



## FREQUENCY OF COLOR NAMES FOR COLORS GENERATED ON A CRT

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A handwritten signature in cursive script that reads "R. G. Walter".

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## SUMMARY PAGE

### PROBLEM

To obtain color naming boundaries within the realizable color space of standard CRT displays.

### FINDINGS

Color naming boundaries were constructed from the responses of 10 subjects to 210 equally spaced equiluminant stimuli for criteria of 50%, 75%, and 95%. At the 95% criterion level, only green, blue, and purple regions were obtained. When the criterion was dropped to 75%, yellow, orange, pink, and aqua regions were added to the map.

### APPLICATION

The results of this experiment provide the data base with which to compare alternative strategies for the application of colors to tactical CRT displays.

## ADMINISTRATIVE INFORMATION

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## ABSTRACT

Color naming frequency data were collected for 210 equiluminant colors. These colors represent a sample of the color space realizable on a CRT screen. From these data, color naming boundaries were constructed utilizing criteria of 50%, 75%, and 95%. The results of this experiment provide a data base with which to compare alternative strategies for the application of colors to CRT displays.

## Frequency of color names for colors generated on a CRT

### INTRODUCTION

The application of color to tactical CRT displays has as its goal the improvement of operator performance. The improvement may result from the careful use of color to (a) convey information about the status of a system or subsystem more quickly (e.g., warning or status lights), (b) improve discrimination between different types of information (e.g., target and background), or (c) group related information for faster association (e.g., target and associated alphanumeric data). Adding color properly for these or other purposes requires the consideration of many issues. One major issue concerns the number of colors to use and what they should be. The number of colors should be large enough to make the addition of color enhancing while not so large as to make discrimination between colors difficult. In other words, for many applications the colors should not only be easily discriminable but also easily identifiable. The latter requirement implies that the best sets of colors may be those in which all members have reliably different names.

Currently, display designers use the International Commission on Illumination (CIE) color spaces to specify colors. In the CIE 1976 color space, the linear distance between two equiluminant colors is a first approximation to their perceptual difference (Robertson, 1977). Thus the points on a circle, in this color space, should all be equally distinguishable from the color represented by the

center of the circle, again to a first approximation. This characteristic is more true of certain regions than others. Post & Greene (1985) and Post & Calhoun (1988) have argued that color-naming boundaries should be taken into account when selecting colors on CRT displays. Post and Greene state that "The implicit assumption of this research is that the reliability of subjects' color-naming behavior is indicative of their ability to recognize colors, and hence apprehend color codes." However, is Post's assumption valid? This question can only be answered by experiments that directly compare subject color-naming behavior to color discrimination and identification.

Color-naming boundaries may be defined as contours in a color space enclosing regions within which the application of a given color name exceeds a criterion probability. These boundaries pose an interesting problem when considered in the CIE 1976 color space. Will a pair of colors that straddle a color-naming boundary be more discriminable than a widely-separated pair falling within the same color naming region? Or would the reverse be true? This question may also be asked of color identification. Given the importance of color discrimination and color naming to the application of color to tactical displays, the purpose of the present study was to collect information that will serve as a data base for future experiments concerning the effect of color-naming boundaries on color discrimination and identification. In

the experiment to be described, color-naming boundaries were determined experimentally for a set of equiluminant colors. These data will then be used to evaluate the effectiveness of color-naming boundaries on color discrimination and identification tasks.

## METHOD

### Subjects

Ten color normal subjects, eight female and two male, were paid for their participation in the experiment. The subjects' color vision was tested using the Hardy-Rand-Rittler pseudo-isochromatic plates.

### Apparatus

A Vax 750, a Ramtek 9400/91 graphics display generator, and a Mat-

sushita standard phosphor color monitor were used to generate the colors. The addressability of the monitor was 1280 by 1024 pixels (100 pixels per inch). All color measurements were made with a Photo Research Model 703A Fast Scanning Spectroradiometer. The CIE 1976 chromaticity coordinates ( $u'$ ,  $v'$ ) of the phosphors were (.41,.52) for the red, (.12,.56) for the green, and (.17,.18) for the blue.

