Pseudo-Isochromatic Plates to Measure Colour Discrimination

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Abstract: We have developed 3 series of pseudoisochromatic plates for colour vision testing. The plates are arranged in order of increasing difficulty. In the first (red/green) series, a red Landolt C is shown in front of a green background. This series is used to determine the severity of colour vision deficiency. In the second series, colours are located on the protan confusion line, whereas in the third series, on the deutan confusion line. The plates were printed by a calibrated colour printer, then bound in a book. The plates were used to test 320 persons with colour vision deficiency and 20 ones with normal colour vision. Our results showed a 96.25% efficiency in separating colour anomals and colour normals as verified by an anomaloscope. The test book gives prompt results and it is fun to use. A test takes about 5 minutes so it is suitable for mass tests and moreover, it may also be used to test the colour vision of children.

Keywords: colour vision deficiency; anomaloscope; ishihara test; D15 test

1 Introduction

1.1 An Optical Explanation of Colour Vision Deficiency

Daytime vision is made possible by the approximately 6.8 million photoreceptors (also known as the cones) found in the retina – the interior part of the eye. Some of the photoreceptors are sensitive to the colour red, others to green, and a third group is sensitive to blue. A person can distinguish between and identify more than a million different colours through the degree of stimulation of the three spectrally sensitive receptor groups. The English terms for the receptors sensitive to red, green and blue colours are: long wave, middle wave and short wave sensitive receptor, or L, M and S, for short. Wave-length determined spectral sensitivity is indicated by $l(\lambda)$, $m(\lambda)$ and $s(\lambda)$ [12], (Fig. 1). In medical literature, these receptors are named protos, deuteros and tritos. Colour vision relying on the

three types of receptor is called trichromatic vision. The most common forms of colour vision deficiency are protanomaly (the anomaly of the L receptor) and deuteranomaly (the anomaly of the M receptor), [12].

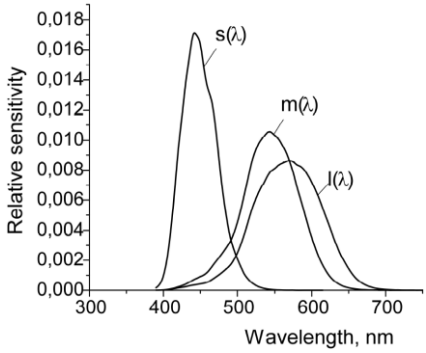

Figure 1

Spectral sensitivity curves of the three daytime receptors of those with normal colour vision, as function of wavelength [Gegenfurtner, Sharpe, 1999]. In the picture l(λ) means the spectral sensitivity of the long wave, m(λ) of the middle wave and s(λ) of the short wave sensitive receptors adapted for white light.

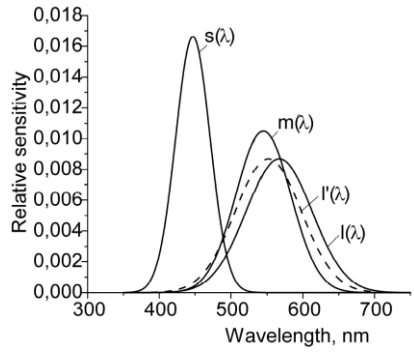

Figure 2

The diagram illustrates the spectral sensitivity disorder in people with protanomaly. The continuous lines show the spectral sensitivity curves of daytime receptors in the case of normal colour vision (l(λ), m(λ) and s(λ)), while the interrupted line shows the spectral sensitivity curve of a person

We developed our colour boosting eyeglasses for these types of colour vision deficiency.

In protanomaly and deuteranomaly, the spectral sensitivity curves of the L and M receptors, respectively are different from those seen in people with normal colour vision. The difference is a shift of the curves along the wavelength axis. The cause of this difference are genetic: different L and M photopigment alleles code for different amino acid sequences, and some differences in the amino acid sequences of the photopigments result in differences in their peak sensitivities.

The diagram in Fig. 2 illustrates the altered spectral sensitivity in people with protanomaly. The continuous lines show the spectral sensitivity curves of daytime receptors in the case of normal colour vision (l(λ), m(λ) and s(λ)), while the dashed lines show the spectral sensitivity curve of a person with protanomaly l'(λ). We can see that protanomaly is caused by the protos spectral sensitivity being shifted toward shorter wavelengths and thus being closer to the sensitivity of the deuteros than happens in subjects with normal colour vision.

