

SAHLGREN'S SATURATION TEST FOR DETECTING AND GRADING ACQUIRED DYSCHRMATOPSIA

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A new sorting test requires only two minutes for quantitative estimation of saturation thresholds for bluish pigment colors. The test is highly sensitive to and specific for differences between normal subjects and individuals with acquired color vision defects. When combined with Ishihara's pseudo-isochromatic plates, it discriminates between congenital and acquired dyschromatopsias and identifies subjects with combined defects.

Clinicians need an easily administered test for acquired dyschromatopsia. Most of the available color vision tests were designed to detect congenital dyschromatopsias, which differ from acquired dyschromatopsias in many important respects.¹⁻⁴

An apparent desaturation of colors seems to be the most striking aspect of dyschromatopsia in patients with acquired disease.^{2,5,6} Colors in the blue sector of the color circle are affected with particular severity.^{6,7} Conversely, individuals with congenital dyschromatopsia are usually not aware of saturation abnormality. Zones of poor saturation tend to be more narrow and located along the red-green axes of the color circle^{6,7} (the actual occurrence of simple congenital dyschromatopsia with a blue-yellow axis is disputed⁸).

Thus, a test designed to estimate saturation thresholds in the blue sector of the color circle should be sensitive to and specific for acquired dyschromatopsia. We have developed such a technique.

SUBJECTS AND METHODS

We decided to test four categories of subjects: (1) normal subjects; (2) patients with congenital color defects; (3) patients with acquired retinal disorders; and (4) patients with acquired optic nerve or chiasmal disorders. We selected the first 20 patients in each category who were referred here for consultation. The patients were assigned to a group on the basis of their medical histories and the results of their clinical examinations.

Group 1 ranged in age from 17 to 66 years (median, 47 years), Group 2 from 20 to 71 years (median, 46 years), Group 3 from 21 to 76 years (median, 56 years), and Group 4 from 16 to 75 years (median, 39 years). Group 3 included five patients with senile macular degeneration, five with diabetic retinopathy, three with glaucoma, and seven with miscellaneous retinopathies. Group 4 included five patients with demyelinating optic neuropathy, seven with compression of the chiasm, three with anterior ischemic optic neuropathy, and five with miscellaneous optic nerve atrophies.

Testing procedures—Color vision was tested binocularly in Groups 1 and 2 and monocularly in Groups 3 and 4. The appropriate corrections were used. For Groups 3 and 4, we used only the results

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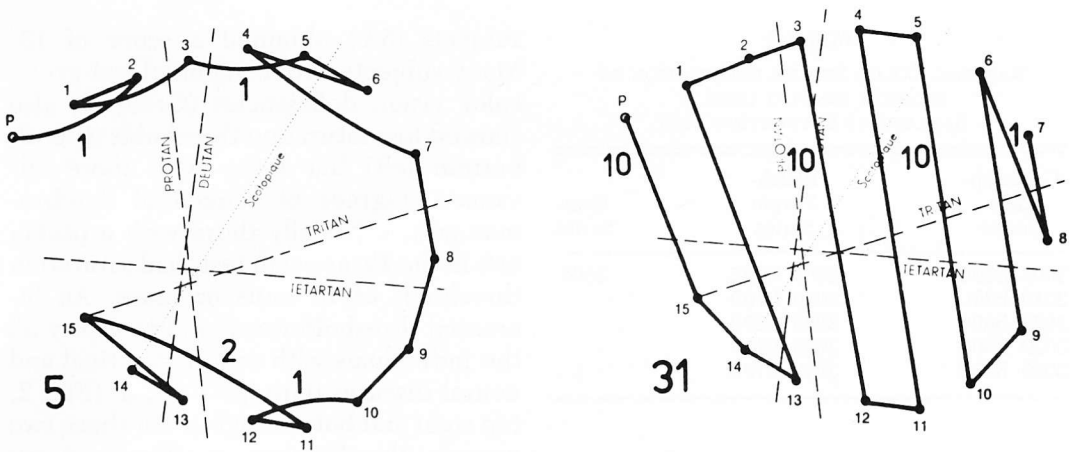


Fig. 1 (Frisén and Kalm). Scoring principles adapted for the Farnsworth and Lanthony tests. Normally, the test chips are placed in numerical order (score = 0). An error score is given when numerical order is violated, but only for primary faults and not for secondary transpositions traceable to the primary fault. Small transpositions, shown by the curved connecting lines (left), are given scores equal to the number of skipped chips. Diametrical transpositions (right) are given a score of 10. Results are given error score sums.

of the right eye for analysis to avoid dependent observations in binocularly affected individuals. All tests were done in artificial illumination in a special light box¹⁰ with a matte gray background and uniform reflection across the spectrum. The light source was a fluorescent tube with a color temperature of 6,500 K; the illumination level was approximately 400 lux. All sources of room illumination were extinguished during testing. The test distance was 0.3 m.