### Stimuli

The coordinates for the red, green, and blue CRT phosphors form the vertices of a triangle in 1976 CIE color space. The colors producible by the display are then represented by the area of this triangle. To select the color stimuli to be used in this experiment a coordinate grid was first placed over the tri-

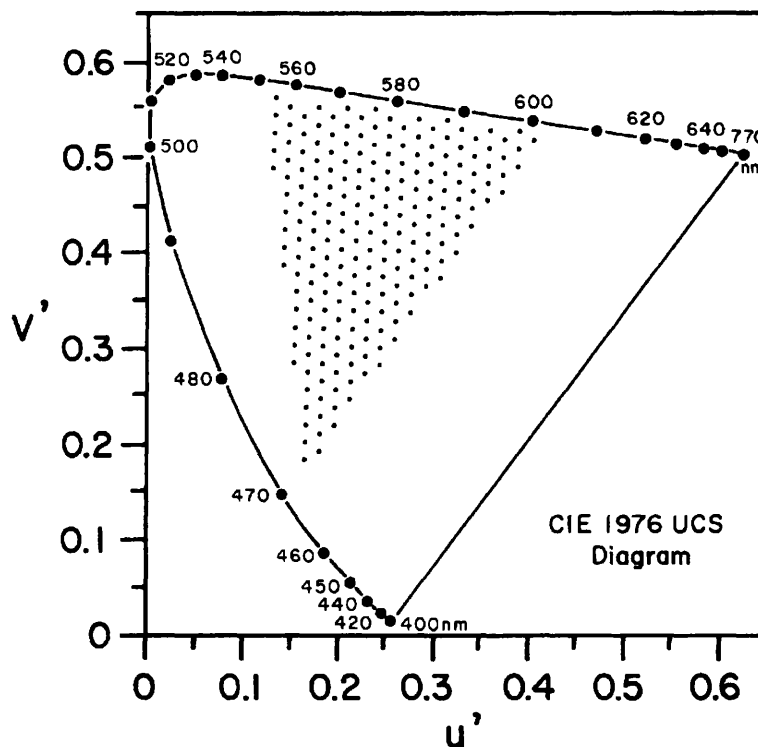


Fig. 1. The 210 stimuli used in the experiment are mapped into the 1976 C.I.E. color space.

angle of realizable colors. The grid consisted of points that were equidistant from all adjacent points. In other words, any three adjacent non-collinear points form the corners of an equilateral triangle. There were 210 points that fell within the area of the color triangle. Points that fell on or outside the legs of the triangle were excluded. Included points then became the  $u',v'$  coordinates for the 210 color stimuli shown in Figure 1.

The CRT was characterized using the procedure of Neri (1990) such that it was possible to produce the 210 equally-spaced chromaticities. The stability of the CRT was such that a computer program using the output of the characterization procedure could produce colors with chromaticities accurate to .01. The luminance of all stimuli was  $10.0 \text{ c/m}^2$ .

#### Procedure

The procedure follows closely that of Post & Greene (1986) and Post & Calhoun (1988). Each of the 210 stimulus colors was presented in isolation as a circular patch subtending a visual angle of 1 degree, against a flat black cardboard background attached to the CRT screen. The subjects were instructed to name each of the colors presented. The ten color names allowed as responses were limited to: red, green, blue, aqua, orange, yellow, pink, purple, gray, or white. These particular color names were selected since Post and Greene (1985) showed in a similar experiment that when subjects' naming responses were not constrained, that 88% of the responses were comprised of these ten color names. Subjects made their response by pressing a number on a keypad. A chart, coding the 10 colors to numbers, was always visible to the sub-

