8. A minimalist test of colour vision

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Abstract

We propose a new test that is intended as a rational reduction of existing arrangement tests of colour vision. The patient is simply required to identify a coloured probe chip placed among five achromatic distractor chips of varying lightness. The probe chips vary in chroma, and their chromaticities lie along dichromatic confusion lines that pass through the chromaticity of the achromatic chips. The test is ideal for monitoring acquired dyschromatopsias, since it is rapid, can be administered at the bedside, and presents the easiest possible task to the patient. The test reliably classifies dichromats, and it recommends itself as an alternative to the D15, since all the probes lie directly on confusion lines. But, like other pigmentary tests, the present version of the test does not separate protanomalous and deuteranomalous observers, and the reason for this is discussed.

Introduction

The test that we propose here is a test that has merely been waiting for a proposer; certainly its ancestry and its immediate forebears will be clear to those familiar with the history of colour vision testing. We set out to prepare a rational test that gives a quantitative and qualitative assessment of colour discrimination, is much more rapid to administer and to score than is the Farnsworth-Munsell 100-hue test, and yet presents to the patient a very simple task, in that it requires neither the construction of an ordered series (as in the Farnsworth-Munsell and other arrangement tests) nor the perceptual synthesis of spatially distributed elements and recognition of the resulting pattern (as in the case of the Stilling test and other pseudoisochromatic plates). We aimed, in fact, at the minimum possible test that would still identify and classify the colour-deficient observer.

In using the Farnsworth-Munsell test (Farnsworth, 1943) to classify congenital colour deficiencies, the examiner collects much unnecessary

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information: the set of chips form an ellipse in the chromaticity diagram and only in very limited regions are the dichromatic confusion lines tangential to the stimulus series (Lakowski, 1969).

In the case of either the D15 (Farnsworth, 1943) or the desaturated D15 (Lanthony and Dubois-Poulsen, 1978), the daltonian is able to reveal himself by making transpositions nearly along confusion lines. But the D15 and its variants have other disadvantages. Firstly, the same set of chips has to serve to identify protan, deutan and tritan deficiencies, and a chip once placed becomes out of play (Fletcher and Voke, 1985). Secondly, the chroma of any given version of the D15 is fixed at a single value; so such tests are dichotomous (as Farnsworth intended) and do not allow the measurement and monitoring of the extent of a patient's achromatic region.

One could imagine equipping oneself with a whole battery of 'D15 désaturés', each at a different chroma. (As Lanthony (1975b) notes, the 'New Color Test' is esssentially such a battery). But then the obvious rationalization is to stop circling around the centre of the chromaticity diagram and instead to measure directly the confusions among sets of chips which lie explicitly along dichromatic confusion lines and which vary in chroma. This is what we have done in the present test. The chromaticities that we have used are shown in Fig. 1. But what should be the patient's task? Miyamoto *et al.* (1983) have already described an arrangement test in which the set of

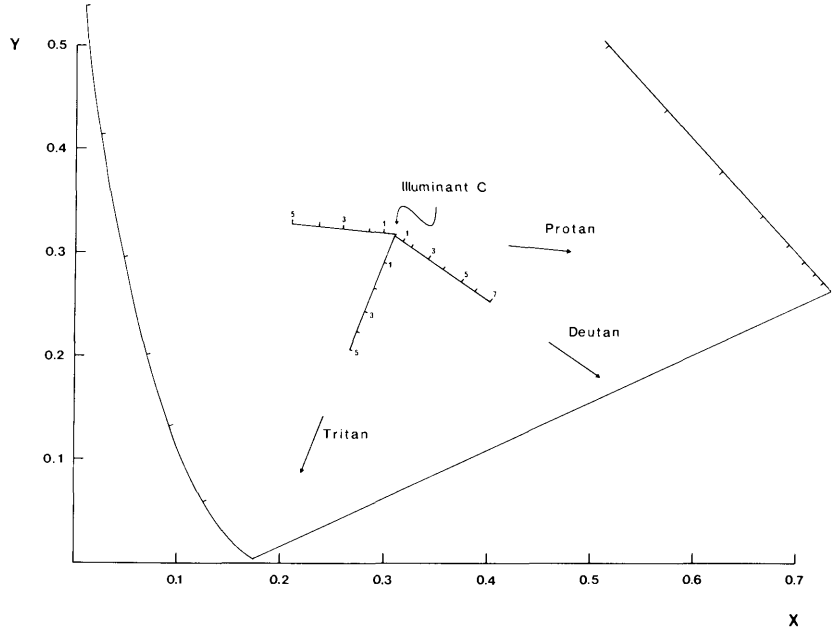

Fig. 1. Section of CIE (1931) chromaticity diagram, showing the chromaticities of the probe chips used in Version 1 of the test described in the text. The three sets of chips lie along the confusion lines of three types of congenital dichromat.

