Colour and luminance contrast sensitivity function of people with anomalous colour vision

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1. INTRODUCTION

The experience of a colored picture is formed of the multitude of spots of different colors and shapes projected on the retina of the eye. The more spots we can distinguish the more details we can see and the more information we can get. It can be observed that people of anomalous color vision are at a disadvantage not only from the point of view of the correct recognition of colors but also from that of seeing less detailed than do that of normal trichromats.

It is rather difficult to measure the detail of colored pictures formed by seeing. It is practical to carry out the measuring with simplified geometry and in limited colors. The most simple test picture is the grating and it is best to limit the colors to two and to their additive mixtures respectively.

The color contrast sensitivity function (CCFS) can be well used to prove that people of anomalous color vision can distinguish less details than those of normal trichromats. Besides this the effect improving color vision (e.g. by color vision correction filters) can also be proved.

Several examinations can be made by gratings created with two colors and by changing their various parameters. We have got appreciable data by changing space frequency and contrast, and redefining colored gratings to the CCSF already known in the examination of sight testing. Thereby we succeeded in demonstrating the difference between normal and anomalous trichromats.

Keywords: Colour contrast, contrast sensitivity function, defective colour vision

2. LUMINANCE AND COLOUR CONTRAST

The subject of our examination was the contrast sensitivity function (CSF). We can determine this function and its curve respectively by gratings which seem to be grey at a given space frequency of the grating under a certain contrast threshold. The calculation of the contrast of the grating is done on the basis of the definition of brightness contrast:

$$K = \left|\frac{I_1 - I_2}{I_1 + I_2}\right| \qquad (1)$$

, where K is the contrast
I_1 and I_2 are the different brightness of two pixels or grid lines marked 1 and 2

The measured curves of space frequency-contrast sensitivity of neutral color are U-shaped.
The definition of the contrast of colored gratings on the basis of formula (1) is made more difficult by the fact that gratings of different colors but of identical brightness are still resolved by the retina but in such cases the contrast according to the definition is 0. Thus if we want to extend the contrast to colored gratings too, we must find a definition which makes the color contrast measurable.

For measuring the CSF it is necessary to change the contrast of colored gratings on different space frequencies. The contrast modulation of colored gratings can be carried out in three ways with the help of two grating colors. If the color coordinates of one grating color controlled on the CRT monitor by computer are R_1, G_1, B_1 and that of the other are R_2, G_2, B_2, then we can modulate the color contrast in the ways given in Table 1..

	Bar 1 and 2 color at K=0..1	Bar 1 and 2 color at K=0..1	Bar 1 and 2 color at K=0..1
color contrast modulation I	R_1,G_1,B_1 R_2,G_2,B_2	M_R=max(R_1,R_2) M_G=max(G_1,G_2) M_B=max(B_1,B_2)	$R_{1,2}=R_{1,2}+(M_R-R_{1,2})(1-K)$ $G_{1,2}=G_{1,2}+(M_G-G_{1,2})(1-K)$ $B_{1,2}=B_{1,2}+(M_B-B_{1,2})(1-K)$
color contrast modulation II	R_1,G_1,B_1 R_2,G_2,B_2	$M_R=(R_2+R_1)/2$ $M_G=(G_2+G_1)/2$ $M_B=(B_2+B_1)/2$	$R_{1,2}=R_{1,2}+(1-K)M_R$ $G_{1,2}=G_{1,2}+(1-K)M_G$ $B_{1,2}=B_{1,2}+(1-K)M_B$
color contrast modulation III	R_1,G_1,B_1 R_2,G_2,B_2	$M_R=0$ $M_G=0$ $M_B=0$	$R_{1,2}=K\,R_{1,2}$ $G_{1,2}=K\,G_{1,2}$ $B_{1,2}=K\,B_{1,2}$

Table 1. Methods of color contrast modulation

At modulation type II the maximum contrast grating number 1 contains only one of the starting colors of the two neighboring grating colors while the two colors belonging to the 0 contrast consists of mixtures of the starting colors of identical intensity. The modulation of the color contrast made in this way suits well the method measuring the CIE L*a*b* color difference as the calculated color difference between the two grating colors defines the color contrast sensitivity. White and black are the grating colors belonging to contrast 1 of the modulation types I and III. In the course of contrast changing at these modulations the identity of the brightness of the grid lines does not exists, and the values calculated by the methods of color differences are not correlated with the decreasing contrast values, so the modulation types I and III have not been used.

