A SIMPLE TOOL FOR PREDICTING THE READABILITY OF A MONITOR

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Background: Human factor practitioners are sometimes required to provide an immediate answer to an acquisition question, e.g., what is the readability of this monitor? Unfortunately, readability is not listed on the manufacturer's brochure. This study proposes a simple tool to quickly assess the readability of a monitor without the need of conducting a lengthy readability study. **Methods:** The text readability of three observers was measured for four colors (red, green, yellow, white), three brightness (.20, .25, .45), at three locations (1.62, 2.38, 3.16 meters) on a 20" color monitor. **Results:** The minimum error-free readable font size could be solely determined by the text/background luminance contrast. Thus luminance, not color determined readability. From these results, a MATLAB program was developed that prompts for background and text RGB values and returns the minimal error-free readable font size. **Conclusions:** The tool is a fairly robust and quick predictor to assess the readability of a monitor.

INTRODUCTION

Quite often, an acquisition program manager will request the assistance of a human factor professional to answer a specific question in a short period of time. The acquisition program manager's job performance is based on the ability to deliver the product on schedule. If the product is delayed, this will negatively impact the entire system as well as reflect poorly on the manager's ability to manage a program. Therefore, any delays are not tolerated. When human factors problems arise, the acquisition office wants a quick solution usually at that instant or within a day or two. Unfortunately, the human factors professional does not have the luxury to conduct a study to answer a specific problem that cannot always be answered by referring to a human factors reference. Therefore, to assist human factors professionals' simple and robust analytical tools should be developed to aid specific human factors problem-solving situations.

Today's cathode ray tube and liquid crystal display monitors allow an observer to choose between a wide range of functions and capabilities. There are numerous standards and recommended procedures to characterize the color and luminance of a display (Society of Automotive Engineers, 1989; Video Electronics Standards Association, 2001), color field uniformity (Electronic Industry Association, 1995), contrast (Electronic Industry Association, 1987a), specular gloss (Electronic Industry Association, 1987b), raster response (Electronic Industry Association, 1987c), resolution (Video Electronics Standards Association, 2001), and to measure the monitor's mechanical and physical characteristics (Video Electronics Standards Association, 2001). In addition, a monitor manufacture typically provides qualitative performance metrics about each monitor, i.e., the monitor's weight, intensity, frame rate, screen size, resolution, and addressability. However, it does not quantify text readability. Users often want to know what is the readability of the monitor for a given font size, text color, and background color. So far there is no simple method to determine a monitor's readability other than conducting time consuming and expensive human performance readability tests for specific types of text.

A common technique used by human factor professionals to assess monitor's readability is to measure observers' reading performance for displayed text. Text can be depicted by luminance contrast or color contrast. A number of studies have demonstrated that readability can be predicted from text contrast (Ahumada, 1996, Scharff, Hill, and Ahumada, 2000). Legge and Rubin (1986) also showed that luminance contrast determined participants reading rate regardless of text color. On the other hand, it was found that the visual system does not differentiate between color contrast and luminance contrast even though there are two distinct physiological neural pathways (Legge, Parish, Luebker, and Wurm, 1990). Knoblauch, Arditi, and Szlyk (1991) found that, although colors affected reading performance at threshold luminance contrast and at very small text size, the performance was unaffected by chromatic contrast with the presence of suprathreshold luminance contrast (0.12) over a large range of text font sizes.

Conducting readability experiments is resource limited and time consuming. An alternative approach would be a simple tool that would allow human factors professionals to predict the readability of a monitor by entering limited number of recorded photometric values from the desired monitor. The objective of this paper is to demonstrate that a simple software tool can be used to predict the readability of a monitor. We first performed human readability tests in order to quantify the factors that might affect text readability, such as luminance contrast, color and view distance. We then fitted the experimental results into an analytic equation that predicted the readability from the text size and luminance contrast. Finally, we developed a software tool to asset the text readability for color monitors. The simple tool, with a limited number of photometric measurements, allows user to input any given background and text RGB values to determine minimal error-free readable font size. We used this tool to predict the minimal error-free readable font size for a proposed Federal Aviation Administration color replacement tower display monitor. The simple tool was also validated for another monitor to determine how well it could predict readability performance.

METHODS

Observers: Three observers (ages 34, 40, and 40) had normal or corrected-to-normal visual acuity and normal color vision as tested with the Farnsworth Dichotomous Test for Color Blindness and Dvorine Color Plate test. Observers had 14 years ($\sigma = 3$) of air traffic control experience. Informed consent was obtained from all observers. All observers were naïve to the experimental hypothesis.