Fig. 3 illustrates the spectral sensitivity of the deuteranomalous receptor. In this case, the spectral sensitivity of the deuteros is shifted toward longer wavelengths, and is found closer to the sensitivity of the protos than in subjects with normal colour vision.

The ability to discriminate between hues in the red-green segment of the spectrum is due to the different sensitivities of the L and M pigments. In protanomaly, as well as in deuteranomaly, the spectral distance between the L and M pigments is reduced compared to people with normal colour vision. Therefore, the ability to distinguish between red and green hues is impaired in both cases; this is the reason for sub-normal red-green colour vision. Correspondingly, colour identification is also impaired: the anomalous L and/or the anomalous M pigments are not sufficiently sensitive to red-green differences. Instead, the sensitivity to yellow hues dominates in the middle-to-long end of the spectrum.

The impairment characteristic of protanomaly is shown by the protan confusion line, whereas that of deuteranomalous people by the deutan confusion line in the CIE xyY system (Fig. 4).

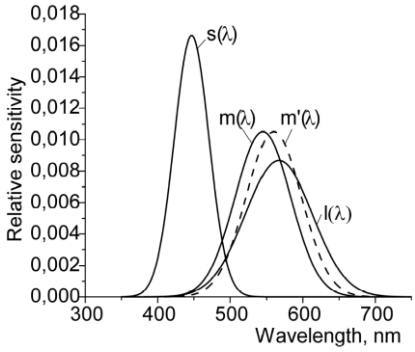

Figure 3

The diagram illustrates the spectral sensitivity disorder in people with deuteranomaly. The continuous lines show the spectral sensitivity curves of daytime receptors in the case of normal colour vision (l(λ), m(λ) and s(λ)), while the interrupted line shows the spectral sensitivity curve of a person with deuteranomaly m'(λ).

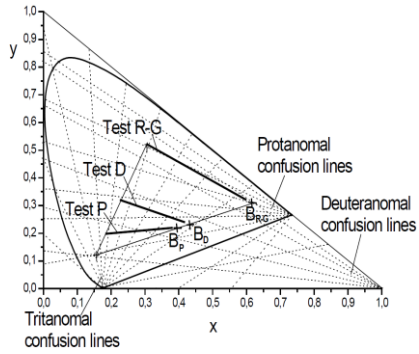

Figure 4

Points of the pseudoisochromatic plates in the CIE xyY chromaticity space. Test $_{R\text{-}G}$, Test $_{P}$, Test $_{D}$ and are the points of the plates in the three (R-G, P and D) series, B R-G, BP and BD are the points of the background in the series.

Colour vision deficiency is tested in most cases by anomaloscopes, the original form of which was constructed by the well-known mathematician Lord Rayleigh, and by different types of pseudo-isochromatic plates.

1.2 Our New Colour Vision Test

Our objective was to develop a colour vision test as simple and effective as the Ishihara test yet as accurate as an anomaloscope, providing quantifiable results. We also aimed at developing a prompt, simple method, also suitable for testing children.

There are some excellent colour vision tests that comply with these criteria [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. However, we wished to develop a test that could be able to distinguish 15 levels according to the severity of colour vision deficiency.

Our test was composed series of pseudoisochromatic plates. These plates do not show numbers or letters but Landolt C-s in various positions. The method was tested on 320 persons with colour vision deficiency and 20 ones with normal colour vision. These test persons had first been tested by the Ishihara test and anomaloscope. The criteria for diagnosis were developed according to the histograms of the measured results. The efficiency of separating patients with colour vision deficiency from those with normal colour vision was 96.25%.

2 Methods

The pseudoisochromatic plates were designed using the principles described in the book of J. Birch [12].

The pseudoisochromatic plates were designed in the colour system of CIE Lab, by a software that utilises confusion lines. The coloured dots on the plates are circular, and their density and sizes are similar to those in the Ishihara images. Both the Landolt-C and the background are composed of dots of 3 shades of the same colour.

