

Search for coloured objects in natural surroundings by people with abnormal colour vision

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Background: People with abnormal colour vision often report difficulty seeing coloured berries and flowers in foliage, which suggests they will have a diminished capacity for visual search when target objects are marked out by colour. There is very little experimental evidence of the effect of abnormal colour vision on visual search and none relating to search for objects in natural foliage.

Method: We showed 79 subjects with abnormal colour vision (seven protanopes, 10 deuteranopes, 16 protanomals and 46 deuteranomals) and 20 subjects with normal colour vision photographs of natural scenes and asked them to locate clumps of red berries, to trace the length of a red string on grass and to name the season depicted in a photograph taken in the Autumn and the same scene photographed in the Summer. Colour vision was assessed using the Ishihara, the Medmont C100, the Farnsworth D15, the Richmond HRR and the Nagel anomaloscope.

Results: All the subjects with abnormal colour vision located fewer clumps of red berries than those with normal colour vision. The subjects who failed the Farnsworth D15 performed significantly worse than those who passed but the distribution of scores in the two groups overlaps. The majority of subjects with abnormal colour vision could not trace the full length of the string; only 38 per cent of anomalous trichromats who passed the Farnsworth D15 test and three per cent of those who failed it were able to trace the full length of the string. Fifty-five per cent of those classed as having a mild deficiency by the HRR test could trace the whole string. Most dichromats were unable to identify the Autumn season and those who did may have been assisted by guessing. Most (94 per cent) of those who passed the Farnsworth D15 test and all those classified as having a 'mild' deficiency by the HRR test could identify the season.

Conclusions: All people with abnormal colour vision, even those with a very mild deficiency, have some degree of impairment of their ability to see coloured objects in natural surroundings. A pass at the Farnsworth D15 test or a 'mild' classification with the Richmond HRR test identifies those likely to have the least problems with visual search and identification tasks. The results have practical implications for the selection of personnel in occupations that involve visual search in natural terrain.

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It is well known from anecdotal reports that people with abnormal colour vision have problems seeing coloured flowers and berries on trees and bushes. Cockburn¹ reports that he tends to overlook tomatoes on the bush and has trouble seeing red flowers on eucalyptus trees because of his extreme deuteranomaly. Blake,² a moderate deuteranomal, reports the same problem seeing flowers on trees and bushes and recounts how slow he is picking blackberries and youngberries, compared to other members of his family, because he cannot find the fruit. Spalding,³ a deuteranope, recalls one occasion when he headed in the wrong direction when walking in the mountains because he failed to see a red arrow painted on a rock that designated the right path.

These anecdotes suggest that people with abnormal colour vision are less efficient in visual search when the target object is marked out by colour. There is some experimental evidence to support that proposition. Observers with abnormal colour vision are significantly less likely to notice the presence of road traffic signals and road signs than observers with normal colour vision because the colours of the signal lights and the colours of the backgrounds of signs are less effective in attracting their attention;⁴ they are slower and less likely to see redundantly colour coded information in aviation flight instrument displays;⁵ and they are slower and less successful than colour vision normal observers in finding a target in a complex background that is distinguished by its shape and is also redundantly colour coded.⁶

Those with abnormal colour vision have difficulty using colours in natural environments to acquire information about ripeness and how well meat is cooked.⁷ Blake² observes that he suspects Autumn is much more muted for him and that he does not notice the changing colours of trees until the Autumn is well advanced. He also reports that he picks lemons and limes when they are not ripe. Observers with abnormal colour vision are known to have difficulty seeing rashes and other coloured signs of illness.⁷⁻⁹



Figure 1. The four photographs used in the study. Reproduced from reference 10 with kind permission of Dr JA Spalding.

Spalding and Arden¹⁰ produced a book of coloured photographs of everyday scenes and objects designed to be used in the consulting room to demonstrate to patients and their families the sort of problems that a person with abnormal colour vision may encounter. The book includes photographs of red flowers and berries in natural settings and the patient is invited to outline the berries, flowers and other objects using a chinagraph pencil on the clear plastic covering over the photographs.

We selected four of the photographs in this book and showed them to a sample of people with various deficiencies of colour vision to quantify the difficulty each category of deficiency has seeing the coloured objects.

