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The new Richmond HRR pseudoisochromatic test for colour vision is better than the Ishihara test

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Aim: The Hardy-Rand-Rittler (HRR) pseudoisochromatic test for colour vision is highly regarded but has long been out of print. Richmond Products produced a new edition in 2002 that has been re-engineered to rectify shortcomings of the original test. This study is a validation trial of the new test using a larger sample and different criteria of evaluation from those of the previously reported validation study.

Methods: The Richmond HRR test was given to 100 consecutively presenting patients with abnormal colour vision and 50 patients with normal colour vision. Colour vision was diagnosed using the Ishihara test, the Farnsworth D15 test, the Medmont C-100 test and the Type 1 Nagel anomaloscope.

Results: The Richmond HRR test has a sensitivity of 1.00 and a specificity of 0.975 when the criterion for failing is two or more errors with the screening plates. Sensitivity and specificity become 0.98 and 1.0, respectively, when the fail criterion is three or more errors. Those with red-green colour vision deficiency were correctly classified as protan or deutan on 86 per cent of occasions, with 11 per cent unclassified and three per cent incorrectly classified. All those graded as having a 'mild' defect by the Richmond HRR test passed the Farnsworth D15 test and had an anomaloscope range of 30 or less. Not all dichromats were classified as 'strong', which was one of the goals of the re-engineering and those graded as 'medium' and 'strong' included dichromats and those who have a mild colour vision deficiency based on the results of the Farnsworth D15 test and the anomaloscope range.

Conclusions: The test is as good as the Ishihara test for detection of the red-green colour vision deficiencies but unlike the Ishihara, also has plates for the detection of the tritan defects. Its classification of protans and deutans is useful but the Medmont C-100 test is better. Those graded as 'mild' by the Richmond HRR test can be regarded as having a mild colour vision defect but a 'medium' or 'strong' grading needs to be interpreted in conjunction with other tests such as the Farnsworth D15 and the anomaloscope. The Richmond HRR test could be the test of choice for clinicians who wish to use a single test for colour vision.

Key words: colour vision, Ishihara, New Richmond HRR

The HRR pseudoisochromatic test was developed by Hardy, Rand and Rittler[1,2] and was first published by the American Optical Company in 1955. It has been much loved by the cognoscenti of colour vision because it included plates to detect tritan colour vision deficiency, as well as the protan and deutan deficiencies and had a carefully designed set of plates to differentiate protan, deutan and tritan deficiencies and grade their severity. The HRR provided the clinician with more

information than the Ishihara in a test that was just as easy to administer. The Ishihara test, renowned for its high sensitivity and excellent specificity for the detection of protan and deutan deficiencies, has no tritan plates and the number of errors made gives little indication of severity.[3–5] Moreover, its four protan-deutan classification plates are not very reliable.[5,6]

A second edition of the HRR test was published in 1957, using material from the first print run but with a rearrangement of the order of the plates.[7] No further editions were published by the American Optical Company and the test has not been available for many years.

Richmond Products, a US-based manufacturer of ophthalmic equipment, published a replica of the test in 1991 but this was not an exact copy of the original test and it was not well received. On the basis of his colorimetric analysis, Dain[7] concluded that it was 'a pale imitation of the real thing'. Richmond Products published a further edition in 2002, the colours of which have been carefully re-engineered with the assistance of Jay and Maureen Neitz and James Bailey.[8]

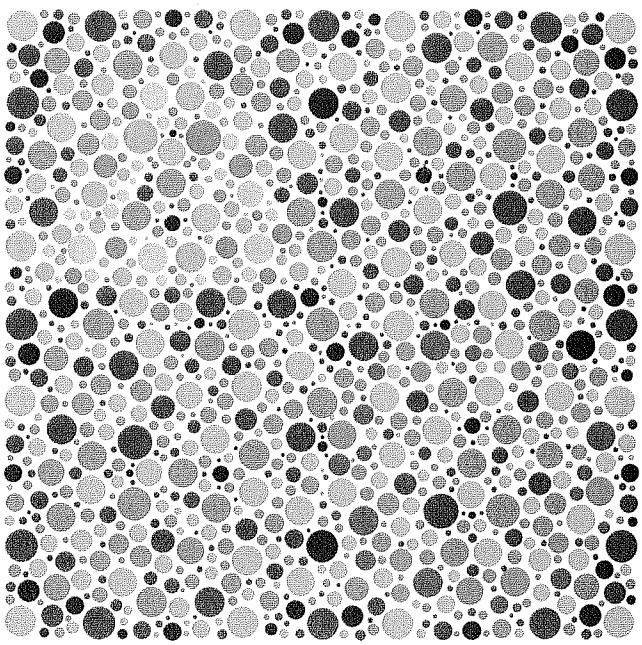

Figure 1. A plate from the diagnostic series of plates of the Richmond HRR test showing two of the coloured symbols on the background of grey dots. The colours of the symbols lie (in this case) on the protan and deutan confusion loci.