stimulus tiles do lie explicitly along a confusion line (the tritan line passing through the achromatic point), but these workers retained Farnsworth's task: the patient was required to order a number of tiles according to saturation (93, 47 or 23 of them in different versions of the test). We sought a task that was simpler than that of ordering in a series, since we hoped to develop a test that could be used even at the bedside and that would place minimal demands on a patient's concentration, cognitive ability, and dexterity. Yet we wanted a performance task that was not dependent on the subject's criterion. The latter requirement rules out a sorting task, such as is embodied in the 'New Color Test' of Lanthony (1975a, b, 1978) or the 'Sahlgren Saturation Test' introduced by Frisén and Kalm (1981). We in fact chose the simplest possible performance test of discrimination, the oddity task.

Description of test

The examiner is furnished with a pool of achromatic chips ranging in Munsell value from 4 to 6, in steps of 0.25. Five of these are placed randomly on a table illuminated by Illuminant C. To these, the examiner adds one coloured chip, mixes it randomly with the grey chips, and invites the patient to identify the 'coloured chip' by touching it with a pointer. The first such probe chip is a saturated orange, which does not lie on any confusion line: this chip serves to demonstrate the task and to allow malingering or gross pathology to reveal itself. The examiner next draws a probe chip from the middle of the protan series. If the patient correctly identifies this probe, the examiner then moves inwards along the confusion line and presents the least saturated chip; if, on the other hand, the response to the first protan probe is incorrect, then the examiner moves outwards to the most saturated chip. On subsequent trials, a simple staircase procedure is used to establish the maximal chroma at which the subject makes errors. The same process is then repeated for the other two confusion lines. For a normal subject, the test can be completed in about one minute; and a patient with a colour deficiency requires only a little longer.

In the first version of the test, we have restricted ourselves to chromaticities available as standard Munsell papers. Five probe chromaticities are available on the protan and tritan lines and seven on the deutan line (Fig. 1). All the coloured chips have a Munsell value of 5. Matt papers are used and they are mounted in black plastic caps, such as are used for the Farnsworth-Munsell and D15 tests. The exposed area of the Munsell paper has a diameter of 12.5 mm. The chips are stored in order in a box, in an arrangement that symbolically represents the confusion lines; this allows the examiner to work rapidly, while yet keeping track of the sequence.

The subject's score for each confusion line is the number of the chip that he or she can reliably identify among the distractors. When, as in the case of many dichromats, the subject cannot identify the most saturated chip on a

particular line, the score is one more than the number of the most saturated chip. The normal score on each axis is 1.

Since colour-deficient observers are often abnormal in their spectral sensitivity (Pokorny *et al.*, 1979; Marré and Marré, 1986), all tests of colour discrimination have to ensure that the task cannot be solved on the basis of differences in perceived lightness. This is the purpose, in the present test, of using distractor chips that vary in Munsell value.

Results

Acquired dyschromatopsias

The test proves to be very suitable for examining acquired deficiencies, since it offers a simple task to the sick, the elderly, or the cognitively impaired patient. It is especially suitable for use in conditions where colour discrimination is improving or deteriorating, or where a drug dosage must be controlled; for it is quick to administer, but yet is quantitative enough to allow the clinician to monitor the expansion or contraction of the achromatic region that characterizes acquired deficiencies (Lanthony, 1977). Figure 2 shows data for four patients at successive stages of recovery from an acute episode of optic neuritis (in the case of JS, measurements included the acute phase). The upper of each pair of graphs in Fig. 2 shows, as a function of time, the cumulative score on the three axes shown in Fig. 1 and indicates the changing shape and size of the patient's achromatic region as recovery progresses. Notice that these optic neuritis patients exhibit losses on all three axes.