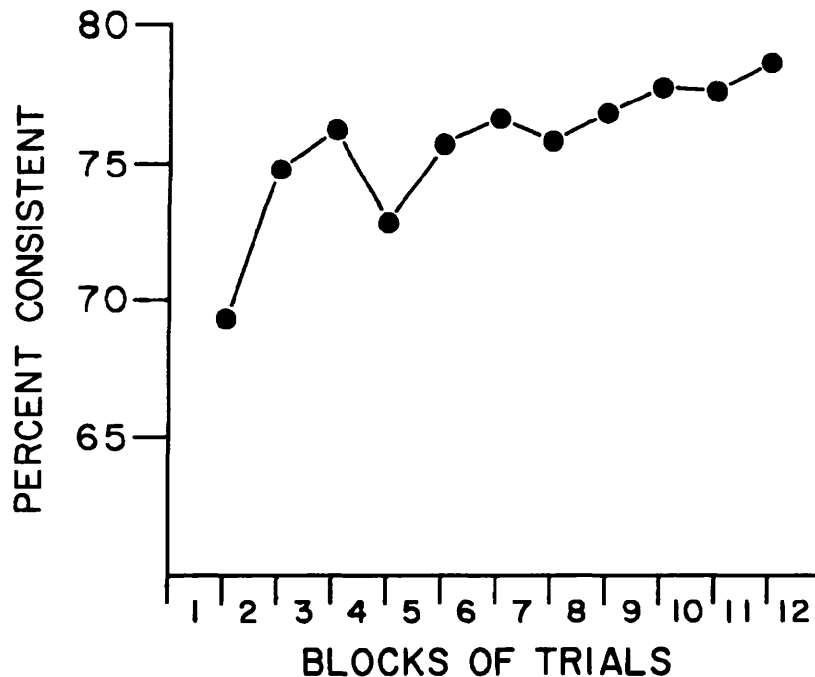


Fig. 2. Average consistency across subjects between adjacent blocks of trials.

ject. After each response was entered, the program informed the subject of the color name he or she had ascribed to the stimulus and asked the subject if this was the correct name. If the subject responded yes then a new color was presented. If the subject responded no, the program allowed the subject to reenter the number that corresponded to the color name. In this manner subjects were given a chance to correct any mistakes that may have arisen from pressing the incorrect number.

A block of trials consisted of each of the 210 colors being randomly presented once. Subjects were tested on a total of 12 blocks of trials for a total of 2,520 responses per subject.

## RESULTS

Figure 2 shows the percentage of "same" responses for the same colors between successive blocks of trials, averaged across the 10 subjects. That is, between successive blocks of trials the responses to each individual stimulus were compared for all subjects and the number of stimuli that were called by the same name is given by a percent. Between blocks one and two, for example, the subjects' consistency is about 69%. It rises to 75% between blocks 2 and 3. It stays above 75% after the second trial except for an unexplained drop between trials 4 and 5. Since the consistency of response is fairly well established by the third block of trials, the first two blocks have been treated as practice trials. Therefore, the results of the experiment are based on the last 10 block of trials.

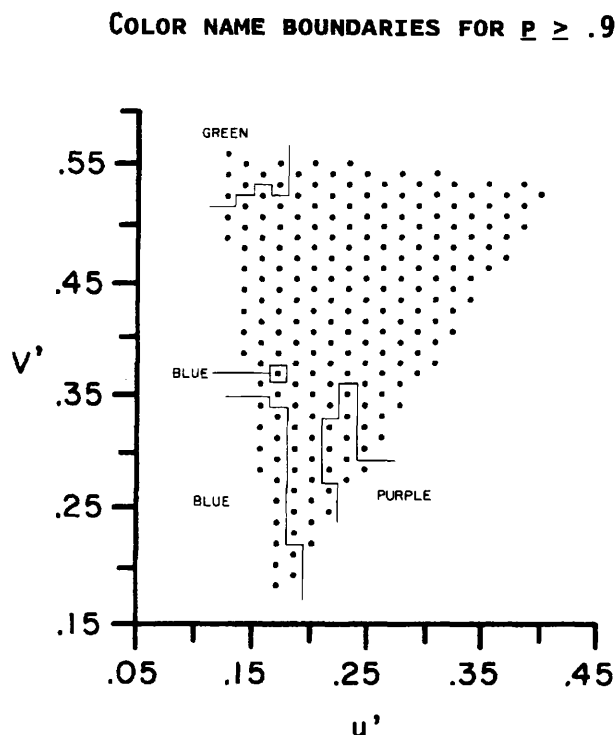


Fig. 3. Color-naming boundaries for a modal response of 95% or greater.