The re-engineering of the test has moved the colours nearer to the dichromatic confusion lines and has used a revised deutan copunctal as the origin of the deutan confusion lines based on new knowledge gained since the HRR test was first designed.[8] In addition, the colours of the characters on some plates were desaturated slightly, so that dichromats would be graded as having a severe colour deficiency, which was not always the case in the original HRR test.[9] Colorimetric analyses of the new HRR test[7,8] suggest that it should perform better in differentiating protans and deutans and in grading severity.

The design of the HRR test is based on very sound principles. It comprises 24 plates each displaying either one or two symbols, which can be a cross, a circle or a triangle (Figure 1). The symbols are constructed of coloured dots on a background of grey dots. The coloured dots have chromaticity co-ordinates that lie on or close to the protan, deutan or tritan dichromatic confusion loci that pass through the chromaticity co-ordinates of the grey background colours. The patient is asked to name the shape of each symbol they see and indicate its location, which can be in one of four quadrants of each plate.

There are four demonstration plates in which the colours of the symbols are such that they can be seen by all observers. One of these plates has no symbol so that patients understand that a symbol might not be seen on some plates.

There are six screening plates, four for the protan-deutan deficiencies and two for the tritan deficiencies. These are followed by 14 plates designed to grade the severity of the deficiency and to differentiate protans, deutans (10 plates) and tritans (four plates). The colours of the symbols lie on the protan, deutan or tritan achromatic confusion loci and become increasingly saturated as the patient proceeds through the plates. The principle is that those with a severe deficiency of colour vision will not see the symbols with colours lying on their confusion loci, even those constructed using the most saturated colours, but will see the symbols that have colours lying on the other confusion loci. Patients have their colour vision deficiency graded as mild, medium or severe, depending on whether they see or do not see the symbols on the more saturated plates. There are 10 grading plates for the protan/deutan defects: patients who make one or more errors in the two plates with the most saturated colours are graded as severe, those who make an error in the next three most saturated plates are graded as medium. Those who make errors only with the five least saturated plates are graded as mild.

When the test was designed, it was thought that there might be a fourth kind of dichromasy, tetartanopia, arising from the absence of a yellow receptor. A yellow receptor had been hypothesised because there are four unique colours, red, yellow, green and blue and unilateral protanopes and deuteranopes have been found to perceive yellow despite lacking one of the long-wavelength receptors. Some of the

plates have symbols using colours lying on the theoretical tetartan confusion locus. Tetartan colour vision deficiency has never been demonstrated convincingly but Richmond Products has retained the plates that test for it so that its edition faithfully reproduces the format of the original test.

Despite the elegance of its design the original HRR test did not always perform as might be hoped. Sometimes, it is passed (zero errors) by those with mild abnormal colour vision and sometimes failed by those with normal colour vision.[5,6,9–11] Its sensitivity for the detection of protan/deutan defects is about 0.97 to 0.98,[12] somewhat less than the 0.99 to 1.00 sensitivity of the Ishihara test (with a fail criterion of three or more errors).[4,11,12]

There has been only one report[5] of the ability of the original AO HRR to detect tritan defects. In this report six of nine congenital tritans failed one or both of the two tritan screening plates. The three who saw all the symbols reported that the tritan symbols were very faint compared to the tetartan ones that are paired with the tritan symbols.

The original AO HRR test often failed to classify the type of abnormal colour vision correctly. Sometimes, all the grading plates were read correctly so no classification was possible and sometimes, equal numbers of protan and deutan errors were made. The test correctly classified protans and deutans on 80 to 90 per cent of occasions.[3,5,6,9]

The original AO HRR test also had shortcomings in grading severity. Dichromats should be classified as having a severe colour vision deficiency but nearly 50 per cent are graded as medium and occasionally as mild.[5,9] Mild anomalous trichromats, those with a Nagel anomaloscope range of less than 10 or 15 units, should be classified as mild but they are often classified as medium and sometimes as severe.[5,9]

The Richmond HRR 2002 test has been re-engineered to address these shortcomings and there is some evidence that this might have been successful. Bailey, Neitz, Tait and Neitz[8] administered the revised Richmond HRR to 23 persons with abnormal colour vision. They found that all subjects failed the test and the one subject with a tritan defect also failed with one error on the HRR tritan screening plates. Its sensitivity in detection of abnormal colour vision seems to have been improved. All dichromats were graded as strong and all anomalous trichromats were graded as mild or medium, suggesting that the test may successfully differentiate these two classes. However, they found that the test did not differentiate protans and deutans as well as the original test.