We administered the tests in the following order: (1) Ishihara's pseudoisochromatic plates (38-plate edition); (2) Farnsworth's Panel D-15; (3) Lanthony's desaturated version of the Farnsworth Panel D-15; and (4) Sahlgren's Saturation Test.

Ishihara test—We discarded the plates for illiterates and those with figures read only by individuals with color deficiencies. We used plates 1 to 17 and plates 22 to 25. The number of misread plates was recorded. Spontaneous corrections were allowed.

Farnsworth test—We administered this test according to the manufacturer's

instructions. The results were plotted on a standard diagram and scored as shown in Figure 1.

Lanthony test—We used this test only when the result of the Farnsworth test was normal or difficult to classify. It was administered and scored in the same way as the Farnsworth test (Fig. 1).

Sahlgren test—This test* is based on 12 chips made of matte black plastic. Each has a circle of pigment-coated paper 18 mm in diameter. The pigments were taken from the atlas of the Natural Color System, recently approved as the official Swedish color standard.¹¹ (Table 1). Five chips are greenish-blue, five are bluish-purple, and two are gray.

The chips are similar in hue and value to series BV and series PB in the Lanthony test,^{12,13} which is based on Munsell color standards.¹⁴ The saturation levels for the colored chips were 5, 10, 20, 30, and 40 chromaticness units. The 20-unit level closely matches the lowest satura-

*Available from Visumetrics, Hallstehagen 26, S-421 56 V. Frölunda, Sweden.

TABLE 1
NATURAL COLOR SYSTEM DESIGNATION OF
PIGMENT SAMPLES USED IN
SAHLGREN'S SATURATION TEST

Greenish- Blue Series	Bluish- Purple Series	Gray Series
3005 B20G	3005 R80B	3500
3010 B30G	3010 R70B	
3020 B30G	3020 R70B	
3030 B30G	3030 R70B	
3040 B30G	3040 R70B	

tion level in the New Color Test (chroma 2 in the Munsell designation). The paper circles are all semi-matte and have a lightness of approximately 0.70 on the Natural Color System Lightness Meter.

The subject's saturation threshold is obtained quantitatively by recording the saturation values for colored chips that the subject perceives as pure gray. Completion time is usually less than two minutes.

We arranged the test chips in random order in the upper part of an oblong box that was painted matte black. The subject was instructed to transfer all bluish-purple or greenish-blue chips to the lower section of the box. Only chips that appeared to be pure gray were to stay in the upper section. We recorded the chips perceived as gray and used the sum of their saturation values (or more precisely, their Natural Color System chromatic numbers) as the subject's saturation threshold.

The version of the Sahlgren test described here was the result of preliminary trials of several variants. As expected from its design, subjects with normal color vision (Group 1) had low scores, that is, low saturation thresholds (Fig. 2, top left). We tentatively considered a score of 10 chromaticness units as the upper normal limit; only one of 20 normal

subjects (5%) obtained a score of 15. Many subjects with congenital red-green color vision deficiencies (Group 2) also showed low saturation thresholds (Fig. 2, bottom left) but those with more advanced degrees of congenital dyschromatopsia, especially those with a protan axis in the Farnsworth test, had saturation thresholds of 15 units or more. An increased threshold was found in nearly all the individuals with acquired retinal and neural diseases (Groups 3 and 4) (Fig. 2, top right and bottom right). For these two groups, the increase in threshold appeared to be roughly commensurate with conventional clinical indices of severity of disease.

The results of the Ishihara test were not unexpected.¹⁵ Subjects in Group 1 made very few errors (less than three), but all those in Group 2 made many errors (nine or more). Subjects with acquired disease (Groups 3 and 4) showed considerable variation in their ability to read the pseudoisochromatic plates. Approximately 50% of these subjects made less than three errors on the Ishihara test.

