THE FARNSWORTH-MUNSELL 100-HUE TEST

for the examination of Color Discrimination

MANUAL

by Dean Farnsworth

Revised 1957

MUNSELL COLOR
MACBETH, DIVISION OF KOLLMORGEN INSTRUMENTS CORP.
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INTRODUCTION

PURPOSE

The Farnsworth-Munsell 100-Hue Test offers a simple method for testing color discrimination. It yields data which can be applied to many psychological and industrial problems in color vision. Its primary uses are, first, to separate persons with normal color vision into classes of superior, average and low color discrimination, and second, to measure the zones of color confusion of color defective persons. A few examples will suggest the variety of special purposes for which it has been used:

Examination of inspectors of color goods, of colorgraders, of dye and paint mixers.

Testing for type and degree of color defectiveness.

Detection of poor color vision in salesmen.

Selection of applicants for vocational training.

Design of specialized tests for color vision.

Measurement of effects of medical treatments.

Independent control on validity of other color vision tests.

There are two purposes for which the 100-Hue Test was *not* designed: (a) it was not intended to distinguish fine degrees of differences between persons of superior aptitude, and (b) it was not intended to dichotomize color deficiency into "pass-and-fail" classes. With respect to (a): the 1978 Color Matching Aptitude Test was developed by a committee of the Inter-Society Color Council † to grade superior aptitude into degrees of excellence. With respect to (b): the "Dichotomous Test for Color Blindness" is recommended for the detection of persons who are functionally color defective, and the detection of employees who cannot surely distinguish colored products of ordinary industrial usage.*

Since this test is designed to measure a particular psychological aptitude it must not be expected that the scores will correlate directly with other tests for color vision. Pseudo-isochromatic plates, color vision lanterns, anomaloscopes and colorimeters isolate certain factors of color deficiency but do not measure general color discrimination directly as does the 100-Hue Test.

† *Test available from Federation of Societies for Coatings Technology, 1315 Walnut St., Suite 830, Philadelphia, Pennsylvania 19107.*

* *Test available from The Psychological Corporation, 757 Third Ave., New York, New York 10017.*

MATERIALS

The materials include four wooden cases, a total of ninety-three plastic caps in which the colors are mounted, and the score sheets. Each case consists of two hinged panels which enclose one-fourth of eighty-five numbered, removable color caps. (Two caps are repeated and fixed as pilot colors at either end of one panel in each case, making a total of ninety-three caps.) The scoring sheets contain four rows of numbers corresponding to the numbers on the backs of the removable color caps in the four cases, a scoring diagram, and spaces for recording other customary data.

Pigments in the color caps are made from the most stable materials available, but no chemical is absolutely permanent, and the caps should not, therefore, be unduly exposed to light. The matt surface of the painted papers is necessary in order to give the same spectral characteristics from any angle, but it is sensitive to fingerprints. It has been found that slight soiling has no effect upon the diagnostic value of the test; however, if the caps become severely smudged or damaged, they may be replaced individually or as a complete set. Additional score sheets, in pads of 100, are also available.

ADMINISTRATION

LIGHTING

Reliable results cannot be expected from this test unless standard illumination is used. The illumination should approximate 6,740° Kelvin (Illuminant "C" or average daylight) preferably at 25 foot candles or more. Such illumination is provided by daylight lamps of the type manufactured by the Macbeth Corporation.*

If natural daylight is used, the test should be given near a window illuminated chiefly from the north sky, lightly to moderately overcast. 6,500° *Daylight* Fluorescents may be used if necessary, but both natural daylight and fluorescent lighting are variable, and results cannot be expected to be as stable as when the test is given under standard illumination. Ordinary incandescent room lights should be switched off or shielded from the test area.

The most convenient position for the administrator of the test is across the table from the examinee. The light should be from above so that the angle of illumination is about 90° and the angle of viewing about 60°

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PROCEDURE

1. Open one case lengthwise before the examinee so that the empty, inclined panel to which the pilot caps are fixed is nearer the subject. The cases may be given in any order. Before being presented to the subject, the caps have been arranged in random order (see step No. 5).

2. Instruct the subject as follows:

"The object of the test is to *arrange the caps in order according to color*. Please transfer them from this panel (indicate) to this panel (indicate) and place them so they form a regular color series between these two caps (indicate). It should take you about two minutes per panel. However, accuracy is more important than speed—so you will be told when the two minutes are up but the panel will not be taken away from you. Arrange them as best you can, but don't dawdle. Do you understand? Begin."