Apparatus: Stimuli were displayed on a General Digital 20" AMLCD color monitor. Observers viewed the screen from three different distances of approximately 1.62, 2.38, and 3.16 meters for positions 1 through 3, respectively. The screen resolution was 1024 by 768 pixels with 3.2 pixels/mm in the vertical and horizontal direction.

Stimuli: Figure 1 illustrates the eye chart used in the experiment. The eye chart consisted of eight rows of letters (Lucida Console font) with each row containing nine unique letters that are commonly used in the Snellen eye chart. Physical x and y pixel dimensions of each character box from lowest to highest rows were 8 by 10, 9 by 11, 10 by 12, 11 by 15, 12 by 16, 14 by 18, 15 by 19, and 16 by 22, respectively. Text color was red, green, yellow, white or black.

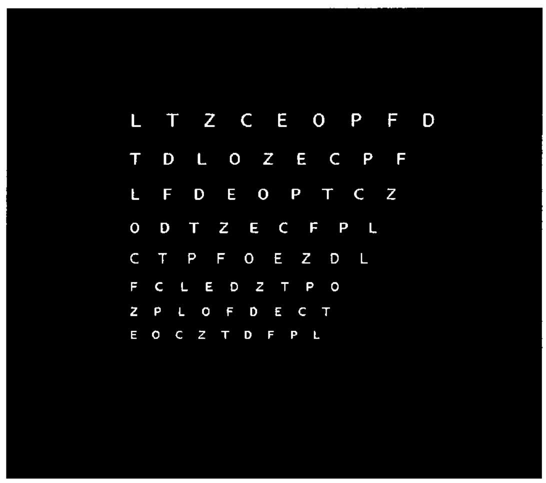

Figure 1. Eye chart stimulus

RGB input	Y	x	y
red	110	0.621	0.344
green	259	0.323	0.57
blue	51	0.152	0.137

Table 1 shows the CIE color chromaticity coordinates (x, y) for each RGB input.

The screen background was set to black (0, 0, 0) with a mean luminance 2.62 cd/m^2. Red, green, yellow, or white text were displayed at 20%, 25% and 45%

brightness level, where brightness was defined as the input analog multiplied by brightness setting (e.g., an analog RGB input value of 255, 0, 0 with a 25% brightness setting would have a new analog input of 64, 0, 0).

Procedure: The observers' task was to start at the top of the screen and read each row of letters. No feedback was provided but observers were encouraged to guess. The experimenter located outside the observer's field-of-view recorded the vocal responses. Observers were allowed periodic rest throughout the experimental session.

Thirty-six trials (3 brightness levels, 3 positions, and 4 colors) were presented to each subject. Position and color were randomly assigned within each block of brightness trials.

RESULTS

RGB-Luminance Computation

We made a series of RGB-Luminance measurements in order to derive the RGB-luminance relationship for a given monitor. The data showed that no single gamma value could fit the whole luminance range. Therefore, a piecewise linear interpolation was used to compute luminance for any given RGB values.

Lr is the luminance for red only (r);
Lg is the luminance for green only (g);
Lb is the luminance for blue only (b);
Lrgb is the luminance when r=g=b; where

Lrgb=Lr+Lg+Lb+Lmin;

Lr, Lg and Lb were measured for 12 values of r, g, b each equally spaced between 0 and 255. The r, g, b values and the corresponding luminances were converted into the log scale. For any given RGB, log(Lr) was computed by linearly interpolation between the two adjacent measured log(Lr) values, so were log(Lg) and log(Lb). The corresponding luminance for the given RGB was the sum of the three luminance components: (Lr+Lg+Lb+Lmin).

View Distance versus View Angle

The readability measurement was made from three view distances (1.62, 2.38, 3.16 meters). We converted the font size of the texts into their angular sizes (arc min.). The percentage of correct reading vs. angular font size was plotted for each view distance. The three curves aligned each other when plotted in the same graph against the same horizontal axis (angular font size), suggesting that the angular font size, not the absolute view distance, determined the readability.

Minimal Font Size For Error-Free Reading

For each of the four colors and three brightness tested, the percentage of correct reading was plotted against the angular font size. The correct percentage increased with the font size. A minimal font size for error-free reading was defined as the font size beyond which the reading was 100% correct. This size was used to assess the readability of a monitor. The minimal font sizes for the 4x3 color-brightness combinations were thus determined from the plotting of correct reading percentage versus angular font size.

Text Contrast Versus Minimal Font Size

The text contrast is typically defined as (Lt-Lb)/Lb, where Lt is the text luminance and Lb is the background luminance. The text contrasts of four tested colors and three brightness were computed by converting RGBs into luminance. The result was plotted in figure. 2. The vertical axis represents the minimal font size of error-free reading and the horizontal axis represents the text contrast. Different plotting symbols indicate the four colors. The solid curve was a multivariate fitting of the data into the following equation:

font size = A*exp(-(abs)contrast/sigma)+A0

where A, A0 and sigma were free parameters to fit.