The lower of each pair of graphs in Fig. 2 records concurrent measurements of acuity. In the cases shown here, the recovery of colour discrimination is roughly correlated with that for acuity, but this is not always the case (Chisholm, 1869) and the present test may indicate a disturbance of colour vision when acuity has recovered to normal levels: we have recorded one case of optic neuritis who exhibited an acuity of 6/6 while yet scoring 5, 5 and 6 on the protan, deutan and tritan axes of the present test.

Other examples of scores in clinical patients are 4, 3, 3 (optic neuropathy), 4, 3, 2 (optic neuropathy), 3, 2, 2 (optic atrophy), 4, 5, 3 (progressive myopia) and 1, 1, 4 (ocular hypertension). In the clinic, an advantage of the test is that it quickly probes both of the two subsystems of human colour vision — the phylogenetically recent subsystem that compares the signals of the long- and middle-wave receptors, and the ancient subsystem that compares the signals of short-wave receptors with some combination of the signals of the long- and middle-wave receptors (Mollon and Jordan, 1988). We have seen one patient who appeared to have experienced a central loss of the ancient subsystem: presenting with a self-description of bilateral tritanopia of sudden onset, she scored normally on the Ishihara plates but

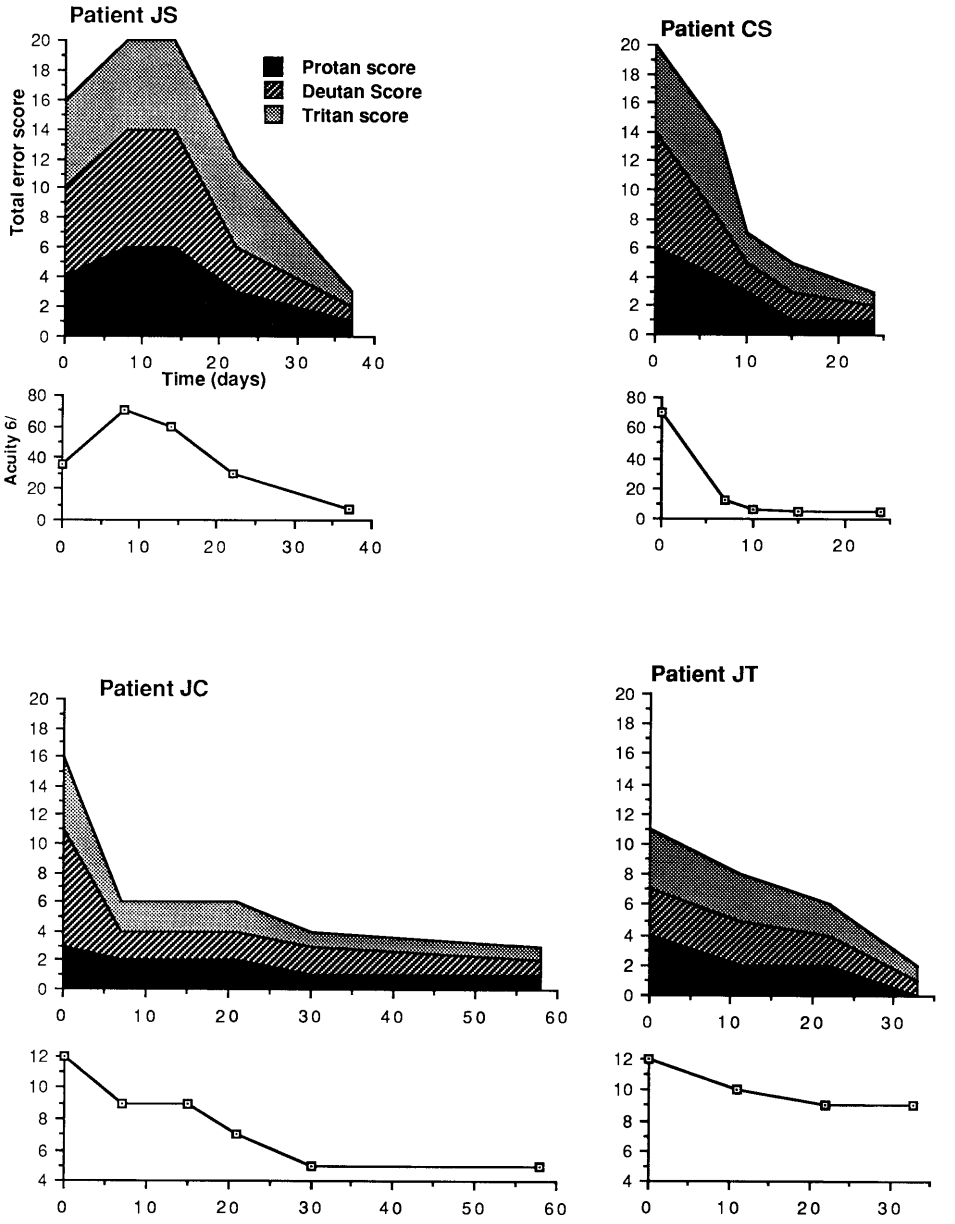