If the subject does not show comprehension, say,

"Take the button which looks most like that (indicate a pilot button) and place it there . . . and the button most like that (indicate the last one) and place it there, and so on."

TIME

3. Allow subject as long as necessary for him to arrange the buttons in an order with which he is happy. If two minutes have passed and he isn't through, quietly remind him that two minutes are up, and let him finish his task.

For each panel, record the time spent on it and whether it was the first panel, second, etc., given. This information might be useful in interpreting results.

RECORDING DATA

4. Space is allowed on each data sheet for recording two trials, a test and retest. Where the numbers are found to be in correct order, draw a line above (on retest, below) the printed numbers. When they are not in serial order, record them in the order in which they are arranged by the examinee. An example is given at the bottom of Figure 1. Time will be saved if this and the following step are performed while the examinee is arranging the next panel.

5. After the arrangement of the caps has been recorded, transfer them to the opposite panel, rearranging them in random order. Then close the case and turn it over. It is now ready for future testing.

The transfer of caps should be made as recommended above because the backs of the caps are then uppermost and there is no danger of soiling the colors; also because the recessed design of the caps was selected to facilitate handling from this side.

SCORING AND DRAWING THE PATTERN

If but a few transpositions are made, the errors can be counted at once. It is not even necessary to draw the pattern. Count 4 for each 2-cap transposition and 8 for each 3-cap transposition.

If there are many errors it will be necessary to draw a pattern consisting of the scores for each cap. *The score for a cap is the sum of the differences between the number of that cap and the numbers of the caps adjacent to it.*

For example, note the scores of the following series of caps:

Recorded order of arrangement	5	6	7	8	13	11	9	10
Score for cap above		2	2	6	7	4	3	
How derived (sum of differences of adjacent numbers)		(1+1)	(1+1)	(1+5)	(5+2)	(2+2)	(2+1)	

The line of numbers on the score sheet is printed only for the administrator's convenience when there are few or no errors. In scoring an irregular series, *remember that only the examinee's order is concerned in the scoring and that it bears no relation to the printed numbers.*

The inner circle of numbers on the chart corresponds to the number of the caps. Take the first (inside) dotted line as a score of 2 (the lowest possible); the heavy dotted circles will be at 5 and at 10. *Mark the score for each cap on the radial line carrying its number.* Connect the points by lines of different colors for each test. An average can be found graphically by connecting points intermediate between the points on each radial line for each test.

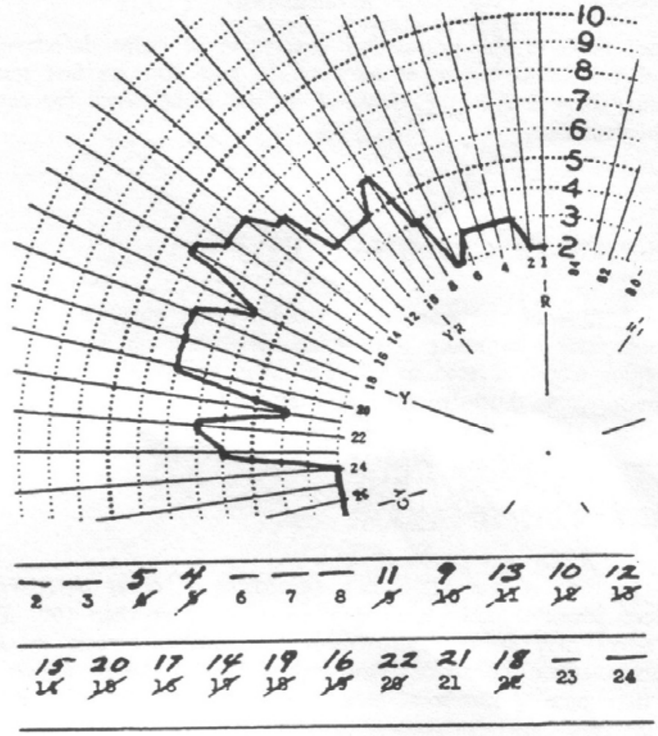

Fig. 1. Section of a subject's profile illustrating how error scores are plotted.