The results of the Farnsworth test and the more sensitive Lanthony test were more difficult to evaluate because subjects who seemed to have normal color vision in the other tests sometimes made major errors (usually one major confusion along a tritan axis). The same observations have been made by other investigators.^{16,17} An error score of less than 12 was tentatively regarded as normal. Many individuals with congenital dyschromatopsia made very few errors in these tests. This was also the case in Groups 3 and 4 (Fig. 3).

The computed indices of sensitivity and specificity for the individual tests are shown in Table 2.

Combining the Sahlgren test with the Ishihara test appeared to be a more effective way of correctly classifying congeni-

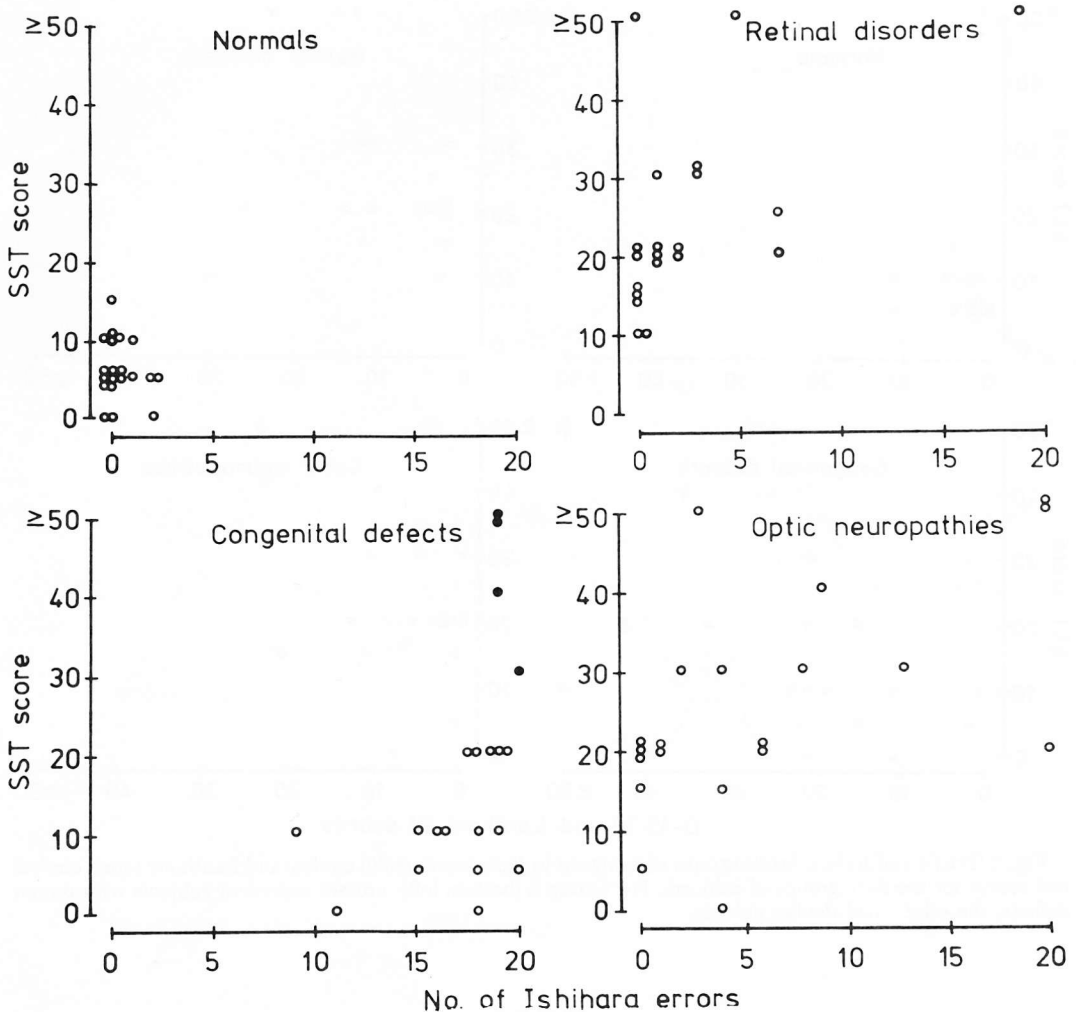


Fig. 2 (Frisén and Kalm). Scattergrams of Sahlgren vs Ishihara test scores for the four groups of subjects. For Group 2 (bottom left), open circles represent subjects with deutan defects, and solid circles those with protan defects.

tal vs acquired color vision deficiencies than any other combination (Figs. 2 and 3 and Table 2). Superimposing the results of the Sahlgren and Ishihara tests for all four groups showed a clearcut separation of the groups (Fig. 4). There was overlapping only in the low-Sahlgren low-Ishihara region (one normal subject and three with early acquired disease) and in the area diagonally opposite (where three subjects with congenital protan dyschromatopsia overlapped with three individuals with severe acquired disease). The latter area of overlap should produce no difficulty in clinical diagnosis, because the two groups can be easily distinguished by other tests (a simple visual acuity test, for example). The overlap between normal individuals and subjects with early acquired disease is unavoidable.