In this paper we report results from administering the Richmond HRR 2002 pseudoisochromatic test to a larger sample of people to establish its sensitivity and specificity as a screening test for abnormal colour vision, its ability to differentiate protans from deutans and its ability to grade severity.

METHOD

The Richmond HRR 2002 test was given to 100 consecutively presenting patients attending the colour vision clinic of the Victorian College of Optometry specifically for advice on their colour vision, having been referred by private optometrists, employers or licensing agencies. One subject in the consecutively presenting series of patients was excluded because he could not do the Nagel anomaloscope and was generally unco-operative. He was aged nine years. He did not see most of the HRR plates, including half of the tritan and tetartan symbols.

The age of the 100 subjects ranged from eight to 52 years with an average age of 28.2 ± 10.8 years. One subject was aged eight years and six subjects were aged from 10 to 14 years. All subjects had a visual acuity of at least 6/7.5 in the better eye and had no history of ocular disease. Two subjects had slightly reduced visual acuity in one eye (6/12 and 6/9) but normal visual acuity in the other eye (6/6, 6/4.8). Subjects wore glasses to do the tests if needed.

The colour vision of the patients was diagnosed by the Ishihara test (24 plate, 1993 edition), the Medmont C-100, the Farnsworth D15 test and the Type 1 Nagel anomaloscope, except that the anomaloscope was not used for four subjects because of equipment malfunction. However, three of these passed the Farnsworth D15 test and are presumed anomalous trichromats and the fourth was classed as mild by the HRR test. The Ishihara and Farnsworth D15 tests were given using a Macbeth easel lamp, which approximates illuminant C and gives an illuminance of 200 lux. With the anomaloscope, subjects were required to adjust the red-green mixture and the yellow brightness to obtain a colour match at least three times. The limits of their matching range were determined by the experimenter adjusting the red-green mixture in small steps with subjects restoring the match, if they could, using the yellow brightness control.

Table 1 gives the number of subjects for each class of abnormal colour vision.

The HRR test was placed on an angled stand in a light box that we use for colour aptitude testing, so that the plates were approximately perpendicular to the line of sight and the subjects viewed the plates binocularly from a fixed distance of 400 mm. The plates were illuminated at 1280 lux in the plane of the plates by two GE Polylux 860 18 W tri-phosphor fluorescent lamps (Manufacturer's specification: colour temperature 6300 K, colour rendering index 85). Subjects were given about three seconds to respond to each page of the PIC tests. Each symbol missed with the HRR test was counted as an error.

The test was also given to 50 persons with normal colour vision (39 males, 11 females; age range 12 to 59 years; average age 33.6 ± 12.3 years), all of whom passed the Ishihara test, had no signs of ocular disease and had a visual acuity (with glasses if necessary) of better than 6/7.5 in the better eye. One subject had visual acuity of 6/7.5 in the worse eye but 6/6 in the other eye.

RESULTS

Detection

All the subjects with abnormal colour vision made errors on the protan/deutan HRR screening plates. The average number of errors on the protan-deutan screening plates was 4.97 ± 0.86 (out of the six symbols to be recognised). No subject made errors on any of the tritan plates.

The smallest number of errors on the screening plates was two made by two subjects, both mild anomalous trichromats with anomaloscope ranges of six and 14 units. One of these, the one with the anomaloscope range of 14, made numerous errors on the protan-deutan HRR grading plates. Both clearly failed the Ishihara test, with five and 14 errors, respectively.

On this evidence, the Richmond HRR has a perfect sensitivity of 1.0, if the fail criterion is two or more errors on the screening plates. Therefore, it can be relied on to detect all subjects with congenital red/green abnormal colour vision with this fail criterion.

Two subjects (one male, one female) with normal colour vision (CVN) failed to see one symbol on the first of the screening plates and two subjects (both males) failed to see both symbols on that plate. This means that the specificity of the Richmond HRR is 0.96, if the failure criterion is two or more errors: that is four per cent of subjects with normal colour vision were wrongly identified as having abnormal colour vision with this fail criterion.

