The Visibility of Colored Characters on Colored Backgrounds in Viewdata Displays

Margaret Bruce and Jeremy J. Foster

An experiment is reported in which subjects were required to identify letters and digits presented on a viewdata display, and identification times were recorded. All 42 possible color-on-color combinations were shown as separate displays. The results indicate which color-on-color pairings significantly reduce character visibility, and a list of recommended combinations is given.

Viewdata is one of the most significant developments in mass communications of recent years. It consists of a system in which the user's television is connected to a central computer via a telephone link. The computer has a store of thousands of pages of information which the user can have displayed on his television screen by entering the appropriate page numbers on a key pad. The system differs from broadcast teletext in the number of pages available, the greater control that the user has over what information he can access, and in the ability of the user to communicate to the central computer. Viewdata systems are in operation in a number of countries, the first public system having been initiated in the UK by the British Post Office (now British Telecom).

Viewdata provides information in the form of verbal and numerical displays, but the facility for transmitting pictures is becoming available. A notable contrast with printed alphanumeric displays is the ease with which color can be used. With a color television receiver the characters can be in any of seven alternative colors: white, yellow, cyan, green, magenta, red, blue. Each individual character can be displayed on a background of any of the other colors. (Characters are drawn within a 6 x 10 matix, and those cells of the matrix which are not part of the character form the background of that character.) There are, therefore, a total of 42 different color/color combinations available, and the color of characters and backgrounds can be varied individually within a line.

This facility compensates, to some extent, for the spatial limitations of the TV screen. It has no practical counterpart in print. The relative luminosity of a colored character is likely to be more degraded by a colored background in print than in CRT mode, and so it is unlikely that studies of the visibility of colored print (e.g., Konz et al., 1972) can be applied directly to viewdata. Experiments on the visibility of projected slides may be more relevant to CRT displays. Snowberg (1973), for example, varied

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background color and measured readers' visual acuity using a snellentype chart. However, the lettering was black and this has no equivalent in viewdata. Nevertheless, it is worth noting that he recommends a white background, which maximises the contrast between the characters and the ground.

The newness of the medium has meant that little information has been published concerning the visibility and legibility of viewdata displays. This situation has been commented upon by various authorities (e.g., Reynolds, Spencer, and Glaze, 1978; Sutherland, 1980) who have also debated whether the design principles known to be appropriate for printed material are also applicable to viewdata's CRT displays. The dissimilar physical characteristics of ink-on-paper and CRTs have led some commentators to argue that it is unwise to generalize across the media (e.g., Hurlburt, 1980). In his discussion of Prestel, Sutherland (1980) observes that there have been no studies on the visibility of colored characters on colored backgrounds. The present experiment was designed as an initial contribution to this topic.

METHOD

Respondents were asked to identify aloud alphanumeric characters displayed in lines on a viewdata screen. The character color and the background color of the displays were varied. The experiment consisted of a mixed design, with background color (B) being a within-subjects factor and character color (C) a between-subjects factor.

Stimulus displays

There are 42 possible color/color combinations, and therefore 42 displays were prepared. Each consisted of lines of characters, the first three containing three full upper-case alphabets in random order and the fourth containing each of the digits 0-9 three times, the sequence again being random. A viewdata screen includes 24 lines of 40 character spaces. The top and bottom lines are reserved for information concerning the frame being viewed and routing instructions, so there are 22 lines available for the frame content. In the present displays the top line of characters occupied the centre line and the other three lines were below this one, with a blank line between each line of characters. All the spaces not occupied by characters were filled with the same color as formed the background for the characters, so that the screen contained a large colored rectangle with the lines of characters extending downward from the centre.

Six different character sequences were created, and each was produced in every one of the seven possible character colors. The background colors were allocated so that every possible color-on-color combination was available, and each character color was used once with every character sequence, but with a different background color each time. Background colors were allocated randomly to the particular combinations of character sequence and character color.

Subjects

There were seven groups of eight respondents, who were students from various undergraduate courses and were assigned randomly to the character color groups. None of the subjects had had any prior experience with viewdata. The subjects in any one group saw six displays, all having the same character color but a different background color and a different sequence of characters. The order in which background colors were displayed was determined randomly and separately for each respondent.

Procedure

Subjects were run individually. Trials were run in a cubicle 3 x 3 metre with an ambient illumination from overhead light-bulbs of 50 lux. The subject sat 1.5m from the screen of a 16" ITT Teletext receiver (Model TVX). The surface between the reader and the television screen was matt black, and care was taken to prevent any reflections in the screen. The displays had previously been recorded on audio cassettes, and could therefore be "written" on the screen at will. The experimenter sat 1.5m to the subject's right, and manipulated two tape-recorders, one of which wrote the display while the other was used to record responses. She also manipulated a black screen which was interposed between the subject and the receiver while displays were being changed.

The respondents were asked to identify out loud all the characters. The time taken for each of the four lines was measured later from the tape recordings of the responses. Uncorrected errors were negligible, and insufficient for statistical analysis.