The total error score is obtained by summing the errors on each radial line, now counting the inner circle as zero. (This has the effect of subtracting 2 from each individual score so that perfect sequences appear as zero on the pattern and count as zero on the total error score.)

For example, in Figure 1 the error scores, reading clockwise, are: 0, 0, 0, 4, 5, 2, 6, 6, 6, 4, 7, 6, 6, 5, 3, 3, 3, 4, 2, 0, 1, 1, 1, 1, 0, 0. The total error score is 76. The mid-point of this error series would be 76÷2, or 38, which falls nearest cap 16.

RETESTS

The number of retests required is entirely dependent upon the degree of exactness desired. If it is merely necessary to ascertain that an examinee has no gross color deficiency, and one test shows that, there is no point in testing him again. The position of an individual in a population with regard to aptitude is usually determined by one retest. In general, it may be stated that retests should be given when the subject is inexperienced in handling test materials or when a more precise diagnosis is needed or when the pattern is in any way unclear or atypical.

INTERPRETATION

After the pattern has been plotted, there are various methods of interpreting the results, depending upon the information wanted from the test. Norms are given below for several common groups: superior discrimination, average and low discrimination, and for types of color defectiveness ("color blindness").

Sample distributions which have been found for certain populations are given on Page 6.

AVERAGE DISCRIMINATION

A typical test and retest pattern for an average normal is illustrated in Figure 2. Seven 2-cap transpositions were made on the first test, four 2-cap and one 3-cap transpositions on the retest, resulting in total error scores of 28 and 24 respectively.

About 68% of the population (exclusive of color defectives) make a total error score of between 20 and 100 on first tests. This may be taken as the range of normal competence for color discrimination.

SUPERIOR DISCRIMINATION

About 16% of the population (exclusive of color defectives) has been found to make 0 to 4 transpositions on first test, or total error scores of zero to 16. This may be taken as the range of superior competence for color discrimination.

LOW DISCRIMINATION

About 16% of the population (exclusive of color defectives) has been found to make total error scores of more than 100. The first retest may show improvement but further retests do not materially affect the score. Repeated retests reveal no region of large maximum or minimum sensitivity as is found in color defective patterns. An example of a low discrimination pattern is given in Figure 3.

Error scores by normals often exceed that of many color defectives, yet these individuals do not exhibit color blind indications on this test, on anomaloscopes, or on pseudo-isochromatic tests. Such scores point up the fact that the 100-Hue Test is, as described, a test of color aptitude or ability to make color discriminations. General color discrimination is independent of color defectiveness so it is possible for some normals to have poorer color discrimination than some color defectives. Color normals may have good or poor color discrimination; color defectives may have good or poor color discrimination.

DEFECTIVE COLOR VISION

The pattern of color defectiveness is identified by bi-polarity, a clustering of maximum errors in two regions which are nearly opposite. The regions in which the errors are made can be used to identify the type of color defectiveness if this is also of interest. Typical examples of patterns made by types of color-defective persons are shown in Figures 4, 5 and 6. Each of these cases exhibits a severe degree of defect; moderate cases show small "bulges" and lower total error scores; mild cases with good color discrimination may show no "bulge" and cannot be identified by this test. The position of the mid-points of the errors in the pattern (the middle of the "bulges") will identify the type. (The mid-points can be found roughly by inspection or accurately by the method described on page 3.)

The mid-points for indicating type of defect are best differentiated on the right-hand side of the pattern.

PROTANS (so-called red blind: protanopes and protanomalous) have a mid-point between 62 and 70. See Figures 4 and 7.

DEUTANS (so-called green blind: deuteranopes and deuteranomalous) have a mid-point between 56 and 61. See Figures 5 and 7.

TRITANS (so-called blue blind: tritanopes and tritanomalous) have a mid-point between 46 and 52. See Figures 6 and 7.

The distribution of mid-points from 112 tests are plotted in Figure 7. It shows the scatter to be expected from single test scores. Diagnosis of color defect should be made upon the average of at least two tests. The average of the mid-points of several tests will always fall within the ranges stated above. Some mildly defective individuals will be found whose discrimination or aptitude is so high that no amount of retesting will elicit a color-defective pattern.