If the criterion for failure is three or more errors, the specificity is 1.00, so that subjects with normal colour vision are not misdiagnosed. The sensitivity of the test then drops to 0.98: two per cent of the subjects with abnormal colour vision are missed.

Classification by type of defect

The Richmond HRR test correctly classified 86 per cent of the subjects as protan or deutan when the standard method of classification is used. With this method subjects are classified as protan when more errors are made on the diagnostic plates with the protan symbols than the deutan ones and vice versa.

Three subjects (three per cent) were wrongly classified. Two were protanomals and one was a protanope. Eleven subjects (11 per cent) were not classified, five because an equal number of protan and deutan symbols were not seen in the diagnostic plates and six because no errors were made in the diagnostic series of plates.

Grading for severity

Thirty-one per cent of the colour vision defective subjects were classified as having a mild deficiency, 43 per cent as medium and 26 per cent as strong.

An assessment of the validity of the severity grading of the HRR test requires it to be compared to an agreed benchmark measure of the severity of abnormal colour vision. There are two widely accepted measures of severity, a pass or fail at the Farnsworth D15 test and the matching range at the Nagel anomaloscope. Both are accepted as providing a measure of the loss of colour discrimination associated with abnormal colour vision. The Farnsworth D15 test was designed to pass those who have sufficient colour discrimination to be able to recognise the colour codes of electrical cables[13] and the anomaloscope range is a measure of the loss of wavelength discrimination along the red-yellow-green locus. Table 1 shows that on average, anomalous trichromats who pass the Farnsworth D15 test have a narrower Nagel anomaloscope range than those who fail it, although the distributions of Nagel range in the groups that pass or fail the Farnsworth D15 test overlap.

Table 2 shows how the HRR severity categories of mild, medium and strong relate to a pass or fail at the Farnsworth D15 test. Those who are classified as mild by the Richmond HRR pass the Farnsworth D15 test with one exception, a protanomal with an anomaloscope range of 30 units. For those classified as strong by the HRR, 85 per cent failed the Farnsworth D15 test and for those classified as medium by the HRR 40 per cent failed. Table 3 shows how the HRR severity categories relate to the v Kries classification of the red-green colour vision deficiencies.

	Number	Expected number in the CVD population	Mean Nagel range†	SD Nagel range
Protanomaly mild*	14	8	9.7	±7.0
Deuteranomaly mild*	45	42	11.3	±6.9
Protanomaly moderate/severe*	5	4	29.4	±13.2
Deuteranomaly moderate/severe	16	21	23.8	±18.0
Protanopia	8	12.5	full	
Deuteranopia	12	12.5	full	
Total	100	100		

* Anomalous trichromats are classified as mild or moderate/severe by passing or failing the Farnsworth D15 test. A fail at this test is defined as two or more diametrical crossings.
† Nagel matching range is measured on an arbitrary scale from 0 to 73. Protanopes and deuteranopes were diagnosed by having a full Nagel matching range of 73 and all of them fail the Farnsworth D15 test.

Table 1. Number of subjects by class of abnormal colour vision

HRR classification	Pass D15	Fail D15	Total
Mild	30	1	31
Medium	25	17	42
Strong	4	22	26
Total	59	40	99

Table 2. Number of subjects with abnormal colour vision classified as mild, medium and strong by the HRR test for subjects who pass or fail the Farnsworth D15 (n = 99)

Colour vision diagnosis	Richmond HRR severity grading			Total
	Mild	Medium	Strong	
Protanomaly pass D15	9	3	2	14
Deuteranomaly pass D15	21	22	2	45
Protanomaly fail D15	1	1	3	5
Deuteranomaly fail D15		9	7	16
Protanopia		5	3	8
Deuteranopia		2	9	11
Total	31	42	26	99

Table 3. Richmond HRR grading of severity related to colour vision diagnosis using the Farnsworth D15 test and the Nagel anomaloscope (n = 99)

