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30.1: Color Discrimination of Small Fields on Self-Luminous Displays

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Abstract

Results of psychophysical experiments investigating the field size dependence of color discriminability of symbols subtending angles below 2 degrees are presented. The results indicate color discriminability varies with field size. Measurement of the variability of matches with field size allows the development of a field-size-dependent color discrimination metric.

Introduction

The long term objective of this research is the development of a color difference measure appropriate for the design of small symbology for color displays in various lighting environments. A key point is that by defining this measure in terms of known physiological signals generated within the observer's visual system, we can generalize it to different field sizes through modification of its coefficients. Specifically, we have investigated the field-size-dependence of color discriminability to develop a method for designing highly discriminable color symbols on a CRT. Towards this objective we performed psychophysical experiments with observers to determine the weighting for the luminosity (L/D), red/green (R/G), and tritan axis (or Chartreuse/Violet, C/V) components of color difference that depends appropriately upon target field size and also on surround and ambient lighting conditions.

The infinite variety in size and form of displayed targets has not been adequately considered in experimental or theoretical studies of color discriminability. Consequently, our initial goal has been to define (on the basis of new experimental data) a color difference measure that depends appropriately on target field size. The variation in color processing with field size, or with location in the visual field, appears to be quantitative, rather than qualitative, and we expect that color difference measures appropriate for different field sizes will differ only in the values of certain parameters.[1,2]

The use of color, along with optimal symbol shape, allows displays with large amounts of information to be interpreted quickly and accurately. Display designers using current color science theories have found it difficult to develop displays which have highly discriminable colors for small symbol sizes.[3] Since the existing color difference theory was developed for larger symbol sizes, applying it to smaller symbol sizes provides unreliable results.

Sayer et. al. and Jubis and Turner found limitations of applying the 1976 CIELUV color difference equations to predicting discriminable colors on self-luminous displays with small symbol sizes.[4,5] To remedy this situation, a general approach taking account of symbol size, color and luminance is needed. Jacobsen's work has resulted in modified delta E equations for use with small symbols sizes.[6] These modifications achieved some success. However, rather than rely upon modifications of delta E equations for small field sizes, our investigation has sought to determine a field-size-dependent color difference formula.

The color difference measure adopted for small field sizes depends upon the opponent-color model of human color vision. A registered color difference depends upon the magnitudes of the difference registered in the three color signals delivered to the visual cortex. This in

ISSN0097-0966X/96/2701-0727-$1.00 + .00 © 1996 SID

turn depends upon the difference between the responses elicited in each of three classes of cone photoreceptor.

Methods

During our study we constructed an experimental setup, developed appropriate psychophysical procedures for investigating the influence of color on target detection/identification and completed a number of preliminary experimental studies. Color, luminosity, and size of the symbol, as well as ambient lighting conditions were controlled. The results of observer matching experiments produced estimates of the weighting vectors to be used with the cardinal directions for fields below 2 degrees. From the weighting vectors for color and luminosity we have established the perceptible color differences along the cardinal axes.

Experiments were conducted using a Mitsubishi Diamond Pro 17" monitor controlled by a Number Nine GX5 video card. The monitor was operated at 1024 by 768 resolution with a 60 Hz refresh rate. Ambient illumination for the experiments was 2.26 lux. Subjects adjusted the color along predetermined color directions using a MicroSpeed trackball mouse. Experimental software adapted from programs developed at UCSD by one of us (D. I. A. MacLeod) presented the subjects with targets subtending angles ranging from 0.13 degrees to 1.25 degrees. These targets were displayed in the center of a surround which subtended 8.3 degrees and had a correlated color temperature of 8390 K.

For these experiments eight observers were used and a limited number of conditions were tested. The goal of the experiments was to obtain a basic understanding of the field-size-dependence of color discriminability thresholds. The experiments performed included: matching a target to surround color; setting the target area just noticeably different for a divided field; setting the target field of two fields separated by 2 degrees to a just noticeable difference; and a forced choice discriminability experiment. In every case, these experiments demonstrated a field-size-dependence of discriminability; particularly along the tritan cardinal direction. The cardinal color directions were investigated for all experiments, while selected non-cardinal directions also were investigated for the color matching experiment.

