COLOUR VISION SURVEY

USING THE ISHIHARA, DVORINE, BOSTRÖM AND KUGELBERG, BOSTRÖM, AND AMERICAN-OPTICAL HARDY-RAND-RITTLER TESTS*

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A COLOUR vision survey has recently been carried out on 500 subjects at the Imperial College as a contribution to a *Report on Colour Vision Tests* prepared by a Committee appointed by the International Council of Ophthalmology. Five different sets of confusion chart tests (commonly referred to as pseudo-isochromatic plates) were used, as follows:

- (1) Ishihara (1951)—Japanese, 24 plates with digits.
- (2) Dvorine (1953)—American, 14 plates.
- (3) Boström and Kugelberg (B-K) (1944)—Swedish, 18 plates.
- (4) Boström (B II) (1950)—Swedish, 14 plates.
- (5) American-Optical Hardy-Rand-Rittler (A-O HRR) (1955)—American, effectively 4 plates.

Supplementary observations were also made where required with the Nagel anomaloscope and the Farnsworth-Munsell 100-hue test.

The aim of the survey was to evaluate the merits of each test for screening colour normals from colour defectives, with the selection of drivers of public vehicles especially in mind. This paper, however, is confined to a report and discussion of the data recorded at the Imperial College, and gives the views of the authors, and not of the Committee as a whole, on the general evaluation of the tests for screening purposes.

Test Procedure

500 subjects (468 males and 32 females) were selected at random from the staff and students at the Imperial College, and each of them was shown the complete range of plates, which were viewed in daylight at the normal reading distance. In the case of obvious defectives who made many mistakes, the plates were shown once only. For all other subjects, any plate called wrongly at the first showing in the B-K, B II, or A-O HRR test was presented a second time in accordance with the instructions for the test in question. The five sets were shown in random order, so that neither familiarity with the nature of the test nor fatigue prejudiced the

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rating of one test relative to another. Not more than 5 seconds were allowed for the reading of a plate in the Ishihara, Dvorine, and A-O HRR tests, and fifteen seconds in the case of the B-K and B II tests, although this amount of time was seldom required. With a normal observer all the plates in the five tests could be shown and answered in about five minutes. Any error made and spontaneously corrected was scored as a correct response.

Analysis of Results

In the initial survey of the 500 subjects, the following passing scores were assumed:

<i>Ishihara</i>	—Not more than three errors.
<i>Dvorine</i>	—Not more than one error.
<i>B-K</i>	} —No errors on second showing of mis-called plates unless subject was recorded as normal by the other four tests, in which case one error was allowed.
<i>B II</i>	
<i>A-O HRR</i>	—No errors on second showing of mis-called plates.

If, on these criteria, a subject passed all five tests, he was classified as normal; if he failed all five tests, he was classified as defective; if he passed some tests and failed others, he was left unclassified.

On this basis a first classification was made as follows:

Normal	428
Defective	36
Unclassified	36

The 36 unclassified subjects were then re-tested on a subsequent occasion by supplementary tests on the Nagel anomaloscope and, where possible, by the Farnsworth-Munsell 100-hue test. The original uncertainty in the classification of this group had in most cases arisen from mistakes made with the difficult B-K and B II tests, and this second diagnosis showed that 34 of the group were normal and only two were defective, leading to a final division of the 500 subjects into:

Colour normals	462
Colour defectives	38

The number of errors made by these two classes in each of the five tests is shown in Table I (opposite), using the tabulation adopted by Sloan and Habel (1956). A good screening test will divide the normals and defectives into two compact groups with a minimum of overlap of the borderline cases, but Table I shows that the Dvorine and B-K tests in particular possess long tails in the "defectives" column. There is a significant overlap, too, in the A-O HRR test, where the compactness of the groups is really an artefact due to the small number of screening plates employed. (Additional plates are, in fact, included in the A-O HRR test, but they are intended for the grading of subjects with higher degrees of defect, and although they are admirable for this purpose, do not add to the efficiency of the test for screening borderline

subjects.) It should be added that the subjects marked (a) and (b) in Table I were shown to be clearly deuteranomalous on the Nagel anomaloscope.

TABLE I
DISTRIBUTION OF ERRORS AMONG 462 NORMAL OBSERVERS
AND 38 DEFECTIVES AS DERIVED FROM IMPERIAL COLLEGE SURVEY

Number of Plates Mis-read	Test									
	Ishihara		Dvorine		B-K		B II		A-O HRR	
	Nor- mals	Defec- tives	Nor- mals	Defec- tives	Nor- mals	Defec- tives	Nor- mals	Defec- tives	Nor- mals	Defec- tives
0	249	0	417	1(a)	422	1(a)	406	0	455	2(a) (b)
1	134	0	43	1(b)	33	0	41	0	7	2
2	58	0	2	0	5	1(b)	7	0	0	4
3	17	0	0	1	2	0	5	1(a)	0	8
4	2	0	0	1	0	0	3	0	0	22
5	1	0	0	0	0	1	0	1		
6	1	1(a)	0	1	0	0	0	0		
7	0	1(b)	0	0	0	0	0	1(b)		
8	0	0	0	1	0	0	0	2		
9	0	0	0	0	0	0	0	3		
10	0	1	0	3	0	4	0	4		
11	0	1	0	2	0	4	0	10		
12	0	1	0	3	0	1	0	9		
13	0	2	0	7	0	3	0	6		
14	0	1	0	17	0	10	0	1		
15	0	3			0	13				
16	0	0								
17	0	2								
18	0	3								
19	0	9								
20	0	13								