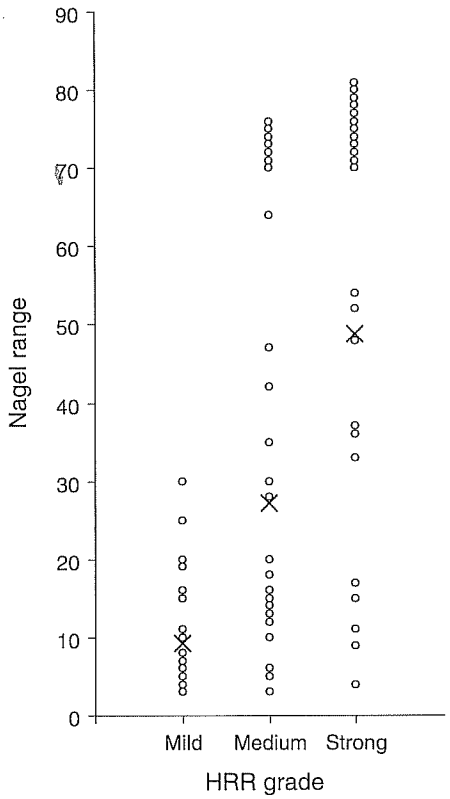

Figure 2. The Nagel anomaloscope matching ranges of the 95 subjects graded by the Richmond HRR test as mild, medium or strong. All the points at or above a range of 70 represent dichromats with a full matching range of 73 but are separated vertically to show the number of dichromats. X is the average Nagel matching range for each HRR grade. Number of subjects is 95 because one subject was too young to cooperate on the anomaloscope and data were lost for four subjects through equipment malfunction.

Figure 2 shows the Nagel anomaloscope ranges of the subjects classified by the HRR test as mild, medium or strong. The average anomaloscope range increases with the HRR severity grading. Those who are graded as mild by the Richmond HRR test have an average anomaloscope matching range of 9.2 units. All of them have a range less than 30 and all but two, 20 or less. This indicates that they have reasonably good colour discrimination, which is concordant with the HRR classification as mild.

While the average anomaloscope range increases in the medium and strong categories, a number of those with narrow anomaloscope ranges are classified in these two categories. Seven of the 19 dichromats were classified as medium.

Categorisation of severity as 'medium' or 'strong' can depend on a single error being made in the medium or severe groups of diagnostic plates and errors may not have been made on all of the preceding less saturated plates. Total errors on the HRR might be a better measure of severity. Figure 3 is a scatter plot of total errors on the diagnostic plates and the matching range with the anomaloscope. The correlation is 0.58, so only 34 per cent of the variance in anomaloscope range is explained by the number of errors on the HRR.

Figure 3 shows that subjects who made fewer than five errors on the diagnostic plates had an anomaloscope matching range of 25 or less and all these subjects also passed the Farnsworth D15 test. However, subjects with equally mild colour vision deficiency can make more than five HRR errors, while some are not distinguished by the HRR from dichromats.

DISCUSSION

The ideal colour vision test will reliably detect, categorise and grade the severity of the protan, deutan and tritan colour vision deficiencies. The Richmond HRR test attempts to do all these things and the results of this study show that while it might fall short of ideal, it is a good test and possibly the best single colour vision test available. However, our results must be viewed with a little caution.

We administered the HRR test under an illuminance of 1280 lux, twice that recommended in the instructions accompanying the test. This arose because we used the light box utilised for colour aptitude testing and overlooked that illuminance at the plane of the test material was high. The effect of this higher illuminance on the Richmond HRR test is unknown but large changes in illumination levels have little or no effect on the results obtained with other pseudoisochromatic tests. Schmidt[14] found that increasing illuminance from 269 lux to either 700 lux or 1076 lux did not significantly change the number of errors made with the Ishihara and the AOC plate test. Aarnisalo[15] found no significant change in errors with the Boström-Kugelberg pseudoisochromatic test for 100 CVD subjects and 30 CVN subjects, when illuminance was increased from 90 to 1800 lux.

Detection

The Richmond HRR test is good at detecting the red-green colour vision deficiencies. We found its sensitivity to be 1.00 and its specificity 0.96, if the criterion for failing the test is two or more errors with the screening plates, where each missed sym-

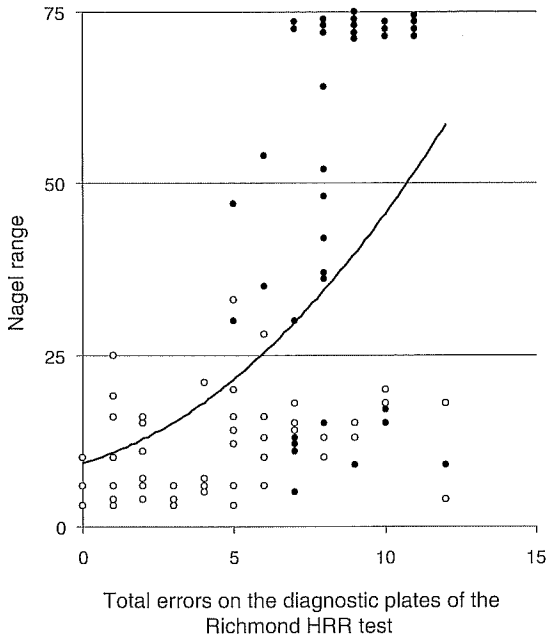

Figure 3. Nagel anomaloscope range versus total errors at the diagnostic plates of the Richmond HRR test. The open circles are subjects who passed the Farnsworth D15 test and the filled circles those who failed it. The trend line is a polynomial regression and is included only as a frame of reference. n = 95