The significance of a pattern can be described by reference to Figure 5. The errors lie chiefly between blue and purple-bluepurple, and between yellow-red and yellow-green-yellow. Research has shown that any series of colors parallel to the above series will also be confused. For instance, there will be low aptitude for discriminating red-purple, green and gray (in the middle of the diagram), low aptitude for discriminating purple from greenish-blue, or red from yellowish-green. On the other hand, the ability to distinguish colors in a green-yellow to blue series or to distinguish yellows from grays will be as good as that of most normals (because these series lie in lines which are parallel to the series in which he makes few or no errors).

As the terms "color defectiveness" and "color blindness" have been employed in literature, they indicate a type of systematic color *imbalance*, that is to say, certain series of colors are less well discriminated than other series of colors. Pseudo-isochromatic tests are designed to test color imbalance, but not to test color discrimination. The 100-hue pattern will indicate the type of the imbalance, the color zones of best and poorest perception and the degree of color discrimination in those zones as compared to normals.

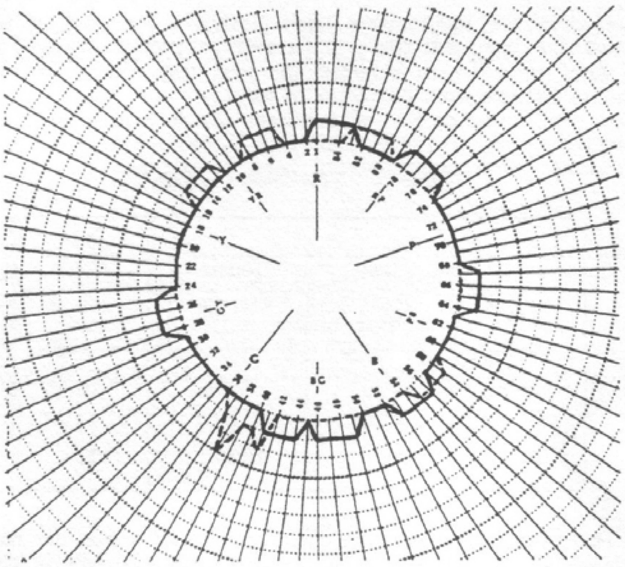

Fig. 2. Specimens of normal, average, discrimination patterns, 2 trials.

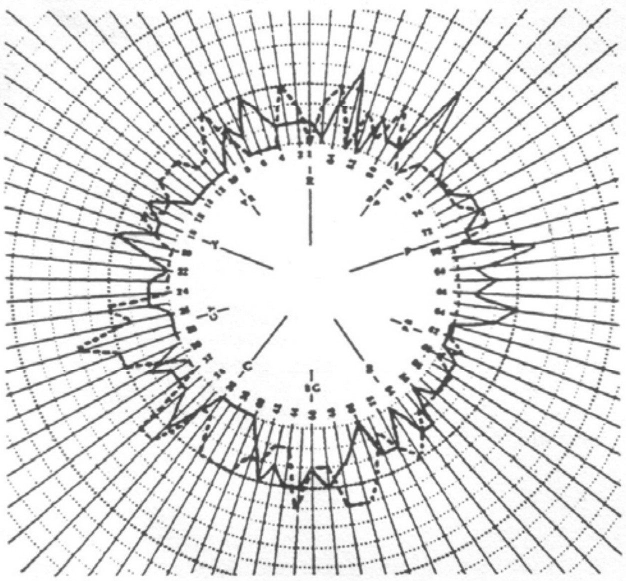

Fig. 3. Specimens of normal, low discrimination pattern, 2 trials.

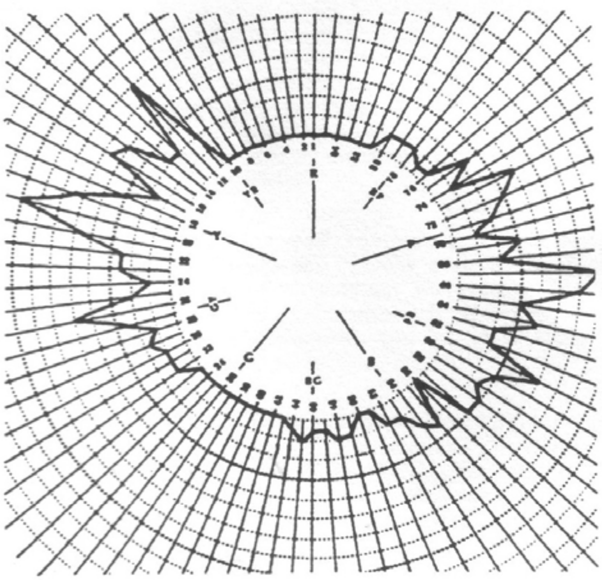

Fig. 4. Specimen of color defective pattern; Protan. Average of 2 trials.