Our initial hope that including two

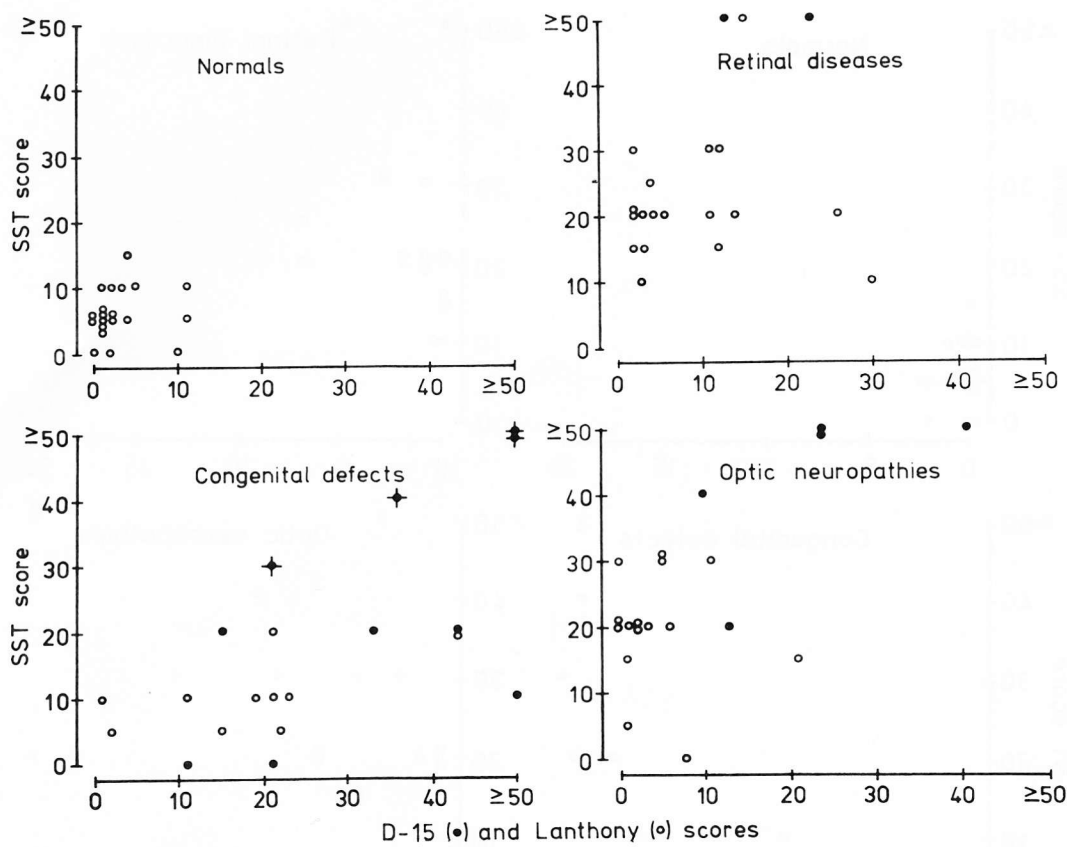


Fig. 3 (Frisén and Kalm). Scattergrams of Sahlgren vs Farnsworth (solid circles) and Lanthony (open circles) test scores for the four groups of subjects. For Group 2 (bottom left), crosses represent subjects with protan defects; the others had deutan defects.

TABLE 2
SPECIFICITY AND SENSITIVITY OF DIFFERENT COLOR VISION TESTS*

Subjects	No.	Tests		
		Sahlgren	Ishihara	Farnsworth and Lanthony
Normal	20	95	Specificity 100	100
With congenital defects	20	45	Sensitivity 100	80
With retinopathies	20	90	33	40
With neuropathies	20	90	60	25
Combined retinopathy and neuropathy groups	40	90	45	33

*Specificity was defined as the percentage of normal individuals correctly classified; sensitivity was defined as the percentage of individuals with abnormalities detected.

