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MEASUREMENT OF COLOR DEFECTIVE AND NORMAL COLOR VISION SUBJECTS' COLOR AND LUMINANCE CONTRAST THRESHOLD FUNCTIONS ON CRT

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Abstract

To perform a more complete diagnosis on the effect of color vision deficiency on visual performance we measured luminance and color contrast threshold functions. Measurements were carried out on CRT for a range of spatial frequencies on color deficient and normal color vision individuals. Luminance and color contrast threshold is a measure of the recognition limits of low luminance and color contrast patterns. Both of them are function of the image features and spatial frequency. In our test patterns of stripes with a sinusoidal luminance profile were displayed on the monitor. The subject's task was to detect the presence and orientation of these gratings. In the study 6 normal and 6 anomalous trichromats were measured. In the case of color contrast threshold measurement it is essential to apply colors with identical luminance sensation, otherwise the test person might be able to differentiate between the presented colors not based on hue but based on luminance. The increasing accessibility of computers and color monitors provides a platform for color vision tests based on brightness sensation correction. In our experiment we define the subject's relative luminance sensation stimulated by the primary colors of the monitor with the method of direct heterochromatic photometry. Although, there were no significant differences in luminance contrast threshold between normal color vision and color deficient subjects, we found significant reduction in red-green color contrast threshold at all color defectives. The results prove the assumption that color deficiency has a negative effect on noticing details in color environment.

Keywords: normal color vision, defective color vision, color contrast, CRT.

1. Introduction

Human vision is based on differentiating and recognizing environmental surface parts with different colors and luminance, which are projected to the retina. The differentiation of surface parts with different luminance is assisted by luminance contrast, while the differentiation of surface parts with different colors is assisted by color contrast. Luminance contrast sensitivity is equally efficient in the event of normal and anomalous trichromats, whereas red-green color contrast sensitivity of anomalous trichromats is considerably lower than that of normal trichromats [1].

1.1. Luminance Contrast

In order that numerical evaluation of measurements could be done, the luminance contrast definitions known (*Eq.* (1)) were interpreted as follows [2].

$$K = \frac{I_1 - I_2}{I_1 + I_2}, \tag{1}$$

where K is the luminance contrast and I_1, I_2 are the different luminances of the two neighboring surface parts. The maximum contrast value is 1, while the minimum is equal to 0.

1.2. Color Contrast

When interpreting color contrast we have to modify the previous definition. The need for this modification can be easily demonstrated through the following example. Let I_1, and I_2 be equal intensity but spectrally different colors. In this case the contrast value is 0, however, we are able to discriminate the bars composed from these two colors. In our current case the bars are generated using only the different tones of red and green color. Let's define a variable, which characterizes the red content of a given color relative to its green content (*Eq.* (2)).

$$\Pi = \frac{R \cdot \varphi_{Red}(\lambda)}{R \cdot \varphi_{Red}(\lambda) + G \cdot \varphi_{Green}(\lambda)}, \tag{2}$$

where R, G parameters are defining the relative ratio of the luminance of the red and green primary monitor colors. $\varphi_{Red}(\lambda)$, $\varphi_{Green}(\lambda)$ are the spectral power distributions of the red and green primary monitor colors, setting their intensity to the maximum. From this the color contrast is calculated using its definition (*Eq.* (3)), where Π_1, Π_2 are characterizing the red/green ratio in the colors of the bars as shown in *Eq.* (2).

$$K = \frac{\Pi_1 - \Pi_2}{\Pi_1 + \Pi_2}. \tag{3}$$

1.3. About Contrast Threshold

Contrast threshold is the lowest contrast value perceived at a given spatial frequency by a human. Contrast threshold, as well as contrast sensitivity, is a function of frequency. Grids with low or high spatial frequencies are difficult to perceive for a human. Contrast threshold is lowest in the event of medium space frequencies, whereas the threshold increases at very small or increasing space frequencies [3]. This tendency holds true both for luminance and color contrast sensitivity threshold.