The plates are arranged in order of increasing difficulty. In the first (R/G) series, a red Landolt C is shown in front of a green background. This series measures the ability to discriminate green and red colours. In the second (P) series, colours are located on the protan confusion line whereas in the third (D) series, on the deutan confusion line. Plates in the R/G series are coded as 300, 280, 260, etc. down to 60, 40, 30, 20. Plates, and in the P and D series they are coded as 200, 180, 160, etc. down to 60, 40, 30, 20.

In each series, the first plate is readily identifiable; that is, there is a pronounced difference between the average colour of the Landolt-C and the average colour of the background. This difference was determined in accordance with previous experiences, in a way that anomalous trichromats could identify the plate while dichromats could not ($\Delta E^*_{a,b}$=60…80). The other plates in the series are arranged in order of increasing difficulty. While the colour of the background remains the same, the colour of the Landolt-C gradually merges into the background. The last, most difficult plate may be identified only by those with excellent colour vision ($\Delta E^*_{a,b}$=8).

The average lightness of the Landolt C and its background is the same in every image.

The test was initially developed for a colour computer screen [13, 14, 15, 16, 17, 18, 19, 20] and eventually we switched to a printed version [21].

Plates were printed by a Canon iX5000 inkjet colour printer. While printing, the consistency of colour stimuli was provided by means of the ICC Color Management system. Printing as well as using the plates is defined for a CIE D65 standard illuminant.

The examination must be conducted with a standard CIE D65 illuminant. Lighting must be diffuse, neither too dark, nor blindingly bright; the ideal is 400…800 lux. There should not be a blinding light source directed at the subject, and neither must the light be in such a way that a glare could disturb the subjects when observing the images [22, 23].

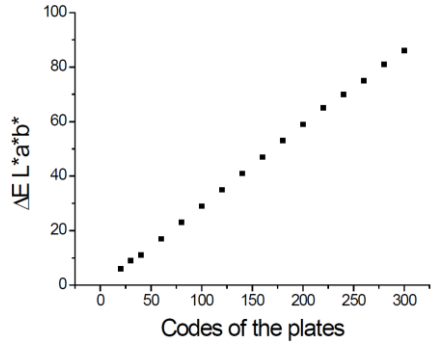

Figure 5
Difference between the average colour of the Landolt-C and the average colour of the background in the series R-G

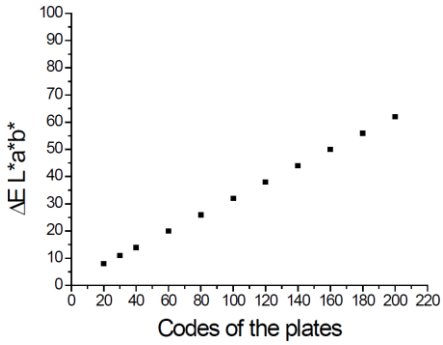

Figure 6
Difference between the average colour of the Landolt-C and the average colour of the

The plates are bound in a book. The book is designed in a way that the test person is able to see one plate at a time only, while the white backside of the next page provides white adaptation for the test person.

Once printed, the colours of plates were verified by Datacolor Microflash 45 (SN: Z151634, White reference: Techkon MF 45.812001). In each plate, 5 ones of the largest dots were measured from the groups of light, medium and dark dots each, then the colours of the background and the Landolt-C were determined from their averages in the CIE xyY system (Fig. 4). As is illustrated by the figure, the colour dots on the plates are near the confusion lines. We also determined the $\Delta E^*_{a,b}$ difference between the colours of the Landolt-C and the background for each plate (Figs. 5, 6 and 7). This difference gradually decreases from plate to plate.

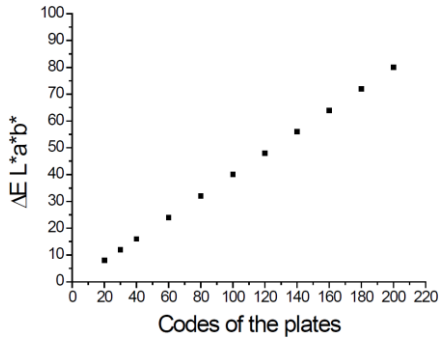

Figure 7
Difference between the average colour of the Landolt-C and the average colour of the

3 Tests

The colour vision of 320 persons with colour vision deficiency and 20 ones with normal colour vision was tested by various methods: anomaloscopy, Ishihara test and the new pseudoisochromatic plates.