Results

Results from the matching target to surround experimental configuration demonstrate the field-size-dependence of color discriminability along the cardinal directions. For the matching experiment, results indicated that the standard deviation of the difference settings increases greatly for the tritan direction (C/V) as the field size decreases. The standard deviation is not as greatly affected for the R/G and L/D directions. It is of interest to note that the L/D direction has the least difference in standard deviation between the smallest and largest fields observed as shown in Figure 1. However, when L/D matches are viewed on an absolute scale, the L/D matches are about 10 times more variable than R/G matches as demonstrated in Figure 2.

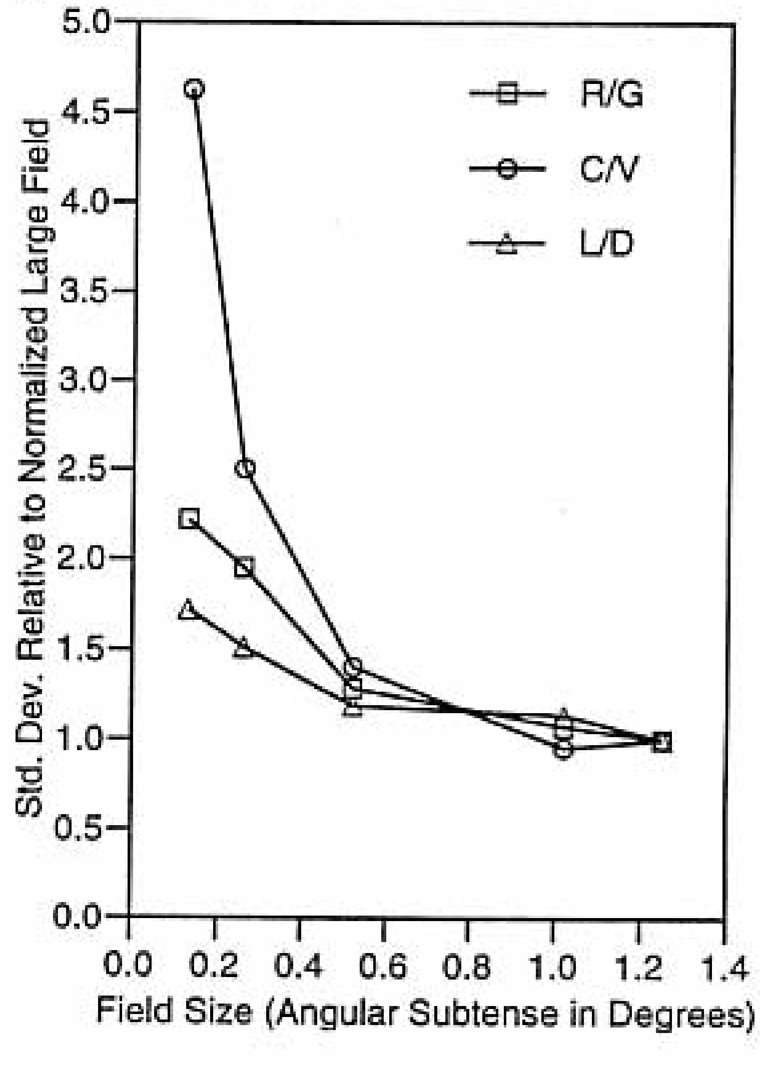

Figure 1. Normalized discrimination thresholds as a function of field size. R/G, C/V, and L/D denote the red/green, tritan, and luminosity directions respectively.