# COLOR NAME BOUNDARIES FOR $p \geq .75$

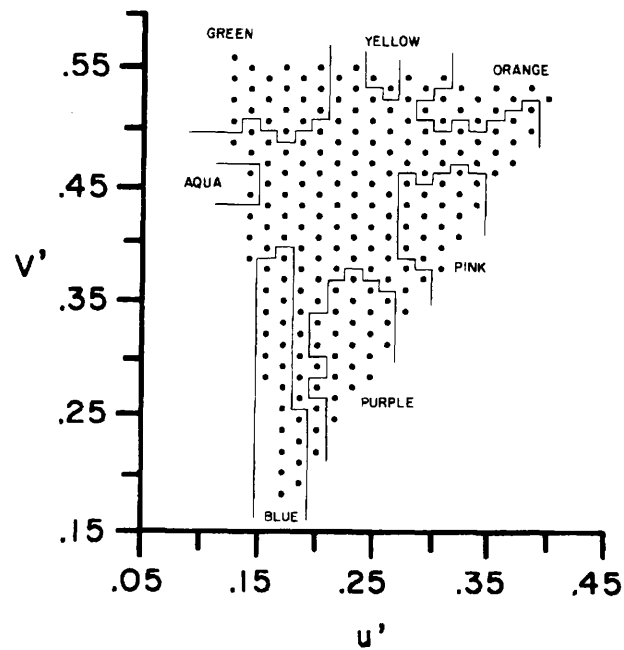


Fig. 4. Color-naming boundaries for a modal response of 75% or greater.

# COLOR NAME BOUNDARIES FOR $p \geq .50$

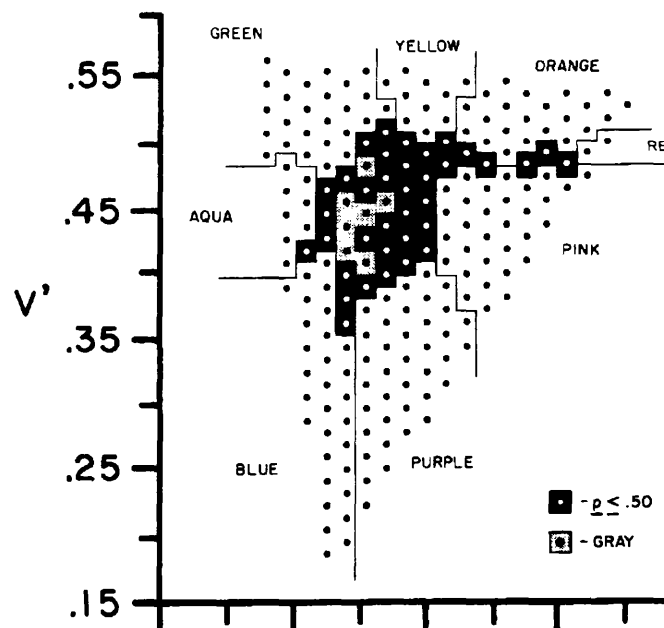


Fig. 5. Color-naming boundaries for a modal response of 50% or greater.

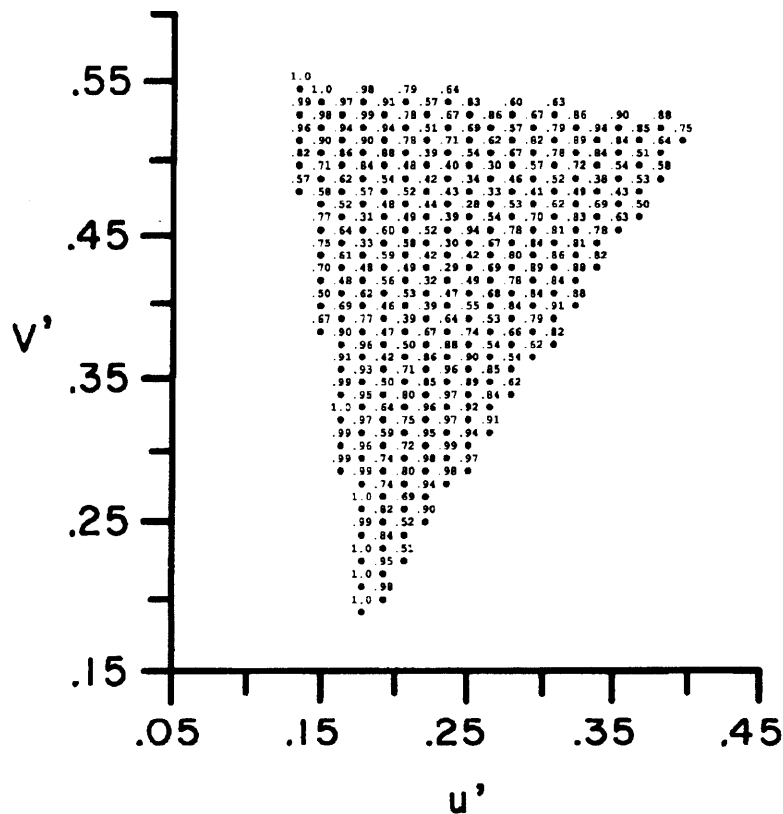


Fig. 6. Probability of the modal response for each of the 210 stimuli tested in the experiment.