The color contrast sensitivity curve CCSF is measurable by the modulation described in method II, which shows the threshold of color contrast sensitivity expressed in the CIE La*b* system is given in the function of space frequency.

3. METHODS

We have made the contrast and space frequency modulation of the red and green gratings by a computer controlled CRT monitor with a software made for this purpose. The computer was a PI MMX-200, the calibrated monitor was a GS Studioworks 57i, and the display adapter was a Matrox Millennium.

We have made the examinations with a group consisting of 10 normal trichromats and 10 anomalous trichromats, by dividing them into three subgroups. Normal trichromats belong to the first subgroup while anomalous trichromats and corrected anomalous trichromats belong to the second and third subgroups. The glasses used for color vision correction contained general correcting filters for protanomalous trichromats developed using tinting technology in Coloryte Hungary. For the choosing of anomalous trichromats we applied Ishihara plates and for choosing the protanomalous people from the anomalous trichromats Heidelberg anomaloscope.

The brightness sensitivity of anomalous and normal trichromats are not identical because the spectrally shifted L and M receptors of the anomalous trichromats. Therefore anomalous trichromats can recognize the given contrast of colored gratings on the basis of the brightness difference without sensing the color difference. As this was not our aim, before the measuring of the CSF curves we carried out heterochromatic brightness matching as well between red and green primaries of the monitor. After this the software carrying out the measuring generates the gratings according to the CRT primary rations.
The gratings consist of red and green lines because the CSF differences between the protanomalous and the normal subgroups can be best demonstrated with these colors. For the background of the gratings we used the color belonging to the 0 contrast, the brightness of which is identical with the colors of the grating lines. The gratings were modulated sinusoidal and besides this in order to avoid the contrast appearing at the edges were shaded into the background.

4. MEASUREMENTS

The measurements were made in a dark room, the CCSF measuring software uses the gamma-corrected brightness rations of the primaries R and G got by heterochromatic brightness matching for creating gratings of identical brightness but different contrast.

The CSSF measuring were carried out on 1, 2, 4, 6, 8, 12, 20 [period/^{o}] space frequencies generally used in CSF measuring. The viewing angle of the test pictures was 1.5^o, and the observation distance was 4 meters.

In the curse of the measuring the color contrasts were increased to the point of the given space frequency at which the person concerned could recognize the grating. As in the curse of the contrast changing the gratings randomly appeared horizontally and vertically respectively, the task of the person concerned was to determine the direction. We accepted and registered the result of the just resolved contrast made at three measurement from both directions. We measured both CCSF and CSF curves at all the three subgroups and besides this we carried out three series of repeated measurements at one normal trichromat to confirm the reliability of the examination.

5. RESULTS

In the curse of the evaluation we determined the brightness contrast (at the CSF) and the color difference in CIE L*a*b* (at the CCSF) on the basis of the monitor emission and the gamma curves of the monitor primaries.

