Measuring Colour Resolution of the Eye by Using Colour Monitor

K Wenzel*, K Ladunga, Gy Abraham**, G Kovacs*, I Kucsera*, K Samu****
**Coloryte Hungary Inc., H-2000, Szentendre, Kozuzo u. 8.*
tel: 36-26-501010, fax: 36-26-501011
***Technical University of Budapest, Dept. of Precision Mechanics and Optics*
H-1521 Budapest, Muegyetem rkp. 3

1. Introduction

Human vision is based upon differentiating and recognizing environmental surface parts, which are projected to the retina with different colours and brightnesses The differentiation of surface parts with different brightnesses is assisted by *brightness contrast*, while the differentiation of surface parts with different colours is assisted by *colour contrast.* According to our measurements while brightness contrast is equally efficient in the case of normal trichromats and anomalous trichromats, whereas colour contrast sensitivity of anomalous trichromats is considerably lower than that of normal trichromats.

When designing lenses, which correct anomalous trichromats, it is crucial to improve colour contrast sensitivity. Therefore, one significant characteristic of the efficiency of the lenses is the improvement of colour contrast. Following is the presentation of colour contrast values in the event of normal and anomalous trichromats as well as the presentation of the colour contrast sensitivity improvement available with the application of lenses, which are correcting colour vision.

Our measurements were performed via applying test picture grids with different space frequencies, different colours and different contrasts on the monitor. During the study, colour contrast threshold sensitivity function (CCTSF) was determined in the event of normal trichromat and anomalous trichromat persons as well as anomalous trichromat persons corrected with corrective filters.

In order to allow numerical evaluation of the measurements, the well known contrast definitions [1,2] were interpreted as follows.

2. Brightness contrast

Upon the basis of the general contrast definition [1,2] *brightness contrast* sensed by the human eye's retina is defined as follows:

$$K_B = \left| \frac{S_1 - S_2}{S_1 + S_2} \right| \qquad /1/$$

where K_B is brightness contrast; S_1 and S_2 are intensities of sensation of two surface parts marked 1 and 2 of the retina

Maximum brightness contrast value is 1 (if one of the values S_1 and S_2 is equal to 0) while minimum brightness contrast value is 0 (if $S_1 = S_2$).

3. Colour contrast

When the two surface parts (1 and 2) have the same intensities of sensations while these sensations are different in colour, the two surface parts can be differentiated by *colour contrast*. Colour contrast is produced by stimulating, to different extents, three types of receptors of the human eye — receptors L (long wave sensitive), M (middle wave sensitive) and S (short wave sensitive). Colour contrast can be determined by the distance of the two colour points C_1 and C_2 in the normal PDT colour system [3] as follows:

$$K_C = \left| \frac{C_1 - C_2}{C_1 + C_2} \right| \qquad /2/$$

where K_C is colour contrast

C_1 and C_2 are two different colour points in the normal PDT colour space.

Colours C_1 and C_2 are composed of the sensations of the three types of receptors, thus they can be considered as three-dimensional vectors. Vectors of points C_1 and C_2 are c1 and c2.

$$\bar{c}_1 = \bar{c}_1(p_1, d_1, t_1)$$
$$\bar{c}_2 = \bar{c}_2(p_2, d_2, t_2) \qquad /3/$$

where p_1, d_1, t_1 and p_2, d_2, t_2 are colour coordinates of two different colours, C_1 and C_2, in the normal PDT colour system,

Using these coordinates, colour contrast value is calculated according to /2/ and /4/ as follows:

$$K_c = \frac{\sqrt{(p_1 - p_2)^2 + (d_1 - d_2)^2 + (t_1 - t_2)^2}}{\sqrt{(p_1 + p_2)^2 + (d_1 + d_2)^2 + (t_1 + t_2)^2}} \qquad /4/$$

Maximum value of colour contrast K_C is 1, if $p_1=d_1=t_1=0$, or $p_2=d_2=t_2=0$. Minimum value of K_C is 0, if $p_1=p_2$, $d_1=d_2$, $t_1=t_2$

4. Contrast sensitivity threshold function

A human senses the contrast as a function of space frequency. Grids with low or high space frequencies (i. e. gridlines with too small clearances or with too big clearances in between) are difficult to perceive for a human, while it is easier to perceive a grid with a medium space frequency [4,5,6,7,8]. This tendency holds true both for brightness sensitivity and colour contrast sensitivity.