METHOD

The four photographs used are shown in Figure 1. The first photograph has clumps of red berries seen against a leaf, grass and earth background and the second has a

red string lying on a variegated grassy background. The third and fourth photographs are of a scene photographed in the Autumn and in the Summer.

The observers were asked:

1. To point out every clump of berries they could see in photograph 1.
2. To trace the string lying on the ground in photograph 2.
3. To state whether the season depicted was Autumn, Winter, Spring or Summer in photographs 3 and 4.

The photographs were shown to 79 observers with abnormal colour vision (10 deuteranopes, seven protanopes, 46 deuteranomal, 16 protanomals) and 20 observers with normal colour vision.

The observers with abnormal colour vision were consecutively presenting patients to the colour vision clinic of the Melbourne Optometry Clinic. Their ages ranged from 8 to 52 years with an average age of 28.0 ± 10.7 (SD) years. The observers with normal colour vision had a mean age of 34.6 ± 14.7 years (range 12 to 57 years). All subjects had a visual acuity of at

least 6/7.5 in the better eye and had no history of ocular disease. Subjects wore spectacles to do the tests if needed.

The investigation was approved by the Ethics Committee of the Victorian College of Optometry and all subjects gave their informed written consent.

The colour vision of the observers was diagnosed by the Ishihara test (24 plate, 1993 edition). Those who had abnormal colour vision, as shown by the Ishihara, were tested with the Medmont C100, the Farnsworth D15 test, the Richmond HRR test (2002) and the Type 1 Nagel anomaloscope to make a diagnosis of the type of colour vision deficiency. The Ishihara and the Farnsworth D15 test were given under illumination from a MacBeth easel lamp approximating illuminant C that provided an illuminance of 198 lux. The HRR test was given in the same light box used to show the four photographs (see below).

Subjects were classified into the v Kries categories of abnormal colour vision (protanopia, deuteranopia, protanomaly, deuteranomaly). The anomalous trichromats were further divided into those who passed and those who failed the Farnsworth D15 test. A fail at the Farnsworth D15 test is two or more diametrical crossings. The Richmond HRR test also enabled the subjects with abnormal colour vision to be classified by severity as 'mild', 'medium' or 'strong'.

The anomaloscope was not used for four subjects because of equipment malfunction. Three of these observers passed the Farnsworth D15 test and the fourth failed the D15 but was graded 'medium' on the Richmond HRR test and all four are presumed anomalous trichromats.

Photographs were placed one at a time on an angled stand in a light box so that they were approximately perpendicular to the line of sight and the subjects viewed them from a fixed distance of 400 mm with their head steadied by a forehead rest. The dimensions of the photographs were 145 mm wide by 97 mm high, (photographs 1 and 2) and 164 mm wide by 104 mm high (photographs 3 and 4). They subtended a visual angle of about 20 degrees wide \times 14 degrees high. They were illuminated at 1280 lux by two GE

Polylux 860 18 W tri-phosphor fluorescent lamps (colour temperature 6300 K, colour rendering index 85). No time limits were placed on subjects in responding to the question asked for each photograph.

RESULTS

Figure 2 shows the average number of clumps of berries located in photograph 1 for each category of colour vision deficiency and for the colour vision normal group.

Colour vision deficient observers perform significantly worse than the colour vision normal controls (single factor ANOVA $p < 0.001$). Multiple range tests showed that the mean number of clumps of berries located by deuteranopes was significantly less ($p < 0.05$) than that for deuteranomals who pass the Farnsworth D15 test but there were no significant differences among the other classes of abnormal colour vision. However, when subjects who fail the Farnsworth D15 test are grouped (including the dichromats, all of whom fail the D15 test) they are significantly worse than the subjects who pass the D15 test (fail D15 test, 1.2 ± 0.20 [mean \pm SE], pass D15 test 2.68 ± 0.23 , $t = 4.70$, $df 79$, $p < 0.001$).

Figure 3 shows that the distributions of the number of berry clumps located by subjects who pass or fail the Farnsworth D15 test overlap considerably but none of them overlaps the distribution of the colour vision normal subjects, which is clearly different.

Figure 4 shows the average percentage length of string traced (photograph 2) for each category of abnormal colour vision. All the subjects with normal colour vision were able to trace the whole length of the string.