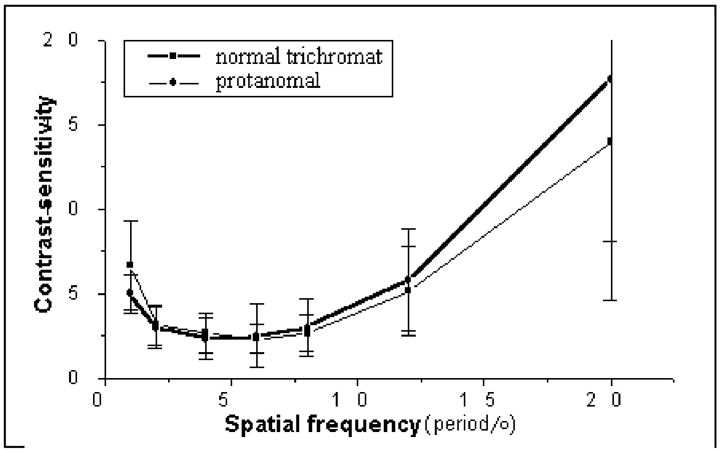

Fig. 2. CSF diagram of normal and anomalous trichromats

The statistical tests carried out and demonstrated on Fig. 2.prove that the neutral CSF measuring has not shown any significant difference between the anomalous and the normal trichromats. The cause of this is that in the development of the sensation of neutral colors, all the three (L, M, S) receptors take part identically disregarding the fact whether the sensitivity of a receptor is spectrally shifted or not. In this case the stimulus contains mainly intensity information (and not spectral information) and thus it can be established that the contrast sensitivity of an anomalous and a normal tricromat does not differ significantly from each other.

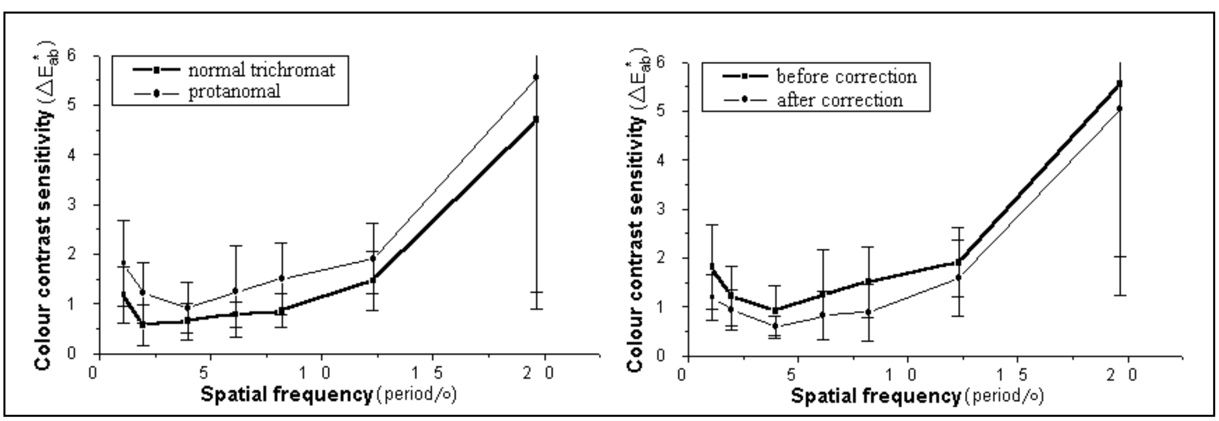

Fig. 3/a CCSF curves of normal and protanomalous trichromats 3/b CCSF curves of corrected and not corrected anomalous trichromats

The significant difference between normal and anomalous trichromats can be seen on Fig. 3/a. as well as the fact that the character of the CCSF curves is similar to those of the CSF ones. The results confirm the observed fact that the details seen by the anomalous trichromats in case of the red and the green colors are worse than those of normal trichromats.

The CCSF curves formed on the basis of Fig. 3/b by corrected and uncorrected anomalous trichromats show a difference that proves that we succeeded in demonstrating the improving effect of the glasses. Moreover if we compare the values of corrected anomalous trichromats it can also be established that by the glasses we succeeded in bringing the color contrast sensitivity to the normal value. Thus by the use of glasses the anomalous trichromats produced about the same contrast sensitivity as those of normal trichromats.

The standard deviation experienced at repeatability measurements is under 10% of the average value proving the reliability of our measurements.

6. CONCLUSION

On the basis of neutral CSF measuring carried out on 10 normal and anomalous trichromats each, we have established that the contrast sensitivity threshold of normal trichromats is identical with that of the protanomalous ones.

In the case of colored gratings the same examination show the difference between the two groups according to which the red-green contrast sensitivity of protanomalous trichromats is worse than that of the normal trichromats, but with the help of color correction glasses used by protanomals they could produce the CCSF results of normal trichromats.

- The results verified our method for contrast modulation;
- The results confirmed the correctness of our definition for CCSF;
- Finally the results verified the color vision correction method.

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