Contrast sensitivity threshold is the lowest contrast value perceived at a given space frequency by a human. Contrast sensitivity threshold function, as well as contrast sensitivity, is a function of frequency. Contrast sensitivity threshold is lowest in the event of medium space frequencies, whereas the threshold increases towards both decreasing and increasing space frequencies. This tendency holds true again both for brightness sensitivity and colour contrast sensitivity.

A normal and an anomalous trichromat does not see the contrast of colours C_1 and C_2 to be identical. This can be traced back to the spectral sensitivity differences of their receptors. As a rule, either sensitivity range of receptor L is shifted toward the shorter wavelength range or sensitivity range of receptor M is shifted toward the longer wavelength range [9]. Therefore the points of red and green phosphors of CRT monitor will be found closer to each other in the PDT colour space of the normal colour vision in the event of an anomalous trichromat than in a normal trichromat. Consequently, the colour contrast sensed by an anomalous trichromat will also be smaller than that of a person with normal colour vision.

5. Measurements

To conduct the measurements, we applied test pictures produced on colour monitor. Distance between the Test Person and the monitor was 4.0 meters. To ensure patients' identical colour adaptation condition as well as identical pupil dimension, the measurements were always carried out in the same room with identical circumstances of artificial illumination (6000K fluorescent tube). For the same purpose, the colour of the background and surroundings were always white against the grid lines.

The test pictures were test grids with different space frequencies; the orientation of the grids was randomly set to be either horizontal or vertical. With highest space frequency of grids on the monitor, distance of two gridlines of the same colour was 2 mm (thus, visual angle was 1.72 minutes). With lowest space frequency of grids, distance of two grid lines of the same colour was 25 mm (thus, visual angle was 21.48 minutes). Total area of the grid surface on the monitor was 50 mm x 50 mm.

In the first place, the grid with the highest space frequency was shown to the Test Persons, then grids with lower and lower space frequencies were shown in turn. The purpose of this task was for each Test Persons to find the highest grid line space frequencies, which they were able to identify. All tasks were repeated three times. Measures were made at 7 different contrasts.

Anomalous trichromacy in its most frequent form is caused by the defective operation of L or M colour sensing receptors**.** Therefore, differentiation of colours red and green is difficult for most anomalous trichromats to do. To demonstrate this, test pictures with red-green grid lines were used. Intensity profiles of test grids were modified by sine function. To determine brightness contrast sensitivity threshold, achromatic test pictures were used. Geometric dimensions of black and white test pictures were identical with those of the colour pictures. Intensity profiles of grids were modified by sine function

The measurements were performed on 6 normal and 5 anomalous trichromats. The Test Persons' colour vision was tested on Velhagen charts and with a Heidelberg anomaloscope. Patients' visus was corrected with spectacles.

Monitor colours red and green are perceived to be having different brightness by normal and anomalous trichromats, and this relative brightness sensation is individually different. Before conducting the test measurements, relative brightness sensation had also been accomplished for each Test Person. This way enhancement of colour contrast sensation with some brightness contrast, which would falsify the measurement, was eliminated, [10]. For this purpose, another set of test pictures was used. Vision field of the colour monitor was composed of two neighbouring semi-circles, against a white background. One of the semi-circles was green, the other was red. The task for the Test Persons was to determine at what setting they saw the two fields having the same level of brightness. Further pictures provided at a given contrast with different grid line space frequencies were produced through balancing each person's relative brightness sensation individually by the software. Before the accomplishment of the measurements, spectral emission and γ curves of the monitors had also been measured. Relying upon these data, test pictures with different grid line space frequencies, adjusted to individual relative brightness sensation while having identical colour contrasts, had been prepared by the software.