The test persons were all males, between 8 and 59 years; the average age of the test persons was 29.67 year. The group of persons with colour vision deficiency was composed of 158 protanomalous and 162 deuteranomalous persons. The test persons cannot be considered as a representative sample of the colour blind as the tests were completed on volunteers.

A standard CIE D65 light source of 600-800 lux was applying for performing the tests.

3.1 Instruments Used

1) Oculus HMC anomaloscope (Typ. 47700, SN 24119901, Germany).

2) Ishihara Tables (ISHIHARA'S TESTS FOR COLOUR DEFICIENCY, 24 Plates Edition, 1999, Kanehara &CO., Tokyo, Japan). The plates were in good condition.

3) Color Vision Test, III. Edition, Printed in 2009.

3.2 Measured Results

A measured result is defined as the code of the first plate the test person was not able to identify in the series of plates of increasing difficulty.

Measured results are first given in the form of histograms. As anomaloscope and the Ishihara test confirmed all the 320 test persons as colour blind, the histograms show the frequency of the results of the new test only.

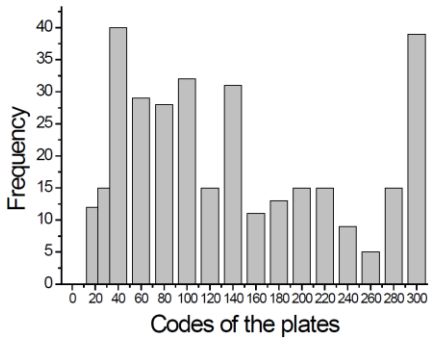

Figure 8
Frequency of the results of colour anomalous people using series R-G

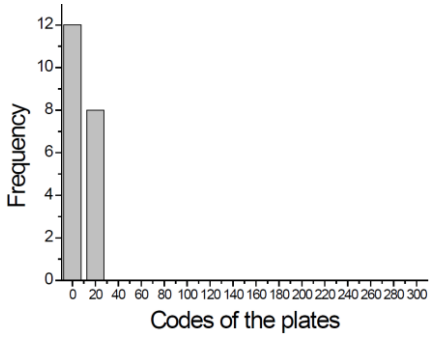

Figure 9
Frequency of the results of people with normal colour vision using series R-G

Fig. 8 shows the results of the R/G series of the test, divided as the measured results for those with colour vision deficiency and Fig. 9 shows the results for control group. On the horizontal axis, the codes of the plates are displayed whereas the vertical axis gives the number of test persons who were not able to identify the orientation of the Landolt-C in the given plate.

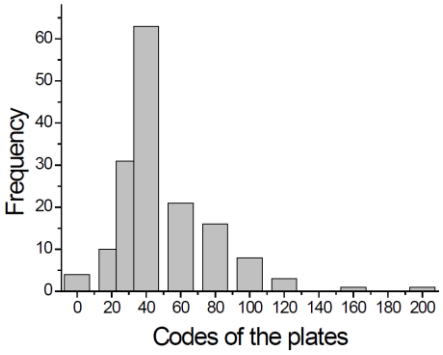

Figure 10
Frequency of the results of protanomalous people using series P

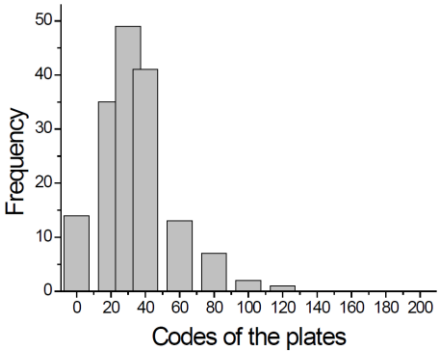

Figure 11
Frequency of the results of deuteranomalous people using series P

Fig. 10 shows the results of the P series of the test for protanomals, Fig. 11 for deuteranomals and Fig. 12 those with a normal colour vision. Protanomals regularly scored lower than deuteranomals in this series.