bol is counted as an error. Bailey and his colleagues[8] report a better specificity: only one of their 29 CVN subjects made an error with the screening plates of the Richmond HRR. If our control group and that of Bailey and colleagues[8] are combined, the specificity becomes 0.975 for a fail criterion of two or more errors.

With a fail criterion of three or more errors, the sensitivity of the HRR based on our study data becomes 0.98 (two per cent of those with abnormal colour vision will be missed) but the specificity becomes 1.0 so the risk of misdiagnosing those with normal colour vision approaches zero.

Put more simply, a patient who makes three or more errors on the screening plates of the Richmond HRR test certainly has abnormal colour vision; a patient who makes only two errors probably has abnormal colour vision, but there is a small risk (2.5 in 100) that this diagnosis is incorrect and the patient may have normal colour vision. Patients who make only two errors should be retested or tested with another test to establish whether they have abnormal colour vision, as is recommended in the instructions accompanying the Richmond HRR test.

This makes the Richmond HRR as good as the Ishihara and better than other available pseudoisochromatic tests in detecting red-green colour vision deficiency. It is certainly better than the original AO HRR test. This is shown in Figure 4.

The Richmond HRR test is most likely to detect the tritan colour vision deficiencies. The original AO HRR failed tritans, although not always.[5] As the colours of the tritan symbols of the revised test are better aligned with the tritan confusion locus and are slightly less saturated,[7] it is probable that it will detect tritans.

Classification by type of defect

The Richmond HRR test successfully categorises protans and deutans 86 per cent of the time with 11 per cent unclassified and three per cent incorrectly classified. This is not a bad performance but the Medmont C-100 test categorises protans and deutans seemingly without error[16,17] and is therefore the preferred test for this diagnostic task.

This is very similar to the performance of the original AO HRR plates. Birch[9] found that 88 per cent of 393 subjects who failed the AO HRR were correctly classified and 2.8 per cent were incorrectly classified, while 9.4 per cent were not classified, either because no errors or an equal number of errors were made on the diagnostic plates. Bailey and colleagues[8] state that the Richmond HRR is no better in classification by type than the AO HRR but do not report detailed data.

Bailey and his colleagues[8] used a method for classification of protans and deutans that was different from the standard method. They assigned a weighting to each symbol in the screening and the grading plates, which increased with increasing saturation of the colour of the symbols. The deutan symbols were assigned a plus sign and the protan symbols a negative sign. Each error made was weighted with the weighting assigned to the particular symbol, depending on the saturation of the symbols and the weighted sum of the errors assigned a protan or deutan classification, depending on whether the sum was negative (protan) or positive (deutan).

When this method of scoring is used for the data in this study, there is little improvement in the way the test classifies protans and deutans. One of the three wrongly classified protans in our sample was correctly classified when errors were weighted but the weighted score was only marginally protan (less than 1.0 weighted error). One of our unclassified subjects became correctly classified and another was wrongly classified but in both cases, the weighted score indicated the classification by only a small margin.

Assessment of severity

The grading of severity by the Richmond HRR test is less satisfactory when its validity is assessed against the benchmarks of a pass or fail at the Farnsworth D15 test or the anomaloscope matching range. When