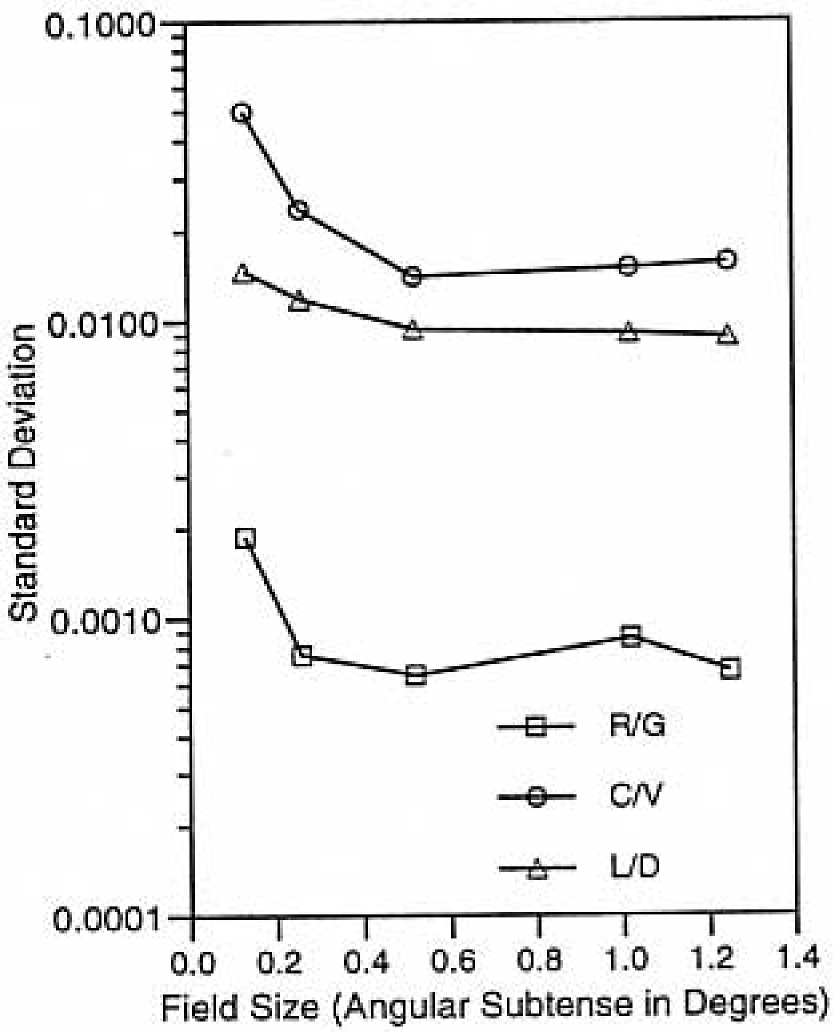

Figure 2. Discrimination thresholds for cardinal directions from one observer. R/G, C/V, and L/D denote the red/green, tritan, and luminosity directions respectively.

Agreement between experiments was observed though the results for some experimental configurations showed the effects of field size more than others (possibly due to fixation effects). Some effects also may have been enhanced by other factors, such as recognition of the color difference in the split field case which requires a spatial resolution of color within the field. In the separate field or the target/surround cases the color differences can be picked up as perturbations of space averaged color which are not necessarily well localized. The effects of fixation also may account for some of the variations in the results; particularly between different configurations of these experiments.

Although small field tritanopia generally is demonstrated using careful fixation together with artificial experimental conditions (chosen, for instance, so as to minimize chromatic aberration), it appeared clearly in these results with no instruction to fixate. Yet the effects were much smaller than those observed in more controlled situations. Williams, MacLeod and Hayhoe, for instance, found evidence supporting the conclusion of König that the fovea is completely blue-blind over a region subtending as much as 20 arcminutes.[7] This strictly blue-blind spot is not evident under more natural conditions, such as those of these experiments, presumably as a consequence of optical spreading, involuntary and voluntary eye movements, etc. However, it is reflected in a selective loss of blue axis sensitivity in the small field.

Impact

The experiments performed indicated that there is an effect on color discriminability for small fields in the controlled conditions similar to those used for the 1931 standard observer. The results obtained for the match field experiments indicate that the ability to discriminate the color of small fields is affected by foveal tritanopia. This effect also is shown to vary somewhat from observer to observer, as was seen in the just noticeable difference experiments.

A theory which incorporates the effect of symbol size on color perception, along with the influences of background and ambient, color and illumination, would allow symbol design trade-off and optimization. However, the theory must be general enough to be applied to a wide variety of existing displays as well as to future display technology.

Acknowledgements

Research supported by Small Business Innovative Research contract N00014-94-C-0188. In addition, the second author was also supported by grant EY01711 from the National Institutes of Health awarded to University of California, San Diego.

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