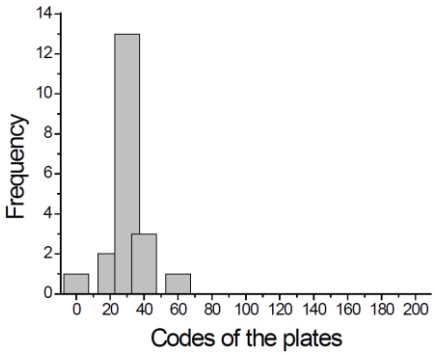

Figure 12
Frequency of the results of people with normal colour vision using series P

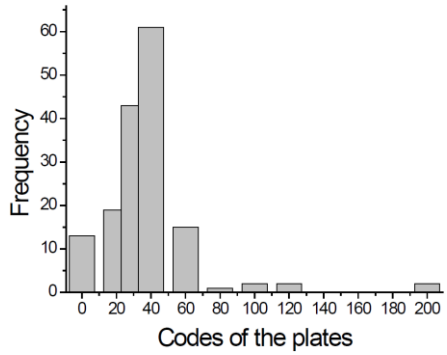

Figure 13
Frequency of the results of protanomalous people using series D

Fig. 13 shows the results of the D series of the test for protanomals, Fig. 14 for deuteranomals and Fig. 15 those with a normal colour vision. Protanomals regularly scored better than deuteranomals in this series.

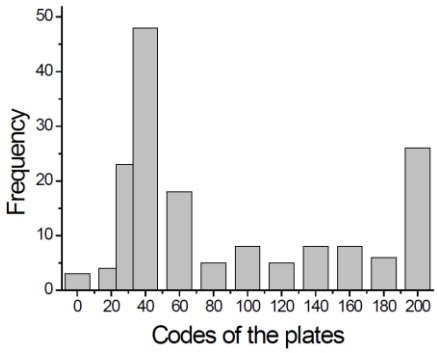

Figure 14
Frequency of the results of deuteranomalous people using series D

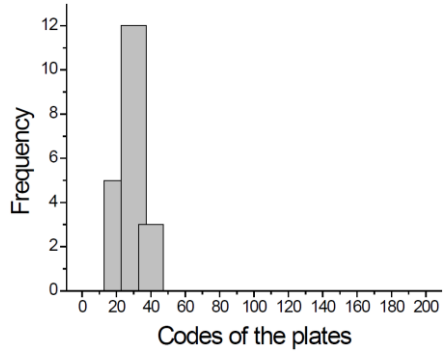

Figure 15
Frequency of the results of people with normal colour vision using series D

3.3 Distinguishing Persons with Colour Vision Deficiency from Those with Normal Colour Vision

Persons with colour vision deficiency are distinguished from those with normal colour vision using the R/G series. Out of the 20 persons with normal colour vision, 12 ones successfully identified all the plates whereas 8 persons could not identify plate 20. Plates with higher code numbers (30, 40, etc.) were readily identified by everybody in the control group.

Accordingly, colour vision deficiency is defined as the inability to identify the plate coded as R/G=30. However, 12 persons out of the 320 test persons with colour vision deficiency were able to identify plate R/G=30, as Fig. 8 clearly illustrates. It means that the results of the test differed from those measured by anomaloscopy in 12 cases; that is the probability of anomaloscopy and the new test yielding the same result is P=((320-12)/320)x100=96.25%.

It should be noted, however, that the ability of discriminate colours deteriorates with age. Our tests were completed on young persons, mostly under 30. Older people or those with impaired vision will not be able to identify plate R/G=40, maybe even plate R/G=60. A possible solution to this problem is to record the codes of the first plates the test person was not able to identify in both the P and D series and consider these values when determining colour vision deficiency using the R/G series. For protanomalous persons, consider the lowest D value, whereas for deuteranomalous ones, the lowest P value.

3.4 Distinguishing Protanomals and Deuteranomals

The recommended criteria for distinguishing protanomals and deuteranomals are as follows:

A person should be considered protanomalous, if P/D>0.9, if not than deuteranomalous.

Our results indicated 124 persons as protanomalous, out of the 158 protanomals as verified by anomloscopy. It means anomaloscopy and the new test yielded the same result in 78.48% of the cases.

A person should be considered deuteranomalous, if P<D during the tests.

Our results indicated 116 persons as protanomalous, out of the 162 protanomals as verified by anomloscopy. It means anomaloscopy and the new test yielded the same result in 71.60% of the cases.

Average of results of the measures is 75%

4 Results

The new R/G series of the pseudoisochromatic plates yielded the same results as anomaloscope in 96.25% of the cases. The test was able to distinguish 16 levels according to the severity of colour vision deficiency.