Results

Every respondent yielded sets of data for 6 color/color combinations. For each of these the data from the 3 lines of letters was averaged to give a measure of the mean time taken to identify each letter, and similarly a mean time taken to identify each digit was calculated. These recognition times, expressed as 1/100sec, form the dependent variable.

Because of the necessary absence of any data for those cases where a colored character would be superimposed on a background of the same color, it was not possible to apply analysis of variance to the total set of data. Instead, the experiment can be seen as seven within-subjects experiments, each of which involved the manipulation of background colour

while character colour was constant. A separate analysis of variance was applied to each sub-experiment, which manipulated two factors: background colour and character type (letter or digit). Since digits were always the final row of the displays, character type is confounded with presentation order, and any effects of character type must be interpreted with caution.

In none of the analyses was there a significant interaction between background color and character type, and consequently in Table I we show the mean recognition time per character for each character color (merging the data for letters and digits). Background colors were compared using Duncan's Multiple Range Test, and the outcomes are shown in the penultimate column of Table I. Background colors which share an underline do not differ from one another at the p<.05 level. The results for each character color will be considered separately.

White characters There was a highly significant background (B) effect (p < .00001), but character type (T) and the B x T interaction were non-significant. Using Duncan's Test, white-on-yellow characters were harder to identify than any of the other combinations, which did not differ significantly.

Yellow characters Background was significant (p < .005), but T and B x T were not. Cyan and white backgrounds were significantly worse than the others; blue, red and magenta formed the group yielding the fastest scores.

Cyan characters Again, background was the only significant factor (p<.002). Green and yellow backgrounds yielded the slowest performance; blue, white and red were the best grounds.

Green characters Background was significant (p < .04), and so was character type (p < .03) but the interaction was not. Digits were identified faster than letters, but as mentioned above, this factor was confounded with presentation order and so should be interpreted cautiously. The most visible backgrounds were, in rank order: yellow, white, red, magenta, and blue.

Magenta characters Background was the only significant factor (p<.00001). Red was the worst background color; blue, white, cyan, and green produced the most visible magenta characters.

Red characters Both background (p < .002) and character type (p < .001) were significant factors, but the interaction was not. Digits were identified faster than letters. The magenta ground was significantly less visible than the others, which did not differ between themselves.

Blue characters Neither of the main effects (background or character type) was significant, nor was the interaction. Despite the non-significant background effect, Duncan's test indicated that red and magenta grounds were worse than white, which was the best ground for blue characters.

DISCUSSION

So far as we are aware, Table I provides the first set of published data on the visibility of colored viewdata characters seen against colored backgrounds. It therefore serves as the first empirically-devised guide for designers wishing to discover which color combinations reduce character visibility.

It is, however, necessary to consider the limitations of the data tabulated here. These limitations derive from the displays, the viewing environment, the subjects, and the task which the subjects were asked to perform. There are three aspects of the displays upon which we feel comment is required. First, the characters were in unbroken lines, with one blank line between successive lines of characters. It is possible that where significant effects were observed here, they would cease to be significant with more generous inter-item spacing. We feel it unlikely, however, that increased inter-item space would produce alterations in the relative visibility of color-on-color combinations where significant differences have been observed here. (For example, we would expect magenta to remain the worst background for red characters). Second, the "empty" areas of the screen were filled with the background color, and it is possible that this affected the magnitude of the effects observed, although we again doubt whether it is likely to have influenced the relative visibilities of the various color combinations. Thirdly, only upper-case letters were used, which means that we cannot be sure that the results apply to lower-case.

The environment in which our respondents viewed the displays had an ambient illumination lower than that recommended by Ostberg (1975, cited in Sutherland, 1980). With a higher level of ambient illumination, the contrast between the colors will be less pronounced, although contrast can be adjusted to some extent by the control on the television set. We expect that those combinations in which the contrast between character and ground is low and which tend to have poor visibility would be even less visible with high ambient illumination. But the precise interactions between ambient illumination and the visibility of color-on-color displays have yet to be determined.

Another aspect of the viewing environment is the particular television set. Sutherland (1980, p.23) writes: "Studies of the legibility of text and of viewer's color preferences on Prestel are bedevilled by the fact that the appearance of characters in a given color varies with the manufacturer of

Table I Mean recognition time per character (1/100 sec) as a function of character color and background color, and the outcome of Duncan's Multiple Range Test to compare background colors.

Character			Backg	ground	d color			
Color	W	Y	C	G	M	R	В	Duncan's Relative MR Test Luminances
White		47.85	39.46	37.72	36.50	37.51	37.85	MRGBCY BRMGCY
Yellow	50.47		48.22	43.50	43.07	41.97	40.35	BRMGCW BRMGCW
Cyan	38.57	44.43		44.20	41.20	39.11	36.86	BWRMGY BRMWYG
Green	36.74	36.66	40.98		39.85	39.41	39.89	YWRMBC BRMWYC
Magenta	40.07	44.07	41.03	42.97		52.38	39.91	BWCGYR BWYCRG
Red	33.49	34.79	35.36	35.75	41.47		36.00	WYCGBM BWYCGM
Blue	38.01	39.06	40.25	40.89	41.77	41.22		WYCGRM WYCGMR

the set, the age of the set and the ambient lighting conditions. On some sets white is a very bright color, on others it appears a rather dirty grey; as sets age, the beams illuminating the different phosphors may get out of alignment, and colors produced by more than one phosphor may yield blurred edges; morever, the phosphors deteriorate with use . . . " These considerations need to be borne in mind when the results of any experimental studies of viewdata visibility are being evaluated or applied.

