecting reading by introducing enhancements. Alterations to the basic text display characteristics are often introduced for reasons of aesthetics or to satisfy user preferences.

*Color*. Coloration of text and its background are becoming more common with the widespread use of color computer monitors and mass distribution technologies such as the Internet. Coloration is often introduced so that the images displayed will be more engaging or compelling to users than monochrome or gray-scale images. When this design philosophy is carried in to the display of electronic text, problems will often arise in reading performance. In part, this problem occurs because coloration of either text , background, or both tends to reduce the contrast between individual characters and the background of the display. Where black text on a white background (or its reverse) provide the maximum contrast available from a display, the addition of color tends to reduce contrast, and as a result, legibility of individual characters ( Lalomia and Happ, 1987; Poynter, 1991; Tinker, 1963).

Adding to the problem of image contrast in reading colored text are chromatic aberrations of the human eye and color deficiencies in the human population. Chromatic aberrations result in differential accommodation of the eye to different parts of the color spectrum. These accommodation problems further reduce the perceived clarity of colored text and may introduce accommodation aberrations such as chromatic stereopsis. Additionally, color vision deficiencies of the human eye, particularly red-green and blue-yellow, may make some text/background color combinations difficult or impossible to discriminate by some individuals. Finally, large variations in the rendering of color in CRT displays makes it difficult to predict whether the intended color combinations are actually displayed on a given monitor. While occasional use of colored text on a non-color background is acceptable for single words or word phrases, use beyond this level risks significant losses in reader performance.

*Typography*. Perhaps no other aspect of typography elicits more debate than the style and size of type fonts. Again, for electronic text, display spatial resolution and other factors must be considered when discussing font characteristics and reading. Fonts with serifs (see Figure 2) are often the style of choice for printed material. The evidence from the studies of Tinker (1963), however, reveal only very modest reading speed benefits (2.6%) for serifed fonts over non-serifed fonts in the reading of paper text. A study by Tullis, et al., (1995) of electronic text showed no advantage for serifed over non-serifed fonts. Evidence for user preference for serifing in display fonts is also mixed (Holleran, 1992; Tullis, et al., 1995). Likewise, proportional spacing of characters in displays when compared to fixed spacing (each character has the same size space assigned to it) does not appear to influence reading performance in displays (Gould, et al., 1987). Increasing the weight of a font with bold facing also has no apparent effect on reading performance (Tullis, et al., 1995).

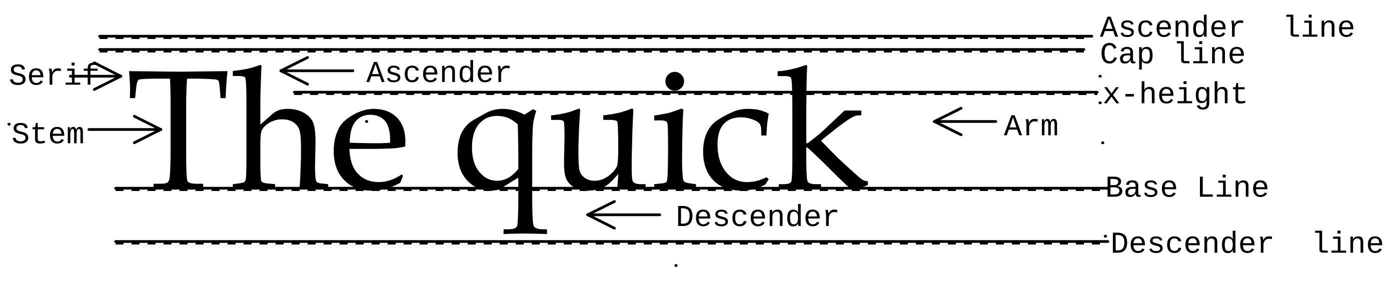


Figure 2 Nomenclature for typography

*Electronic Text on Dynamic Displays*

Unlike paper medium, electronic text displays can take on a variety of presentation modes and sizes and may even allow the user to actually control the mode and rate of the information displayed. While the amount of research available in this area is much less than that available for the reading of more conventional electronic text page format, the likelihood of increasing use of these innovative modes of electronic text display warrant a review of them here. Electronic displays are also being developed in seemingly endless variety of sizes, some of which necessitate the presentation of small segments of text due to the small size of the display area.