The colour vision deficient observers are significantly worse in their ability to trace the length of the string than the colour-vision-normal controls (single factor ANOVA $p < 0.001$). Both dichromats and anomalous trichromats who fail the Farnsworth D15 test perform significantly worse than anomalous trichromats who pass the Farnsworth D15 (multiple range test, $p < 0.05$).

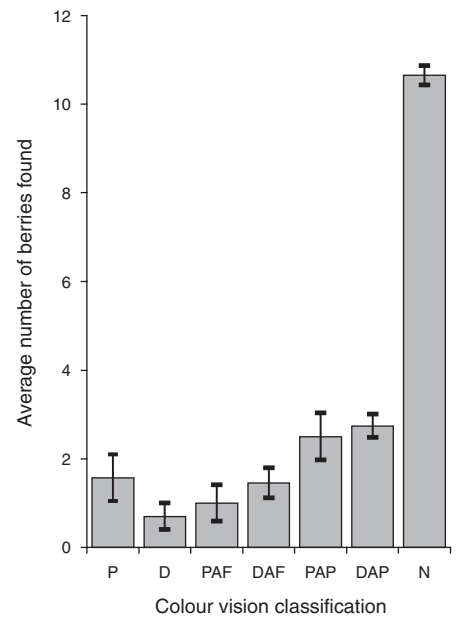


Figure 2. The average number of clumps of berries identified by each category of abnormal colour vision compared to those of colour vision normal observers. P = protanope, D = deuteranope, PAF = protanomal failing the Farnsworth D15 test, DAF = deuteranomalous failing the Farnsworth D15 test, PAP = protanomal passing the Farnsworth D15 test, DAP = deuteranomalous passing the Farnsworth D15 test, N = colour vision normal. The vertical bars are standard errors.

Figure 5 shows the distributions of the length of string traced for dichromats and anomalous trichromats who pass and those who fail the Farnsworth D15 test. While some anomalous trichromats who pass the Farnsworth D15 test are able to trace the full length of the string, two-thirds of them could not. Only one (three per cent) of the colour vision deficient subjects who failed the Farnsworth D15 test could trace the full length of the string. He was an anomalous trichromat. None of the dichromats could trace its full length.

Figure 6 shows the percentage of subjects in each category of abnormal colour vision correctly identifying photograph 3

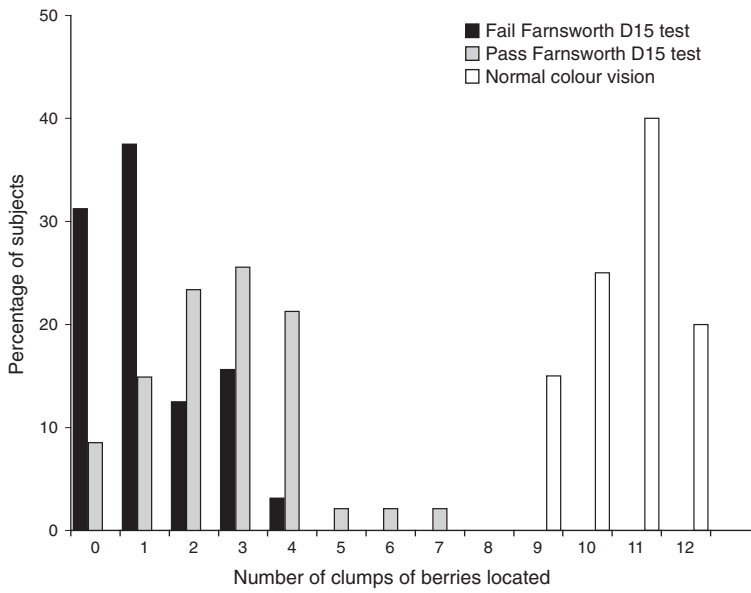


Figure 3. The distributions of the number of clumps of berries located by those who pass and fail the Farnsworth D15 test compared to that for people with normal colour vision.