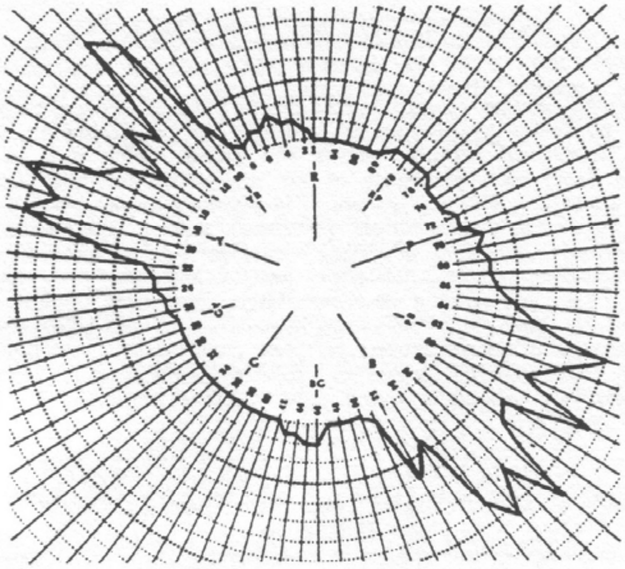

Fig. 5. Specimen of color defective pattern; Deutan. Average of 2 trials.

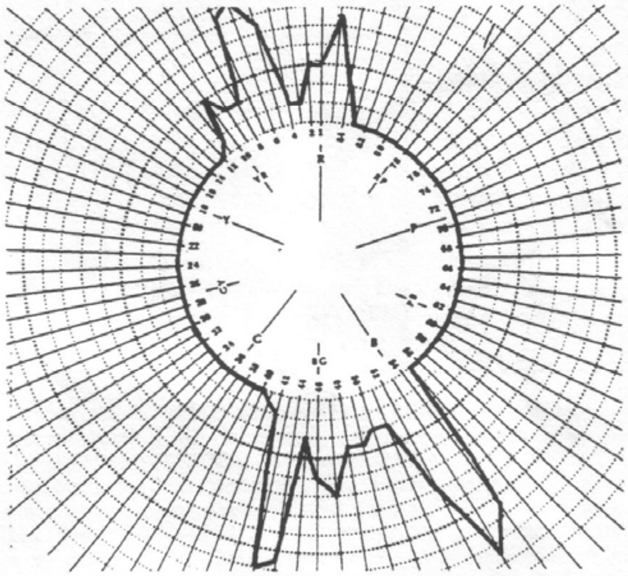

Fig. 6. Specimen of color defective pattern; Tritan. Average of 2 trials.

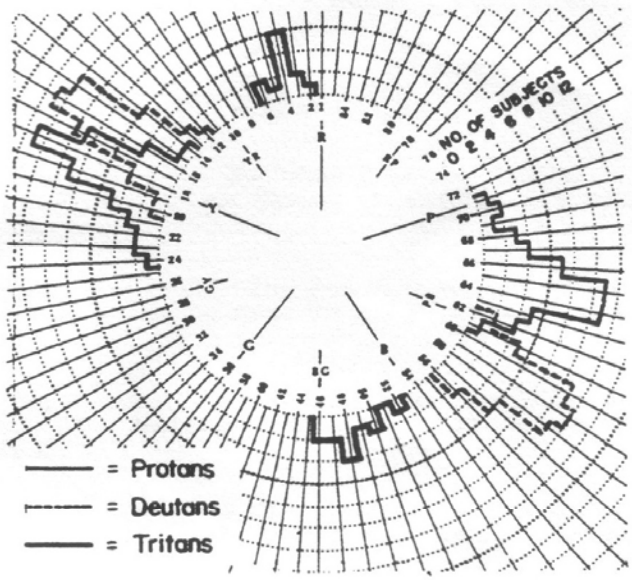

Fig. 7. Distribution of mid-points from 112 tests on color defective subjects: 50 protans, 50 deutans and 12 tritans.