*Moving text*. The most common mode of presenting text on small displays has been to move (or scroll) the text horizontally from right to left in what has been called a Times Square or leading presentation mode. Bevan (1981), in studying the rate of moving text in leading presentation, found the optimum text speed for comprehension and retention to be about 10-15 characters per second, a rate slower than the average reading rate in the U.S. population. Subsequent studies have confirmed the finding that the leading presentation mode reduces the reading rate for electronic text. (Kolers, et al.; 1981; Granaas, et al, 1984; Sekey and Tietz, 1982). Interestingly, giving users control over the rate of scrolling may actually make their reading performance worse (Chen and Chan, 1990), though this may effect may be mitigated by practice (Chen and Tsoi, 1988). A study by Kang and Muter (1989) suggests that the poor reading performance of leading presentation method may be mitigated by a smoother (pixel by pixel) scrolling technique. More research is needed to determine the reliability of this finding, however.

As an alternative to leading presentation, another method called Rapid Serial Visual Presentation (RSVP) was developed. RSVP, as its name implies, displays segments of connected discourse (typically individual words or short sentence segments) in a rapid serial fashion. Research has generally supported the view that RSVP results in reading rates comparable to the fixed page display format (Dillon, 1992; Juola, et al., 1982; Masson, 1983). Different techniques of providing user control over RSVP rates were also investigated by Muter, et al (1988). In addition to self-pacing of RSVP, user regressions (backing the presentation up one or two words) were also examined. Unlike leading presentation, self-pacing (user control) over the rate of presentation had no effect on reading performance. Allowing regressions (as would occur in page format reading) slowed reading performance without increasing comprehension. In a more recent study by Juola (1995), the RSVP format was investigated in a small, eight-character display. Variations in presentation rate (171 wpm vs. 250 wpm) as well as the case of the type (upper vs. lower) were compared. Performance was higher for the upper case format (a finding opposite to that of most page format findings), but did not differ as function of presentation rate. Clearly, RSVP is the most desirable presentation format for displaying connected discourse in very limited display areas, although research should continue with leading presentation display techniques to investigate the importance of smooth scrolling.

## Conclusions and Recommendations

In reviewing the empirical research on the reading of electronic text, it is evident that the variables involved, such as image quality, typography, and others, often interact in complex ways. Thus, recommending a single font style for electronic text or a particular refresh rate, for example, can be problematic as these the effects of these factors are dependent on yet other variables. However, certain general guidelines emerge from the empirical literature as being important for readability. Particularly relevant are those variables concerning aspects of the electronic display itself.

*Image Quality*. Of all of the factors that affect the reading of electronic text, display image quality factors recurs as a critical element throughout the studies reviewed. In general, the upper limit of reading performance for electronic text is largely determined by the physical quality of the image displayed and the perception of this image by the user. Thus, the best measures of a display quality take into consideration the interaction between the physical parameters of the display (such as spatial resolution and contrast) and the operating characteristics of the human visual system. To date, the best overall measure we have of this user-display interaction is MTFA. Unfortunately, the calculation of this measure requires a level of engineering skill not commonly available to the consuming public. However, until display manufacturers use and publish this measure of display image quality on their devices, alternatives other than conventional means of calculating MTFA values need to be developed to aid consumers in choosing among displays. Alternative and less complex methods have, indeed, been developed (Ostberg and Feng, 1994) to derive MTFA values and should be considered.

In the absence of an MTFA measurement, spatial resolution of a display may be used as one index of a display's quality. A spatial resolution of at least 95 dpi (37 dpcm) or higher appears to be needed in order to render the level of detail needed for optimum reading of electronic text. In conjunction with this level of spatial resolution, adequate contrast must be maintained throughout the display in order to render text characters with clarity. In the absence of physical measurement, clarity of the image may have to be determined subjectively by having users rate the image clarity of displays with equivalent spatial resolution. This would also allow user assessment of any flicker present in the image of these displays at the same time. (Currently, no standards exist for refresh rates, but 60 Hz aappears to be too low to eliminate flicker entirely. The more desirable refresh rates are probably in the 80 to 100 Hz. range).