The subjects used here were not screened for visual defects, but none reported when questioned that they suffered from color blindness. They were in the age-range of 18-30 years, and it is likely that elderly people, or those with visual defects, would experience greater difficulties when reading viewdata. People with specific types of color blindness can be expected to find some combinations particularly difficult. It remains to be seen whether the relative visibilities of the color pairings differ for particular groups of readers.

In the present study readers were asked to identify the characters orally, since this ensured that they had indeed identified all the characters displayed. Although this procedure has its drawbacks, we doubt whether it is likely to have biassed the comparisons between the displays. But it may not be wise to generalize the present findings to different tasks, such as those involving visual search. The present findings should not be applied without reservation to the design of text displays; direct studies of the effect of color on text legibility are required.

Table II Recommendations for color-on-color combinations for viewdata displays.

With characters of this color	avoid this color of background	use one of these
White	Yellow	Magenta Red Green Blue
Yellow	White Cyan	Blue (Red) (Magenta)
Cyan	Green Yellow	Blue (White) (Red)
Green	Cyan Blue	Yellow White (Red) (Magenta)
Magenta	Red	Blue White (Cyan) (Green)
Red	Magenta	White Yellow Cyan Green
Blue		White (Yellow) (Cyan) (Green)

Bearing all these qualifications in mind, it is possible to derive from Table I a set of recommendations about which backgrounds to use or to avoid for each character color, and we have done this in Table II. Creating such a set of recommendations involves a certain amount of subjective judgment, since there are no objective rules for deciding where to locate the criteria of acceptance and rejection. The "reject" column of Table II includes those backgrounds which fall in the "least-visible" grouping of each row of Table I. In the "recommended" column of Table II we have entered those background colors which are in the "most visible" grouping of each row of Table I. We have inserted a maximum of 4 background colors in this column. Where the "recommended" colors also featured in the second-most-visible grouping of Table I, we have put brackets to indicate that they possess a less clearcut advantage.

It is not possible to use Table I to compare the visibility of character colors in isolation: to do this, characters should be displayed on an uncolored background. The results of experiments employing such a procedure are summarized in Sutherland's (1980) report.

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Reynolds et al. (1978) state that the theoretical relative luminances of the various colors are: white 100, yellow 89, cyan 70, green 59, magenta 41, red 30, blue 11. It therefore seems worth considering how far the results shown in Table I are related to the relative luminances of the various hues. As an index of relative luminance, we calculated (c-b)/b where c represents the luminance of the characters, and b the luminance of the background. This provides an index of relative luminance, which can be used to predict the visibility of the color-on-color combinations. The final column of Table I lists the background colors in decreasing order of the magnitude of the luminance index, for each character color. These orderings can be compared with the orders of visibility shown in the adjacent column of Table I.

The most notable differences between the two orderings are for red characters, where a blue ground is predicted rank 1 but observed rank 5; for white characters where blue is predicted rank 1 but observed rank 4; and for green characters where blue is predicted 1 and yellow predicted 5 while the observed values are the reverse. The rank correlations between the two orderings of background colors for each character color are: white +0.60, yellow +1.0, cyan +0.77, green -0.09, magenta +0.71, red +0.43, blue +0.94. With the notable exception of green, these suggest that relative luminance is one factor influencing character visibility. Furthermore, the range of luminance indices is much lower for blue than for any other color, and this may be compared with the fact that it was only with blue characters that the analysis of variance failed to demonstrate a significant effect of background color. Also, when the relative luminance index falls below 0.3, the resulting combination is always in the least-visible grouping for that character color. (The converse does not hold: there are least-visible pairings such as magenta on red where the index is above 0.3, in this instance 0.37). As a rule of thumb, one can say that to promote character visibility one should ensure that the relative luminance index does not fall below 0.3. It would not, however, be correct to recommend maximizing the index since this would involve always using blue as one of the pair of colors. The data shown in Table I simply do not support such a strategy.

In more everyday terms, the analysis indicates (1) that a "light" color should not be paired with another "light" color ("light" colors being white, yellow, and cyan), (2) that the "dark" colors (red and blue) should be paired with a light one and (3) that the "medium" colors (green and magenta) should be paired with colors from one of the other groups. These rules are in broad agreement with Table II.

Finally, a further note of caution: the displays used here contained only a single character color and a single background color. It is quite

easy to create displays with both colors varying across the whole range so that one can have a frame containing up to 42 separate color/color combinations. Intuitively one expects there to be a danger of creating a form of visual indigestion by the excessive use of color variations. How color/ color combinations should themselves be combined (if at all) remains to be investigated.

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We would like to acknowledge the assistance given to us by the staff of Mercury 332, the viewdata section of the Bolton Evening News, in preparing the materials for this experiment.