2. Methods

2.1. Measurement Method and Layout

For the measurements we used software driven test patterns presented on color monitor. The test subject was seated 4 m away from the monitor. Test patterns showed a variable spatial frequency grid built from bars of two different colors. The orientation of the grid was randomly set to be either horizontal or vertical. In the case of the highest density grid we presented, the viewing angle of one period (two adjacent bars) was $0°1'13''$ meanwhile in the case of the lowest density the viewing field was $0°59'58''$. The size of the grid was 70×70 mm. The procedure of the measurement was to choose spatial frequency as fixed parameter and increase the contrast between the two colors until the measurement subject could identify the orientation of the grid. Measurements were taken on 8 different spatial frequencies, however, the highest frequency resulted in the size of a pair of bars being below the resolution threshold of the human eye, therefore none could accomplish this task. Three measurements were taken at each spatial frequency for both achromatic and red-green grids. Measurements were carried out in a dark room and the background color behind the test pattern was the monitor's white. In order to assure equal color adaptation status and pupil size for each subject, they were adapted to the monitor white before each measurement. We did not apply additional light sources to further stabilize pupil size because this would have decreased the efficiency of the test significantly.

2.2. Measurement Subjects

Six normal and six anomalous color vision people were chosen for the measurements. All of them were 22–25 years old males. Thus we tried to eliminate the dependence of pupil size from age. Prior to the actual test all of them were tested with Ishihara and Velhagen color vision tests, PDT-2000 equipment [4] and a computer controlled color vision test [5].

2.3. Test Patterns of Achromatic and Red-Green Colors

We applied achromatic test patterns to define the luminance contrast threshold. The geometry of these black-and-white patterns was identical to the colored ones. The intensity profile of the grids was changing following the sine function. The most common occurence of anomalous trichromacy are originated from the defects of the long wavelength sensitive (L) and the medium wavelength sensitive (M) receptors. Therefore discrimination between greenish and reddish colors is very often difficult for many of them. To detect this deficiency we applied test grids made of red and green bars. The intensity profile of the grids was following the sine function for colored grids as well. Normal and anomalous color vision people judge the luminance of the red and green colors of the monitor differently and this perception is changing from person to person as well. In order to eliminate the bias caused by the relative luminance perception difference on the color discrimination at the beginning of the measurements we carried out relative luminance sensation measurement. See details in the next chapter. The software-generated colors were corrected by the subject's relative luminance sensation.

2.4. Brightness Matching Correction

The subject of the experiment defines the relative luminance sensation stimulated by the primary colors of the monitor with the method of direct heterochromatic photometry [6]. The method applies a circle or square shaped test pattern positioned in the middle of the CRT. The size of the pattern and the distance between the observer and the screen is set to allow seeing the test pattern in 10° viewfield. The pattern is split in half, and both halves represent one of the three primary colors. The task of the observer is to set the intensity of the presented colors until the luminosity of both parts seems to be equal for him/her. One set of measurements consists of three settings. The two sides of the test pattern are blue-green, blue-red and red-green. For all three couplings the observer has to set luminance equilibrium between the two parts. For practical reasons the luminance of one of the halves is preset, and the observer or an assistant changes the intensity of the other half until the luminance sensation generated by the two halves seems to be equal for the observer. The measurement protocol was to present the brightest possible blue on one side and ask the observer to match first the green and the red colors presented in the other half of the pattern. In the third step the previously set red was presented on the fixed side, and the observer was asked to match the green color presented on the other side. If the measurement was carried out properly the red/green ratio calculated from the first two settings shall be in close approximation to the red/green ratio actually measured in the third step. If these two ratios differ from each other significantly it might indicate an improperly conducted measurement set. It shall be noted that an observer lacking the knowledge of basic coloristics might have difficulties understanding the task. The observer might find the method too subjective.