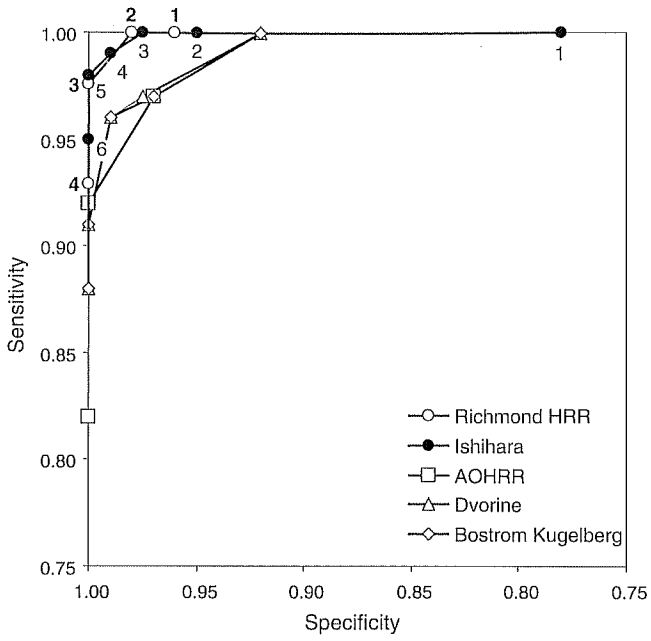

Figure 4. Sensitivity and specificity of various pseudoisochromatic colour vision tests when the criterion for failing the test is varied. The bold numbers and the ordinary face numbers adjoining the data points for the Richmond HRR and the Ishihara tests indicate the fail criterion (number of errors) that give that particular sensitivity and specificity. Thus, if the criterion for failing the Richmond HRR is making one or more errors, the sensitivity is 1.00 (all those with abnormal colour vision fail) and the specificity is 0.96 (96 per cent of those with normal colour vision pass). Sensitivity for the Richmond HRR is based on the data in this study and the specificity is based on the data of this study combined with that of Bailey and colleagues.[8] The sensitivities and specificities for the other pseudoisochromatic tests are from Vingrys.[12] Sensitivity and specificity of the Standard Pseudoisochromatic Plates (SPP) reported by Vingrys have been omitted for clarity but are 0.98 and 0.99, respectively, for a fail criterion of three errors.

the Richmond HRR test grades patients as having a mild colour deficiency this is very likely to be confirmed by a pass at the Farnsworth D15 test and an anomaloscope range of less than 30 and more likely less than 20 (Tables 2 and 3, Figures 2 and 3). Almost all of those with abnormal colour vision classified as 'mild' and about half of those classified as 'medium' pass the Farnsworth D15 test (Table 2). This suggests that classification as 'mild' by the HRR indicates a milder deficiency than does a pass with the Farnsworth D15 test.

An HRR grading of a medium or strong colour vision deficiency is not always concordant with the results of the Farnsworth D15 and the anomaloscope range and not all dichromats are classified by the HRR as strong.

One of the objectives of the re-engineering of the new Richmond HRR test was to ensure that all dichromats were graded as strong,[8] since it is dichromats who are the most severely affected. The original AO HRR test did not do this reliably, even classifying some dichromats as having a mild deficiency[9] and many as medium.[5,9] The validation trial of the Richmond HRR conducted by Bailey and his colleagues[8] had nine dichromats, all of whom were classified as strong, suggesting that the re-engineering had been successful in achieving a correct severity grading of dichromats. This is not confirmed by our results with seven of 19 dichromats classified as medium. However, six of these dichromats were within one plate of falling into the strong category. It is possible that the high illuminance under which we gave the HRR test may have caused these dichromats to fall outside the strong category.

Even so, it has to be noted that a number of anomalous trichromats who would be considered as having a mild or moderate colour vision deficiency because they pass the Farnsworth D15 test and have a narrow anomaloscope range are classified as medium or strong by the HRR. It is not expected that a lower test illuminance would cause them to make fewer errors and shift their HRR classification to mild.

This assumes that the Farnsworth D15 and the anomaloscope range are absolute gold standard measures of severity of abnormal colour vision. They are widely accepted as such but it is well known that these two measures are not infallible predictors of the ability to do practical colour vision tasks. Neither has a particularly close relation to the ability to recognise the colours of signal lights[18] nor the ability to recognise surface colours.[19] Certainly, dichromats and anomalous trichromats who have a wide anomaloscope range and who fail the Farnsworth D15 test make many errors recognising signal lights but some of those with a narrow anomaloscope range or who pass the Farnsworth D15 test cannot recognise signal lights. Likewise, some dichromats and severely affected anomalous trichromats are surprisingly good at naming surface colours.[19]

The failure of the HRR to grade severity of some subjects in concordance with the Farnsworth D15 and the anomaloscope range may be because of individual differences in the orientation of the achromatic confusion loci.