INDUSTRIAL NORMS

The distribution of initial error scores which may be anticipated from particular populations is indicated in the following table. The "unselected" column shows the errors which may be expected from each percentile of an unselected group of people aged 15 to 45. The next column, "in-plant applicants," was drawn from 300 tests of employed personnel making application for promotion to positions of color control in a paint manufacturing plant—shader trainees, laboratory testers and laboratory technicians. The last column is accumulated from tests on 150 personnel of three to twenty years experience in the color control laboratories of manufacturers of dyes, rugs, plastics, textiles and paints. They are designated as "shaders," "matchers," "mixers," "inspectors," "passers," "dyers," and "titration testers."

Table 1. Distribution of Total Error Scores by Percentiles: First Tests

Percentage of group	Expected to make total error scores of, or less than		
	Unselected	in-plant applicants	Experienced
90 pc, upper 10%	12	4	0
80 pc, " 20%	20	8 - 12	0
70 pc, " 30%	28	16	4
60 pc. " 40%	36	20	4 - 8
50 pc, " 50%	46	24	8
40 pc, " 60%	60	28	12
30 pc " 70%	76	36	16
20 pc, " 80%	96	44	24
10 pc, " 90%	120	68	40

The test-retest reliabilities shown in Table 2 are taken from routine tests of applicants for promotion in a paint factory. In most cases the retests were taken within a few days of the first. It will be seen that there is an average reduction of 30 percent in total error scores between the first test and retest but little average improvement on the third test.

Table 2. Test-retest Reliability

	Test	Retest	2nd Retest
Test		.82	.67
Retest			.83
Mean	32.02	22.68	20.55
σ	29.02	23.08	23.44
N	196	196	137

These figures suggest that the second trial yields the more impotrant score. Some of the test-retest unreliability is doubtless due to variations in experience in handling this kind of material and would be eliminated by discarding the first score. However, if it is planned to use norms based on the second trial alone, the following conditions must be met: (1) every individual must certainly be given the second test, (2) the first test must be taken as seriously as the second, and not announced as practice, and (3) test and retest should be separated by a period of hours or days.

While total error scores may be taken as representative of the color discrimination of the individual at that period of his history, they do not indicate that his color discrimination ability may not improve at a later time as a result of further training and experience.

The author gratefully acknowledges the contributions of the many companies and laboratories who have supplied the above data, but especially that of Miss Helen Paulson, in charge of the Color Vision Section of the U. S. Naval Medical Research laboratory, and of the Fabrics and Finishes Department of E. I. duPont de Nemours & Company.

PRINCIPLE OF CONSTRUCTION

An understanding of the material in this section is not necessary for the practical use of this test. However, the information is important if the test is used in connection with research in color vision.

Let us imagine a chart made up of all possible discriminable hues—reds, greens, blues, etc., in all strengths from neutral to high purity, but all of the same brightness. If these colors were organized systematically, they would form a color array similar to that shown diagramatically in Figure 8. Equal distances on this diagram represents equal differences of color to the normal eye.

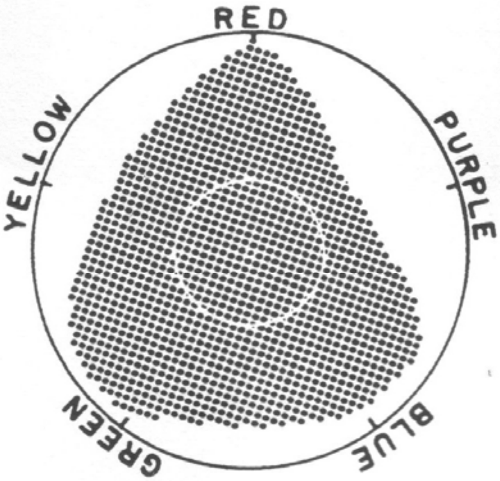

Fig. 8. Schematic representation of a uniform chromaticity scale diagram for normal vision. Neutral colors are in the middle, strong chromas at the edge.