2.5. Calibration of the Display

In order to achieve accurate colorimetric results we carried out both spectral and photometric calibration on the CRT monitor what we used for our experiments. First we measured the spectral power distribution of the three primary monitor colors meanwhile setting their intensity to the maximum. Then we measured the gamma characteristics of the monitor. The spectral calibration was carried out with a Prichard spectroradiometer and the photometric calibration was done using a Cosilux photometer. The monitor we used was a 17′NOKIA driven by a PII processor PC through a 3 × 8 bit color resolution MATROX video card.

3. Results

From the mean of the results measured on the normal and anomalous color vision subjects we concluded the luminosity threshold sensitivity curves (*Fig. 1*) and the red-green color contrast threshold sensitivity curves (*Fig. 2*). Due to the differences in color vision deficient subjects' perception the red-green threshold sensitivity measurements show higher standard deviation in their case.

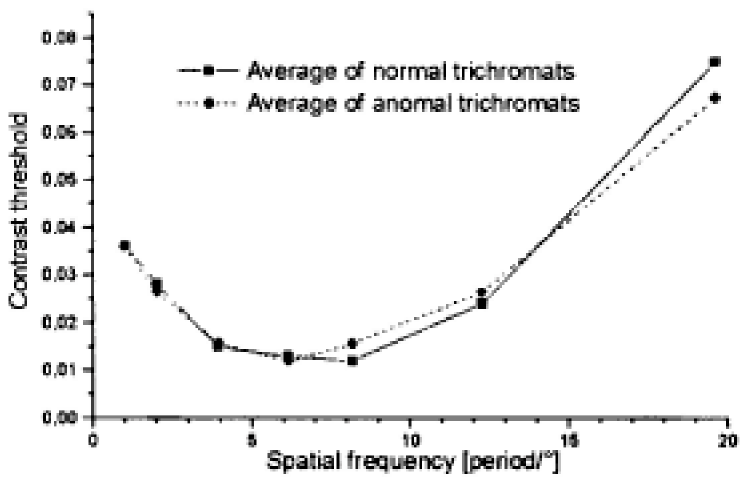

Fig. 1. Measured luminance contrast threshold at normal and anomalous trichromats

4. Conclusion

We have shown that for achromatic patterns normal and anomalous color vision people have closely correlated contrast sensitivity meanwhile the red-green contrast sensitivity of color deficient people is significantly worse than color normals'. Identification of the luminosity and color contrast sensitivity threshold functions via monitor tests allows the qualification of normal and anomalous color vision from the prospective of contrast sensitivity. The described test is capable of overall evaluation of the color vision deficiency combined with other tests and measurements. In order to identify the accuracy of the test further and larger scale measurements needed to be carried out.

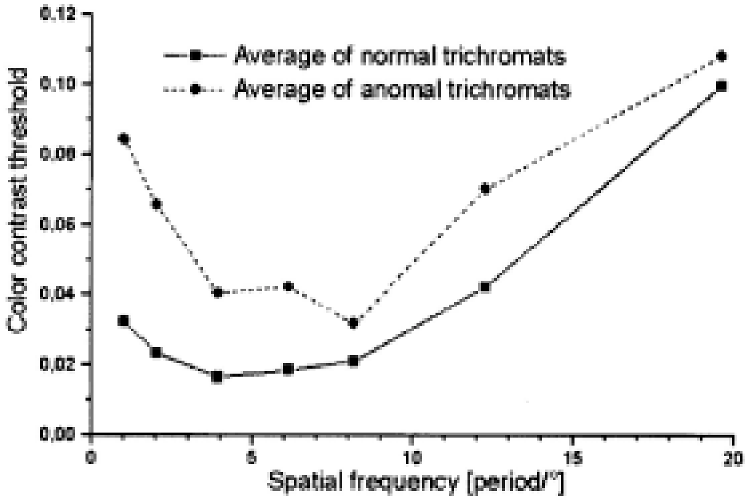

Fig. 2. Measured red-green color contrast threshold at normal and anomalous trichromats

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