Fig. 2. Data are shown for four patients during recovery from an acute attack of optic neuritis (the data for JS include the acute phase). The upper graph of each pair represents the cumulative scores on the three axes of the colour test. The lower of each pair of graphs shows concurrent measurements of acuity. Notice that the two upper patients require different scales on the acuity graphs than do the two lower patients. These data were obtained at the Sussex Eye Hospital.

exhibited scores on the present test of 2, 1, 5 with the right eye and 2, 1, 6 with the left, a response confirmed by tritan patterns on the Farnsworth D15 and 100-hue.

Congenital colour deficiencies

Figure 3 shows scores on the protan and deutan axes for 24 dichromats (upper panel) and 24 anomalous trichromats (lower panel). All subjects were

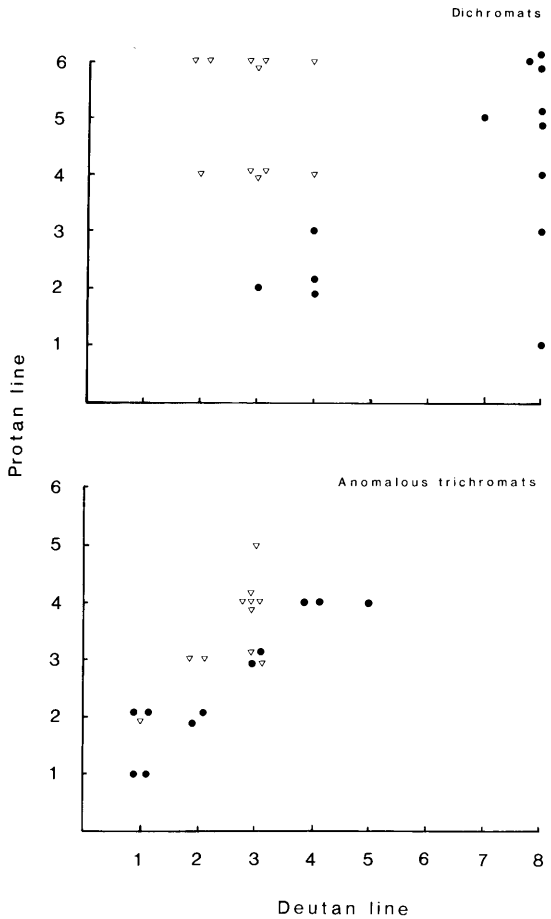

Fig. 3. Performance of dichromatic (upper panel) and anomalous (lower panel) observers on the new test. In each case, the vertical axis indicates the chroma at which a given observer can reliably select a chip that lies on the protan confusion line, and the horizontal axis indicates the corresponding score for the deutan line. Open triangles represent protans and solid circles represent deutans. Observers can fall only at quantized positions in this diagram, and so, when more than one observer plots at a given position, the symbols are arranged symmetrically around the appropriate position.

male. Dichromats were identified by their willingness to accept the full range of matches on the Nagel anomaloscope (Schmidt and Haensch) and anomalous trichromats were identified by a matching midpoint significantly displaced from normal. Protans are identified in Fig. 3 by open triangles and deutans by solid circles.