 

*Digital typography*. While no particular font family is recommended, digital fonts having a least a 7 x 9 pixel array appear to needed in order to provide the level of character detail required. Sans serifed fonts (such as Arial, Helvetica, and others) are more likely to achieve comparable reading performance with paper text than serifed fonts. In any case, the font size selection needs to be larger enough to provide comfortable reading at the viewing distance adopted by the display user. ANSI/HFES 100-1988 standard require text that characters in text (specifically, the height of capitalized text) to be within certain values. Thus, the minimum height of capital letters needs to subtend a minimum of 16 min. of visual arc and a maximum of 24 min. No standards exist for bolding and coloring of text, but either these techniques for enhancing electronic text have no effect on reading performance or are actually detrimental. Except for occasional use in highlighting individual words or short phrases, bolding and coloring of text should be avoided. Finally, no evidence exists to recommend either proportional or fixed space electronic text. More efficient use of display image space is the main advantage of proportional text.

*Image polarity*. Whether electronic text should be displayed in positive (dark text on light background) or negative image polarity has been a source of debate for some time. Although the investigations of this issue have yielded mixed results, the evidence tends to support the use of positive image polarity. However, it is possible that this finding reflects the tendency of CRTs to display light characters with less clarity than dark ones. This is due to the tendency for CRT pixels to "bloom" or bleed into their darker counterparts thereby reducing the sharpness of the image. Future technical advances in display design may eliminate this problem in CRTs and the advantage of positive image polarity text with it.

*Moving text*. On those occasions when the available area for image display is very small, it may be necessary to present individual characters, words, or parts of sentences serially over time or space. The most efficient means of presented text in small displays is the RSVP method where individual words or sentence segments are present serially. Reading rates for RSVP text appear to be comparable to normal reading. Leading presentation or Time Square as it sometimes called reduces reading performance significantly when compared to conventional page format. However, more research is needed into technologies which might allow a smoother presentation and might mitigate the unstable image effects of current leading presentation displays.

*Limitations on recommendations*. As the studies reviewed here where conducted with CRT technology displays, the recommendations given here should to be tempered by this fact. LCD/TFT technology, now used primarily in portable computers, may mitigate the image effects introduced by CRT displays. While recommendations regarding MTFA, spatial resolution and contrast, typography and methods of presenting moving text all apply, LCD/TFT displays do not scan images so refresh rates and flicker are not an issue. Image polarity issues may also be eliminated due to the absence of phosphor elements in these displays (though further empirical research is still required). Finally, all of the studies reviewed in this report employed English text characters. While it is expected that the recommendations here apply to most languages, exceptions may have to made for pictographic or ideographic languages such as Kanji. These languages rely on much more complex individual characters which may require levels of image clarity higher than those recommended here.

## REFERENCES


Bevan, N. (1981) Reading dynamically displayed text. *Behavior and Information Technology*, 8, 33-42.

Chen, H. and Tsoi, K. Factors affecting the readability of moving text on a computer display. *Human Factors*, 30, 25-33.

Creed, A. Dennis, I., and Newstead, S. (1987). Proof-reading on VDUs. *Behaviour and Information Technology*, 6, 3-13.

Cushman, W.H. (1986). Reading from microfiche, a VDT, and the printed page. *Human Factors*, 28, 63-73.

Dillon, A. (1992). Reading from paper versus screens: A critical review of the empirical literature. *Ergonomics*, 35 (10), 1297-1326.

Gould, J.D., Alfaro, L., Barnes, V., Finn, R., Grishcowsky, N., Minuto, A. and Saluan, J. (1987). Reading is slower from CRT displays than from paper: attempts to isolate a single variable explanation. *Human Factors,* 29, 269-299.

Gould, J.D., and Grischowsky, N. (1984). Doing the same work with hard copy and cathode ray tube computer terminals. *Human Factors,* 26, 323-337.

Gould, J.D., and Grischowsky, N. (1986). Does visual angle of a line of characters affect reading speed? *Human Factors*, 28, 165-173.

Granaas, M.M., Mckay, T.D., Laham, R.D., Hurt, L.D., and Juola, J.F. (1984). Reading moving text on a CRT screen. *Human Factors*, 26, 97-104.

Harpster, J., Freivalds, A., Shulman, G., and Leibowitz, H. (1989). Visual performance on CRT screens and hard-copy displays. *Human Factors*, 31, 247-257.

Helander, M.G., Billingsley, P.A. and Schurick, J.M. (1984). An evaluation of human factors research on visual display terminals in the workplace, *Human Factors Review*, 55-129.

Holleran, P.A. (1992). An assessment of font preferences for screen-based text display. *Proceedings of the HCI '92 Conference on People and Computers VII, Graphical User Interfaces*, pp. 447-461.