For each stimulus, the subjects' responses have been pooled. This yields 100 color naming responses for each of the stimuli. In Figures 3, 4, and 5, color naming boundaries have been plotted based on the modal response to each stimulus and a 95% (Figure 3), 75% (Figure 4), and 50% (Figure 5) criterion. That is, the colors within these boundaries have a modal response greater than or equal to the criterion. At the 95% criterion, there are only greens, blues, and purples in the stimulus set. When the criterion was dropped to 75%, yellow, pink, orange, and aqua regions were added. The failure to obtain a color that was named red at least 75% of the time is not surprising for it is a well known fact that the "red" phosphor util-

ized on many CRT screens is not a highly saturated red. At the 50% criterion, nine of the ten color names (all except white) have specified regions in the color space. Lastly, Figure 6 gives the probability of the modal responses to each of the 210 stimuli.

## DISCUSSION

As stated in the Introduction, the results of this experiment will serve as a data base which will allow a comparison of strategies for the selection of easily distinguishable colors for color sets. One strategy is to choose colors with different color names, using one or more of the regions established by varying the modal criterion in this experiment (Post & Greene, 1986; Post & Calhoun, 1988).

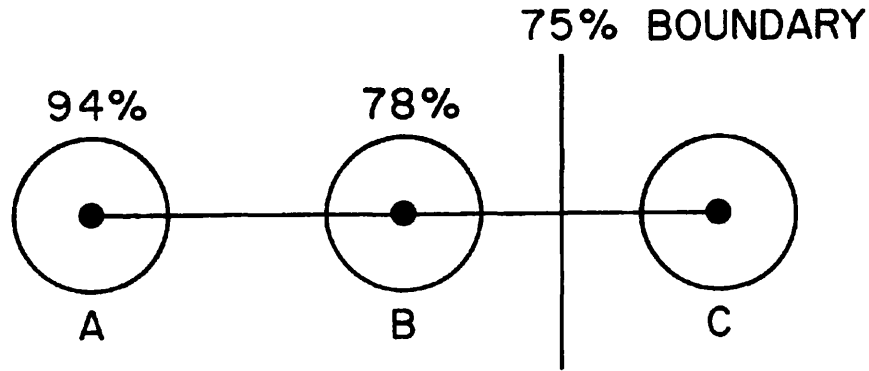


Fig. 7. Colors A and B were called green at least 75% of the time, whereas color C has been called green only 39% of the time. However, the distance between colors A & B and B & C are equal.

Another strategy is to select colors which exceed a minimal delta E value for all possible color pairs in the set. Delta E refers to the difference between two colors in CIE LUV (Silverstein and Merrifield, 1985) space, taking into account both brightness and chromatic differences. Neri, Jacobsen, & Luria (1985) showed that the latter strategy was useful in predicting color matching performance with color sets recommended in the literature.

The two strategies could be at odds under the following conditions. First, the color naming strategy may recommend two or more colors for inclusion in the set that do not exceed the criterion delta E value even though they were reliably called by different names. Second, the color discrimination strategy may recommend two or more colors for inclusion in the set that come from the same color naming region even though they exceed the criterion delta E value. This situation is illustrated in Figure 7. Colors A and B have been called green at least 75% of the time (94% for color A, 78% for color B), whereas color C falls outside this green

color region. However, the distance between colors A and B is equal to the distance between colors B and C. If delta E is a reliable predictor of discriminability then one would predict that colors A and B are as discriminable from one another as colors B and C. However, if color naming has an effect on discriminability, then A and B may prove more difficult to discriminate than B and C. The same holds true for an identification task, or a paired-associate learning task. In each of these tasks we may ask how effective the color naming regions are in predicting performance with colors drawn from different regions.

The issue is not a simple one since many variables come into play. To name just two, there is the role that the relative weight of luminance differences plays in determining delta E with the color discrimination strategy, and the role the proximity of two differently named colors in 1976 CIE space plays with the color naming strategy. The core issue may be whether the application of different color names to two stimuli serves to enhance their perceptual discrimination, or whether

perceptual discrimination is devoid of this cognitive influence. Since there appears to be a primacy to certain named colors (Ratliff, 1976), we suspect that attention to the names ascribed to two color stimuli in examining their discriminability may play at least as large a role as their difference computed by an algorithm based on their Euclidean distance in a roughly perceptual space. The results of this experiment provide the data base with which to compare the two strategies.

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