It is not easy to evaluate the distributions in Table I satisfactorily, but one possibility is to weight each defective who has penetrated into the normal spread by the number of levels to which he has penetrated. Thus, in the Ishihara test, one defective has penetrated by one level only, giving a score of 1; in the Dvorine test, one defective has penetrated by two levels and another by three levels, giving a score of 5; in the B-K test, there is one two-level and one four-level penetration, giving a score of 6; in the B II test, there is one two-level penetration, giving a score of 2; in the A-O HRR test, there are two one-level and two two-level penetrations, giving a score of 6.

On this basis the tests can be rated as follows:

Test	Weighted Overlap
Ishihara	1
B II	2
Dvorine	5
B-K	6
A-O HRR	6

It could be argued that, in this method of rating, the small number of plates in the A-O HRR test has worked to its advantage, since this must inevitably limit the penetration. But this rating does at least bring out the superiority of the Ishihara and B II tests in regard to the overlap of the error distributions, which is the most important feature of Table I.

Screening Efficiency of Individual Plates

It is of interest to compare not only the merits of each test taken as a whole, but also the screening efficiencies of the individual plates. With a perfect plate, every normal subject would read the plate correctly while every defective would read it incorrectly. The inefficiency of a plate can therefore be assessed from the number of normals who mis-read it and the number of defectives who read it correctly, and this information is given in Table II for

TABLE
SCREENING EFFICIENCY OF

Test	Plate Number in Each Series	1	2	3	4	5	6	7	8
Ishihara	Number of Normals Mis-reading	—	0	0	38	2	1	13	3
	Number of Defectives Reading Correctly	—	15	19	2	6	0	5	2
	Screening Inefficiency Number	—	15	19	40	8	1	18	5
Dvorine	Number of Normals Mis-reading	—	6	4	8	4	9	0	1
	Number of Defectives Reading Correctly	—	6	5	6	10	6	11	7
	Screening Inefficiency Number	—	12	9	14	14	15	11	8
B-K	Number of Normals Mis-reading	0	0	0	0	0	2	—	—
	Number of Defectives Reading Correctly	8	16	1	10	17	3	—	—
	Screening Inefficiency Number	8	16	1	10	17	5	—	—
B II	Number of Normals Mis-reading	—	0	0	4	21	0	0	20
	Number of Defectives Reading Correctly	—	13	29	3	5	9	7	0
	Screening Inefficiency Number	—	13	29	7	26	9	7	20
A-O HRR	Number of Normals Mis-reading	—	—	—	—	6	1	0	0
	Number of Defectives Reading Correctly	—	—	—	—	2	4	10	14
	Screening Inefficiency Number	—	—	—	—	8	5	10	14

all the plates used in all five tests. The so-called "Screening Inefficiency Number" of each plate is then shown in the Table as the sum of the two mis-classification scores.

Table II confirms that a few of the plates approach very near to the ideal, while a number of others are very inefficient. Hence a judicious selection of plates from each series would evidently produce a highly efficient screening test. Nevertheless, the ability to read these confusion charts is governed by a number of factors, such as the subject's colour-matching functions, spectral sensitivity, colour discrimination, pigmentation, luminance discrimination, temperament, and perhaps also his visual acuity. To design a plate or

plates that will test colour discrimination independently of these other factors is therefore extremely difficult, if not impossible. By a suitable choice of plates, a test can evidently be made so hard that no defectives are passed, or so easy that no normals are rejected. For the occasional borderline subject who cannot be classified by these means, other tests, such as the Nagel anomaloscope, employing light of greater spectral homogeneity, must be used.

Variations in colour printing between one copy of a test and another may also affect the subject's ability to read the plates. Any printer undertaking the production of a confusion chart test is therefore faced with the responsibility of maintaining the colour quality of the plates to within very close limits, and unless he is prepared to accept this the test will have only a limited validity.

II
INDIVIDUAL PLATES IN EACH SERIES

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
124 0	2 8	2 7	13 1	34 2	0 5	0 6	9 6	63 1	— —	— —	— —	— —	12 5	0 8	3 6	1 6
124	10	9	14	36	5	6	15	64	—	—	—	—	17	8	9	7
7 4	5 4	0 12	1 5	2 6	0 8	0 3	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
11	9	12	6	8	8	3	—	—	—	—	—	—	—	—	—	—
0 9	4 3	0 4	30 2	0 2	1 5	— —	10 3	1 2	1 8	— —	— —	— —	— —	— —	— —	— —
9	7	4	32	2	6	—	13	3	9	—	—	—	—	—	—	—
3 1	1 1	5 16	24 4	4 1	0 3	0 32	— —	— —	— —	— —	— —	— —	— —	— —	— —	— —
4	2	21	28	5	3	32	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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