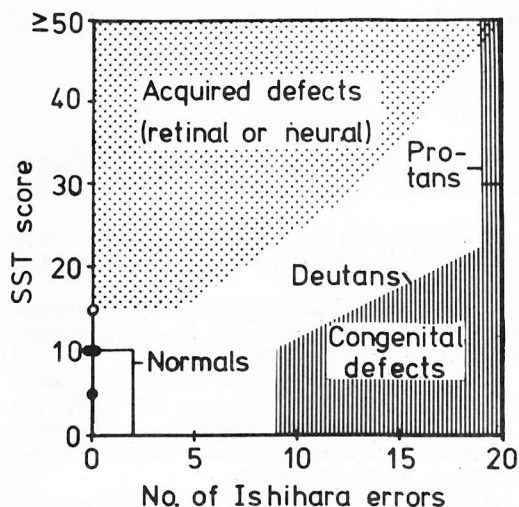


Fig. 4 (Frisén and Kalm). Summary of Sahlgren and Ishihara test results for the four groups of subjects. Note overlap in low-score region between one normal subject (open circle) and three subjects with acquired disease (solid circles) and in high-score region between subjects with congenital protan dyschromatopsia and subjects with severe acquired disease.

different hues in the Sahlgren test would allow a reliable differentiation between retinal and neural disorders⁴ was not realized. A preponderance of bluish-purple desaturation appears to be no more than suggestive of retinopathy (Fig. 5). The Ishihara test was more informative in this regard, tending to be more difficult for patients with neural disorders (Fig. 2 and Table 2).

The following case (not included in the 80 analyzed here) demonstrated that acquired dyschromatopsia superimposed on congenital dyschromatopsia can be diagnosed with the Sahlgren test.

CASE REPORT

A 50-year-old man was referred here for neuroophthalmologic evaluation because of personality changes. He had no ocular complaints but he had been informed on many previous occasions that he had a congenital dyschromatopsia. Abnormal findings were limited to the visual system. His best corrected visual acuity was R.E.: 6/7.5 (20/25) and L.E.: 6/6 (20/20). There was a subtle afferent pupillary defect on the right side.

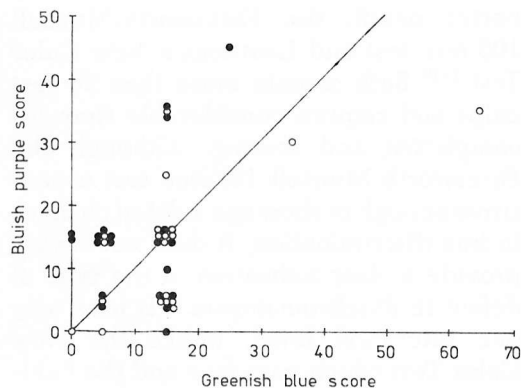


Fig. 5 (Frisén and Kalm). Greenish-blue and bluish-purple saturation scores obtained by patients with retinal (solid circles) and neural (open circles) disorders. Each dot represents one subject. The diagonal line represents identity of partial scores.

Perimetry disclosed a generalized depression of the right visual field, more pronounced nasally. He was unable to read any Ishihara chart with either eye except the demonstration chart. The Farnsworth test disclosed a protan-type dyschromatopsia bilaterally. As expected, his score on the Sahlgren test was fairly high (30 units) on the left. The saturation threshold on the right was 80 units. The fundi were normal.

We considered these findings indicative of compressive optic neuropathy on the right, superimposed on a congenital protan defect. Subsequent studies showed a large subfrontal meningioma on the right; surgical findings showed that it was compressing the right optic nerve. Postoperatively, the visual field defect and the afferent pupillary defect disappeared, and the Sahlgren test score decreased to the same level as on the left side.

DISCUSSION

The results we obtained with the new Sahlgren test emphasized the observations made by Lanthony^{6,7,12,13} and by Gunkel and Cogan¹⁸ concerning the tendency of acquired color vision defects to increase saturation thresholds in restricted areas of the color circle, particularly in the bluish area. This part of the color circle is poorly represented in the Farnsworth Panel D-15, Lanthony's desaturated version of the Panel D-15, and Ishihara's pseudo-isochromatic plates.