Human Factors Society. (1988) *American National Standards for Human Factors Engineering of Visual Display Terminal Workstations, ANSI/HFS 100-1988*. Santa Monica, CA: The Human Factors Society, Inc.


 

Jin Kang, T. and Muter, P. (1989). Reading dynamically displayed text. *Behaviour and Information Technology*, 8, 33-42.

Jorna, G.C., and Snyder, H.L. (1991). Image quality determines differences in reading performance and perceived image quality with CRT and hard-copy displays. *Human Factors*, 33, 459-469.

Juola, J.F., and Tiritoglu, A, Pleunis, J. (1994). Reading text presented on a small display. *Applied Ergonomics*, 26 (3), 227-229.

Juola, J.F., Ward, N.J., and Mcnamara, T. (1982). Visual search and reading of rapid serial presentations of letter strings, words and text. *Journal of Experimental Psychology*: *General*, 111, 208-227.

Kak, A.V. (1981). Relationships between readability of printed and CRT displayed text. *Proceedings of the Human Factors Society 25th Annual Meeting*, 137-140.

Kolers, P.A., Duchinicky, R.L., and Ferguson, D.C. (1981). Eye movement measurement of readability of CRT displays. *Human Factors*, 23, 517-528.

Kruk, R.S. and Muter, P. (1984) Reading of continuous text on video screens. *Human Factors*, 26, 339-345.

Lalomia, M.J. and Happ. (1987) The effective use of color on IBM 5153 color display. *Proceedings of the Human Factors Society*, pp. 1271-1275.

Lunn, R. and Banks, W.P. Visual fatigue and spatial frequency adaptation to video displays and text. *Human Factors*, 28, 457-464.

Masson, Me.j. (1983). Conceptual processing of text during skimming and rapid sequential reading. *Memory and Cognition*, 11, 262-274.

Monk. A. F. (1984). Reading continuous text form a on-lined visual display. *International Journal of Man-Machine Studies*, 21, 269-277.

Morrison, R.E. and Inhoff, A. (1981). Visual factors and eye movements in reading. *Visible Language*, 15 (2), Spring.

Muter, P. and Kruk, R.S., and Buttigeig, M.A. Read-controlled computerized presentation of text. *Human Factors*, 30, 473-486.

Muter, P. and Maurutton, P. (1991). Reading and skimming from books: the paperless office revisited? *Behaviour and Information Technology*, 10, 257-266.

 

Muter, P., Latremouille, S.A., Treurniet, W.C. & Beam, P. (1982). Extending reading of continuous text of television screens, *Human Factors*, 24, 501-508.

Ostberg, O. and Feng, Y. MTFA templates for quick and inexpensive assessment of display image resolution. (1994). *Applied Ergonomics*, 1994, 25, 252-256.

Pastoor, S. , Schwarz, E., and Beldie, I.P. (1983). The relative suitability of four dot-matrix sizes for text presentation on colour television screens. *Human Factors*, 25, 265-272.

Pawlak, U. (1986). Ergonomic aspects of image polarity. *Behaviour and Information Technology*, 5, 335-348.

Poynter, D. (1991). Contrast sensitivity and English letter recognition. *Proceedings of the Human Factors Society*, 1422-1426.

Rayner, K., and Pollatsek, A. (1989). *The Psychology of Reading*. Hillsdale, N.J.: Lawrence Erlbaum Assoc.

Rubinstein, R. (1988). *Digital Typography*. Reading, MA: Addison-Wellesley Publishing Co.

Seky, A. and Tietz, J. (1982). Text displays by "saccadic scrolling". *Visible Language*, 16, 62-76.

Tinker, M.A. (1963). *Legibility of Print.* Ames, IA.: Iowa State University Press.

Tullis, T.S., Boynton, J.L., and Hersh, H. (1995). Readability of fonts in the windows environment. *Proceedings of CHI '95 Conference on Human Factors in Computing Systems*., Interactive Posters. New York, N.Y.: Addison-Wellesley Publishing Co.

Wright, P., Lickorish, A. (1983). Proof-reading texts on screen and paper. *Behaviour and Information Technology*, 2, 227-235.

Zwahlen, H., and Kothari, N. (1986). Effects of positive and negative image polarity VDT screens. *Proceedings of the Human Factors Society*. Santa Monica, CA: The Human Factors Society, Inc.