The fitting process searched for the least-summed-square error between the data and the model prediction. We obtained the following equation:

font size = 7.434*exp(-contrast/0.6297) + 5.028

where font size is the angular size (arc min).

The least-summed-square fitting error for the above equation was 0.055, close to the 0.05 confidential fitting error. Thus the above equation was a robust estimation to the RGB-readability measurement.

We also computed the fitting errors for each text colors respectively (fitting the data for all the colors to the same function and then computing the errors for each color). The errors were 0.07, 0.02, 0.05, and 0.02 for white, yellow, red and green text color. Thus, the data obtained with different text colors could be well fitted into the same equation. This suggests that the color factor does not matter to the readability as long as the text contrast is the same.

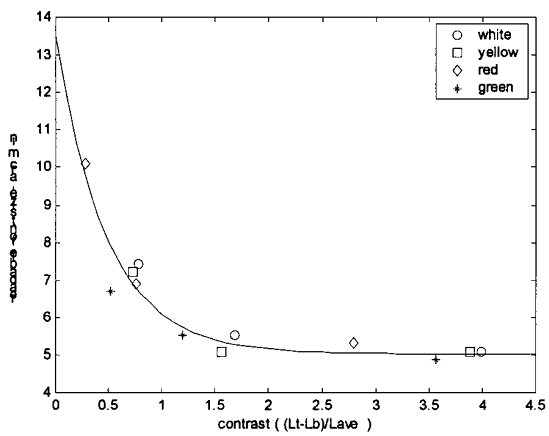

Figure 2. Size by contrast function. The continuous curve represented the fitted equation. Different plotting symbols represented the data for different colors. The data obtained with different text colors fit well to the same function which suggests that the color does not affect readability.

MATLAB Tool to Predict Readability of a Monitor

The MATLAB program (available at http://www.hf.faa.gov/krebs/download.htm) prompts for background and text RGB values. It returns background and text luminance, text contrast and the minimal error-free readable font size (arc min). The screen data of a 20' CRT monitor were included in the RGB-Luminance tables within the program. Those RGB-luminance tables need to be updated in order to assess a new monitor.

MATLAB Tool Validation

Air traffic controllers' readability scores were obtained from another study (WJHTC, 2002) to determine how well the MATLAB tool could predict readability performance. Six air traffic controllers participated in a tower cab study to read data blocks from a flat panel color display during day and nighttime viewing conditions.

Table 2 shows that on average observers were more accurate during nighttime than daytime viewing. There was a significant distance by color interaction. As observers increased distance from the screen, readability performance dropped significantly for all colored text except red. This decrement in performance was more pronounced for the daytime conditions.

Viewing Condition	**Dist meters**	**Green**	**Red**	**White**	**Yellow**
Night (black background)	1.21	94%	90%	91%	95%
Night (black background)	2.13	88%	95%	83%	97%
Night (black background)	3.05	67%	87%	81%	80%
Day (white background)	1.21	94%	89%	78%	66%
Day (white background)	2.13	82%	79%	83%	61%
Day (white background)	3.05	58%	49%	52%	22%

Table 2. Observers' aircraft call signs correctly identified (percentage correct) during day and nighttime viewing conditions (data obtained from WJHTC report, 2002).

Table 3 lists the predicted error-free readability scores for an average observer reading text from the same monitor. On average, an observer positioned 1.676 meters from the screen at day will be 100% accurate in reading red text (5.028 arc minutes in size). The predicted scores showed a similar trend to the behavioral scores, where yellow had the worse performance while white, green, and red were nearly equivalent. Differences between the predicted readability and observed data may be attributed to observers' ability to change font size between and within trials.

Viewing	Accuracy	Green	Red	White /Black	Yellow
Night (black background)	100%	2.16	2.16	2.16	2.16
Day (white background)	100%	1.80	1.68	1.91	1.40

Table 3. The model's output for an average observer correctly reading an aircraft call sign (100% correct response rate) at a given distance (in meters) during day and nighttime viewing conditions. Text size was assumed to be 5.028 arc

CONCLUSIONS

By analyzing the data of our readability experiments and screen color measurements, we found 1) the readability of a monitor can be assessed with the minimal angular font size for error-free reading; and 2) the minimal font size can be solely determined with the text luminance contrast, irrespective to text colors. A MATLAB program was developed from these results. It prompts for background and text RGB values and returns the minimal error-free readable font size. This tool is a fairly robust and quick predictor to assess the readability of a monitor.

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