Currently, there are only two pigment tests available that explore this region in

better detail: the Farnsworth-Munsell 100-hue test and Lanthony's New Color Test.^{12,13} Both contain more than 50 test chips and require considerable time for completion and scoring. Although the Farnsworth-Munsell 100-hue test is sensitive enough to show age-related changes in hue discrimination, it does not always provide a clear indication of the type of deficit in dyschromatopsia.¹² It uses only one saturation level, unlike the New Color Test which uses four and the Sahlgren test which uses five. Two of the saturation levels in the Sahlgren test are lower than the lowest level in the New Color Test; this provides higher sensitivity. Adding other test chips with saturations of less than 5 chromaticness units would not improve the sensitivity or specificity of the Sahlgren test (Figs. 2 and 3). We observed no age-dependence for the Sahlgren test.

The test developed by Gunkel and Cogan¹⁸ is not a pigment test but one using transilluminated color filters, allowing continuous variation of saturation and hue of transmitted light. Their ingenious chromagraph represents a considerably larger investment than a pigment test but is also much more adaptable to various examination procedures. These advantages prompted us to build our own chromagraph using their principles. We found that this instrument produced unacceptable variations in readings between and within individuals, forcing us to discontinue its use.

The Sahlgren test cannot replace these or other more elaborate tests¹⁹ for research purposes, but our early results indicated that it adequately fills the need for a quickly administered and easily scored quantitative test for acquired color vision deficiencies. Combining it with the Ishihara test enhanced its diagnostic value considerably by allowing a confi-

dent discrimination between congenital and acquired dyschromatopsias.

REFERENCES

1. Lakowski, R.: Theory and practice of colour vision testing. A review. *Br. J. Ind. Med.* 26:173, 1969.
2. Verriest, G.: Les déficiences acquises de la discrimination chromatique. *Mem. Acad. R. Med. Belg.* 4:35, 1964.
3. Krill, A. E., and Fishman, G. A.: Acquired color vision defects. *Trans. Am. Acad. Ophthalmol. Otolaryngol.* 75:1095, 1971.
4. Lanthony, P.: Sémiologie clinique de la saturation chromatique. *Clin. Ophthalmol.* 3:47, 1977.
5. Köllner, H.: Die Störungen des Farbensinnes. Ihre klinische Bedeutung und ihre Diagnose. Berlin, S. Karger, 1912, pp. 141-151.
6. Lanthony, P.: Étude de la saturation au cours des dyschromatopsies acquises au moyen de l'album de Munsell. *Ann. Oculist.* 207:741, 1974.
7. ———: La zone neutre des dyschromatopsies acquises. *Ann. Oculist.* 210:937, 1977.
8. Krill, A. E., Smith, V. C., and Pokorny, J.: Similarities between congenital tritan defects and dominant optic-nerve atrophy. Coincidence or identity? *J. Opt. Soc. Am.* 60:1132, 1970.
9. Lanthony, P., and Dubois-Poulsen, A.: Le Farnsworth D-15 désaturé. *Bull. Soc. Ophthalmol. Fr.* 73:861, 1973.
10. Frisén, L., and Hedin, A.: Illumination box for colour vision tests. *Acta Ophthalmol.* 50:520, 1972.
11. Colour Notation System. Swedish Standard SS 019100 E. Stockholm, Swedish Standards Institute, 1978.
12. Lanthony, P.: Le new color test. *Bull. Soc. Ophthalmol. Fr.* 45:217, 1975.
13. ———: The new color test. *Doc. Ophthalmol.* 46:191, 1978.
14. Judd, D. B., and Nickerson, D.: Relation between Munsell and Swedish Natural Color System scales. *J. Opt. Soc. Am.* 65:85, 1975.
15. Sloan, L. L., and Habel, A.: Tests for color deficiency based on the pseudoisochromatic principle. *Arch. Ophthalmol.* 55:229, 1956.
16. Pinckers, A., Nabbe, B., and Bogaard, P. V. D.: Le test 15 hue désaturé de Lanthony. *Ann. Oculist.* 209:731, 1976.
17. Bowman, K. J.: The clinical assessment of colour discrimination in senile macular degeneration. *Acta Ophthalmol.* 58:337, 1980.
18. Gunkel, R. D., and Cogan, D. G.: Colorimetry by a new principle. *Arch. Ophthalmol.* 96:331, 1978.
19. Pokorny, J., Smith, V. C., Verriest, G., and Pinckers, A. J. L. G.: Congenital and Acquired Color Vision Defects. New York, Grune and Stratton, 1979, p. 409.