The test was able to distinguish protanomaly from deuteranomaly in 75% of those cases that were verified by anomaloscope. This difference is probably due to the fact that anomaloscope relies on monochromatic light whereas the new test applies

colours in a broad range, thus the individual variances in the curves of cone-sensitivity of the test person manifest in a different way.

Conclusions

The new test detects colour vision deficiencies with an efficiency of 96.25%, distinguishes protanomaly from deuteranomaly at 75% confidence and is able to distinguish 15 levels according to the severity of colour vision deficiency.

Completing the test takes about 5 minutes while analyzing the results takes only a minute. Thus, the method is suitable for mass tests.

The test is not exhausting; on the contrary, it is fun to use, and moreover the method is suitable to test illiterate children.

Acknowledgement

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References

[1] City University Online Colour Vision Test, web-based colour vision test

[2] City University Online Colour Vision Test, in print version

[3] Dvorine Pseudoisochromatic Plates, The Psychological Corporation, Harcourt

[4] Farnsworth D15 Test

[5] Hardy, Rand and Rittler: HRR Test, American Optical Co.

[6] Ishihara Tests for Colour Deficiency, Kanehara & Co, Ltd. Tokyo, Japan, 1985

[7] Neitz, J., and Neitz, M.: Neitz Test of Colour Vision, Western Psychological Services, 1988

[8] Rabkin, E. B.: Polichromatitseskie Tablicü dlja issledovania svetooshushenia, Medicina, Moscow, 1971

[9] Velhagen, K. and Broschmann, D: Tafeln und Prüfung des Farbensinnes 12031 Wilshire Blvd, Los Angeles,CA 90025-1251, 2001

[10] Regan BC, Reffin JP & Mollon JD. Luminance Noise and the Rapid Determination of Discrimination Ellipses in Colour Deficiency. Vision Research, 34, 1994; pp. 1279-1299

[11] J D Mollon, J P Refin: A Computer-controlled Colour Vision Test that Combines the Principles of Chibret and of Stilling, R.C.S. MEETING, 1989

[12] Birch J.: Diagnosis of Defective Colour Vision. Brace & Company, San Antonio, 1993

[13] K. Wenzel, I. Kucsera: Chromatic Adaptation Testing with a Computer Graphics System, 10th International Conference of Women Engineers and Scientists, Bp. 1996

[14] Ladunga K., Wenzel K.: New Colour Vision Test on Monitor, XVth ICVS Symposium,Göttingen, 1999

[15] Ladunga K., Kucsera I., Wenzel K.: If I were Colour Blind, CIE Symposium '99, Budapest, 1999

[16] Wenzel K., Ladunga K., Ábrahám Gy., Kovács G., Kucsera I., Samu K.: Measuring Colour Resolution of the Eye by Using Colour Monitors, Colour and Visual Scales Conference, London, 2000

[17] M Piazol, N A Zanc: Medical Tourism - A Case Study for the USA and India, Germany and Hungary, Acta Polytechnica Hungarica Vol. 8, No. 1, 2011

[18] Samu K, Wenzel K, Ladunga K: Colour and Luminance Contrast Sensitivity Function of People with Anomalous Colour Vision, AIC Conference, Rochester, 2001 June 24-29, Proceedings of SPIE Volume 4421

[19] K. Wenzel, K. Ladunga, K. Samu: Measurement of Colour Defective and Normal Colour Vision Subject's Colour and Luminance Contrast Threshold Functions on CRT, Periodica Polytechnica, Vol. 45, No. 1, pp. 103-108, 2001

[20] K Samu, K Wenzel: Presenting Surface Colours on Computer-controlled CRT Displays, Facta Universitatis (NIS), Ser.: Elec. Energ. Vol. 16, 2003, pp. 177-183

[21] Wenzel K, Ladunga K, Samu K, Langer I and Szőke F. Pseudo-Isochromatic Plates for Measuring the Ability to Discriminate Colours. 21st Symposium of the International Colour Vision Society, 2011

[22] Pokorny J, Smith VC, Verriest G & Pinckers AJL. Congenital and Acquired Colour Vision Defects. Grüne & Stratton, New York, 1979

[23] Balázs Vince Nagy, György Ábrahám: Spectral Test Instrument for Colour Vision Measurement, Journal of Bionics Engineering, Vol. 2, pp. 75-79, Issue 2, 2005