6. Results

Achromatic CCTSF curves calculated from the mean of the measurement values of 6 normal and 5 anomalous trichromats are shown in Figure 1, whereas red-green CCTSF curves are in Figure 2. In Figure 3 CCTSF curves of Test Person 9 are shown, with and without the corrective lenses designed to be appropriate for him.

According to Figure 1, normal and anomalous trichromats' average achromatic CCTFS curves have, basically, no difference of any significance. Nonetheless, Figure 2 shows that normal and anomalous trichromats' average red-green CCTFS curves do have a significant difference: threshold values of anomalous

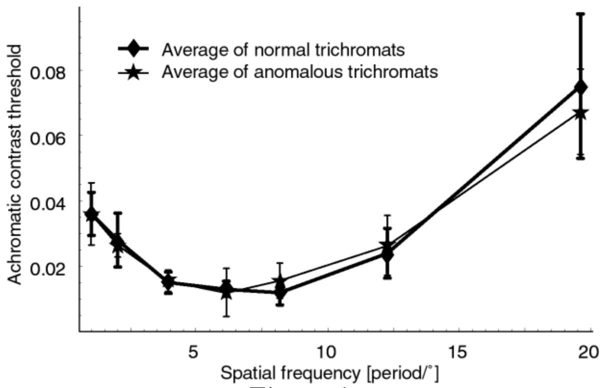

Figure 1.
Average contrast sensitivity threshold function of six normal trichromats (bold line) and of five anomalous trichromats (thick line) when using achromatic test pictures

trichromats are nearly twice as high as of normal trichromats. Figure 3, red-green CCTFS curve of the patient corrected with appropriate lenses shows remarkable improvement: his values approximate the values of normal trichromats.

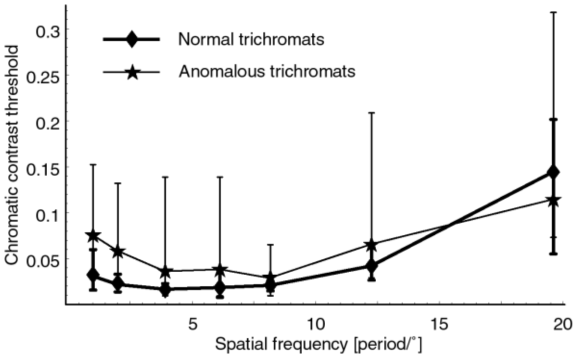

Figure 2.
Average colour contrast sensitivity threshold function of six normal trichromats (bold line) and of five anomalous trichromats (thick line) when using coloured test pictures

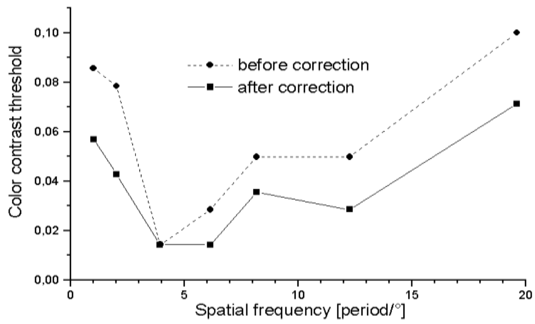

Figure 3.
Colour contrast threshold sensitivity function curves of an anomalous trichromat with (continuous line) and without (dotted line) corrective filters

7. Conclusion

Determination of CCTFS curves by monitor tests enables us to evaluate normal and anomalous trichromats' colour vision regarding to contrast sensitivity, and to demonstrate the efficiency of the corrective filters as well. This method, along with other tests and measurements, is applicable for a full, detailed evaluation of colour deficiency. It takes several further measurements, however, to determine the precision level of this measuring method.

8. References

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