The upper panel of Fig. 3 shows that the minimal test firmly separates protanopes and deuteranopes into two non-overlapping groups. In classifying dichromats the test thus promises to be at least as successful as the D15. (All our present daltonian subjects were tested on the D15: one deuteranope was misclassified by the D15 as protan and a second deuteranope gave an ambiguous pattern of errors.)

Comparison of the upper and lower panels of Fig. 3 suggests that firm evidence of dichromacy is given by a maximum score on at least one axis. However, it is clear that the present test, like the D15, does not achieve an absolute separation of dichromats and anomalous trichromats, since a subset of dichromats are able to identify probes that nominally lie on their confusion lines. And from the lower panel of Fig. 3 it is clear that the test does not reliably separate protanomalous and deuteranomalous observers. Moreover, some simple deuteranomals pass the test without error. Thus, in its present form, the test cannot serve as a *screening* test for congenital deficiencies. Its value lies (a) in monitoring acquired colour deficiencies and (b) in classifying dichromats. In the former role it offers an alternative to the Farnsworth-Munsell 100-hue or the desaturated D15, in the latter role, an alternative to the standard D15.

A particularly striking aspect of Fig. 3 is the difference in the forms of the distributions for dichromats and anomalous trichromats: in the case of the dichromats, there is rather little relationship between performance on the two axes, whereas anomalous trichromats exhibit a strong correlation between their scores on the protan and deutan axes.

Limitations of pigment tests

We designed a test that seemed *a priori* to offer the most rational and minimal way to identify the colour deficient. The failure of the present version to classify, and often even to detect, anomalous trichromats is in itself instructive. This failure recalls the failure of earlier pigmentary tests that attempt to classify anomalous trichromats by analogous means. Thus, the H-R-R plates (Hardy *et al.*, 1954) present coloured mosaic targets of graded saturations against achromatic backgrounds, and the colorimetric measurements of Lakowski (1966) do show that the targets fall reasonably accurately along dichromatic confusion lines which pass through the chromaticity of the background. Yet it is known that the H-R-R passes some anomalous trichromats and fails to classify or misclassifies others (Walls, 1959).

Two considerations are relevant here. Firstly, in constructing our minimalist test, we assumed, as is traditional, that the confusion lines of dichromats

can be used to identify anomalous observers; that is, we supposed that the discrimination ellipses of anomals are exaggerated along the confusion lines of the corresponding dichromats. Chapanis (1944) showed experimentally that some anomalous trichromats do have maximum saturation thresholds at the wavelengths of the neutral points of the corresponding dichromats, i.e. it is at these wavelengths that the largest proportion of monochromatic light has to be added to white before the anomal can detect a difference and thus, in the chromaticity diagram, his discrimination ellipse would be oriented along the dichromat's confusion line. But one deuteranomal out of the four anomals tested by Chapanis did not exhibit any well-defined maximum of threshold near the deuteranopic neutral point. And it is anomals of this kind that are likely to be difficult to classify by any of the large category of tests that measure chromatic discrimination — as opposed to the other traditional category of colour tests, those that measure colour matches.

The preceding consideration applies equally to pigmentary tests and to tests that use raster displays. But a complete separation of protanomalous and deuteranomalous is achieved with our raster-display test (Reffin *et al.*, 1991), which has a conceptually similar basis in so far as it measures saturation thresholds along dichromatic confusion lines. To understand why the raster test is in this respect more successful than the present test, we should perhaps consider the spectroradiometric differences between these two types of test. A Munsell chip and a patch on a raster display may be colorimetrically equivalent, i.e. they may be metamers for a normal trichromat and for a dichromat. But they are unlikely to be metamers for an anomalous trichromat, since they are likely to differ in the spectral composition of the light they present to the eye. The phosphors of raster displays, though far from monochromatic, will typically be closer approximations to narrow-band sources than are the broad-band pigments used in tests that depend on reflected light. A second difference is that the primaries used in a raster display remain the same for stimuli of different chromaticity, whereas this is not necessarily the case with pigmentary stimuli. Since only colorimetric, and not radiometric, specifications have been published for Munsell colours, we do not know to what extent our probe chips modulate the second subsystem of anomalous colour vision, the subsystem that compares the quantum catches of the two long-wave pigments. As Lakowski (1966) insisted, pigmentary tests for anomalous trichromacy can be optimized only if the spectroradiometric properties of the stimuli are known.

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