Let us suppose that each dot represents a color which is just easily perceptably different from each adjacent color. We now have a unit of measurement which can be applied to color discrimination. It may be that in some regions of the chart, certain adjacent colors can*not* be distinguished by a particular person or by a normal under some particular condition of viewing, and it may be necessary to skip three or five or ten color units before coming to a color which is just easily perceptably different from the first. If, for each particular purpose, or individual, it were possible to test each of the thousands of combinations on the diagram, a full description of color discrimination could be obtained for that condition or individual.

The principle or method of the F-M 100-Hue Test is to sample the color diagram in all *directions* and thereby indicate the degree and orientation of discrimination throughout the color field. Because changes in discrimination are systematic throughout the chromaticity plane generalized deductions can be made from the *sample* data furnished by the test.

By elimination and replacement in a series which originally consisted of one hundred Munsell colored papers,[1] a circuit of eighty-five papers was constructed, in which the hue differences were "just easily noticeable" by normals when the papers were suitably mounted. This mounting consists of plastic caps with black rims which separate the exposed part of the color discs by about their own diameter. It is also necessary that there be slight differences from disc to disc in value and chroma. The latter factor is the device which requires some expression of aptitude in normals, which detects color defectives by forcing them to resort to criteria of other than hue difference and, with the factor of black-rim separation, makes the test short enough for practical purposes. The positions of the 85 test colors are shown in Figure 9, plotted on the Farnsworth Uniform Chromaticity Scale Diagram #33. Their relation to the schematic array of colors is suggested by the white circle in Figure 8.

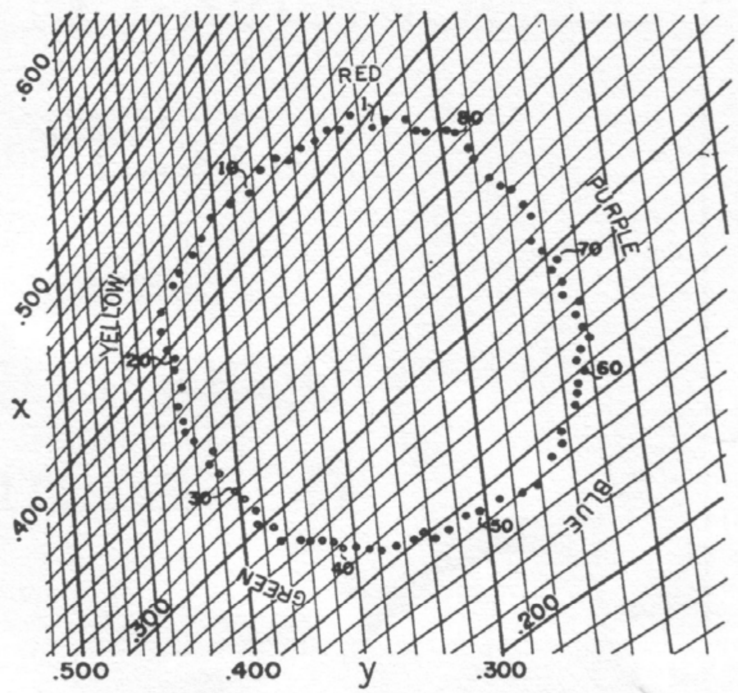

Fig. 9. Position of the test colors on a perspective projection (Farnsworth R.U.C.S. #33) of the C.I.E. Diagram.

The FM 100-Hue Test is recommended as an adjunct test for the analysis of color defectiveness. Examples of other specialized uses have been described by the author.[2] The same article describes the theory of its construction in somewhat more detail than is given in this instruction book. The organization of types and degrees of color defectiveness is briefly described in a pamphlet by the author obtainable from the Psychological Corporation.[3] The manner in which the test data can be related to the co-punctal loci is shown in a Medical Research Laboratory Research Report.[4]

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1. Dorothy Nickerson and Walter Granville, "Hue Sensibility to Dominant Wave-length Change," J. Opt. Soc. Am. *30,* 159 (1940).

2. Dean Farnsworth, "The Farnsworth-Munsell 100-Hue and Dichotomous Tests for Color Vision," J. Opt. Soc. Am., *33,* 568 (1943).

3. "The Farnsworth Dichotomous Test for Color Blindness, Panel D-15," The Psychological Corporation, 522 Fifth Ave., New York 36, N. Y.

4. Dean Farnsworth, "An Introduction to the Principles of Color Deficiency," Report No. 254, Medical Research Laboratory, 8 Sept. 1954.

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