Another possibility is that there is no single measure of severity of abnormal colour vision. The basis of the three measures of severity differ: the anomaloscope range measures wavelength discrimination around 590 nm, the Farnsworth D15 test measures colour discrimination for surface colours circling Illuminant C white, while the HRR measures loss of saturation discrimination. It is possible that these

three kinds of colour discrimination are not closely correlated in people with abnormal colour vision. There is certainly variability in doing practical colour tasks. Some people with severe loss of colour discrimination, as measured by the Farnsworth D15 or the anomaloscope range, can do remarkably well in practical colour vision tasks.[18,19]

The Richmond HRR can be used confidently to detect red-green colour vision deficiency and is as good as the Ishihara in doing this. In addition, it is reasonable to assume that it will detect tritan deficiencies, which the Ishihara does not. The HRR is not as well known as the Ishihara, so the risk of persons learning the correct answers to enable them to pass the test is very small and in any case the HRR can be presented upside down to confound those who have been industrious enough to learn the correct answers. The HRR is good at differentiating protans and deutans, which it will do correctly for 86 per cent of patients, although the Medmont C-100 test is better.[17] An HRR severity grading as 'mild' indicates that the deficiency is indeed mild but there is doubt about how a grading of medium or strong should be interpreted. As the most valid and useful measure of severity of abnormal colour vision is uncertain, there might be merit in taking heed of the results of the HRR in combination with the Farnsworth D15 and the anomaloscope range, in making judgements about severity.

REFERENCES

1. Hardy LH, Rand G, Rittler MC. HRR polychromatic plates. *J Opt Soc Am* 1954; 44: 509–523.
2. Rand G, Rittler MC. An evaluation of the AO HRR pseudoisochromatic plates. *Arch Ophthalmol* 1956: 56: 736–742.
3. Crone RA. Quantitative diagnosis of defective color vision. A comparative evaluation of the Ishihara test, the Farnsworth dichotomous test and the Hardy-Rand-Rittler polychromatic plates. *Am J Ophthalmol* 1961; 51: 298–305.
4. Cole BL. Misuse of the Ishihara test for colour blindness. *Br J Physiol Optics* 1963; 20: 113–118.
5. Cole BL. Comments on some colour vision tests and their use for selection. *Aust J Optom* 1964; 47: 56–64.
6. Walls GL. How good is the H-R-R test for color blindness? *Am J Optom Arch Am Acad Optom* 1959; 36: 169–193.
7. Dain SJ. Colorimetric analysis of four editions of the Hardy-Rand-Rittler pseudoisochromatic test. *Visual Neurosci* 2004; 21: 437–443.
8. Bailey JE, Neitz M, Tait DM, Neitz J. Evaluation of an updated HRR color vision test. *Visual Neurosci* 2004; 21: 431–436.
9. Birch J. Clinical use of the American Optical company (Hardy, Rand and Rittler) pseudoisochromatic plates for red-green colour deficiency. *Ophthalmic Physiol Opt* 1997; 17: 248–254.
10. Sloan LL, Habel A. Tests for color deficiency based on the pseudoisochromatic principle. *Arch Ophthalmol* 1956; 100: 176–182.
11. Belcher SJ, Greenshields KW, Wright WD. A colour vision survey using the Ishihara, Dvorine, Böstrom and Kugleberg, Böstrom and American Optical Hardy-Rand-Rittler tests. *Br J Ophthalmol* 1958; 42: 355–359.
12. Vingrys AJ. An analysis of colour vision standards in the transport industry. PhD thesis. The University of Melbourne: 1984.
13. Farnsworth D. The Farnsworth-Munsell 100-Hue and dichotomous tests for colour vision *J Opt Soc Am* 1943; 33: 568–578.
14. Schmidt I. Effect of illumination in testing color vision with pseudo-isochromatic plates. *J Opt Soc Am* 1952; 42: 951–955.
15. Aarnisalo E. Effects of reduced illumination on the results obtained with some diagnostic colour vision tests in subjects with congenital red-green defects. *Acta Ophthalmol Scand Suppl* 1980; 142: 1–66.
16. Cole BL. Does defective colour vision really matter? In: Drum B, ed. *Colour Vision Deficiencies XI* Dordrecht: Kluwer; 1993. p 67–86.
17. Metha AB, Vingrys AJ. The C-100: a new dichotomiser of colour vision defectives. *Clin Exp Optom* 1992; 75: 114–123.
18. Cole BL, Maddocks JD. Can clinical colour vision tests be used to predict the results of the Farnsworth lantern test? *Vision Res* 1998; 38: 3483–3485.
19. Cole BL, Orenstein JM. Does the Farnsworth D15 test predict the ability to name colours? *Clin Exp Optom* 2003; 86: 221–229.

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