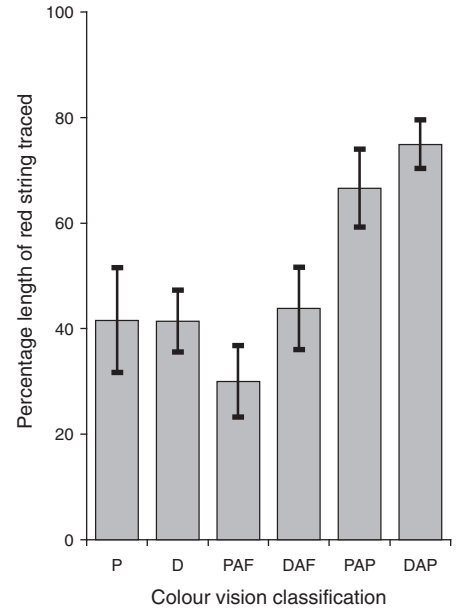


Figure 4. The average length of string (as a percentage) traced for each category of abnormal colour vision. P = protanope, D = deuteranope, PAF = protanomalous failing the Farnsworth D15 test, DAF = deuteranomalous failing the Farnsworth D15 test, PAP = protanomalous passing the Farnsworth D15 test, DAP = deuteranomalous passing the Farnsworth D15 test. The vertical bars are standard errors. All subjects with normal colour vision could trace the full length of the string.

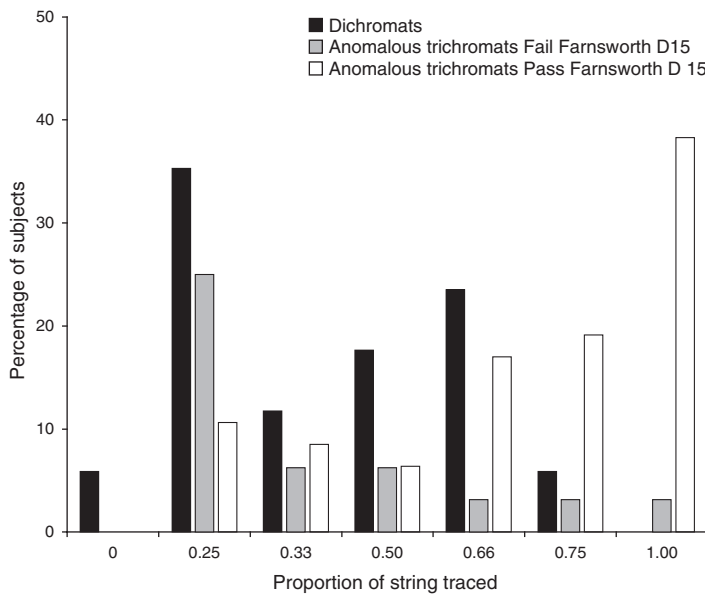


Figure 5. The distributions of the length of string traced for dichromats and anomalous trichromats who pass and fail the Farnsworth D15 test. All subjects with normal colour vision traced the full length of the string.

as depicting Autumn. All the controls correctly identified the season. The colour vision deficient observers (grouped as dichromats, anomalous trichromats who fail the Farnsworth D15 test and anomalous trichromats who pass) perform significantly worse than those with normal colour vision in their ability to identify the season in photograph 3 ($\chi^2 = 12.3$, $df = 3$, $p < 0.01$). Dichromats performed worse than anomalous trichromats ($\chi^2 = 9.4$, $df = 1$, $p < 0.01$). There were no significant differences between the two classes of dichromats or between anomalous trichromats who passed and failed the Farnsworth D15 test.

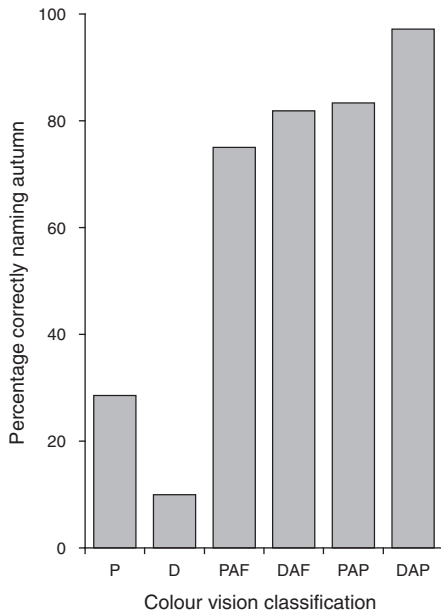


Figure 6. The percentage of subjects in each class of abnormal colour vision correctly identifying the season in photograph 3. P = protanope, D = deuteranope, PAF = protanomalous failing the Farnsworth D15 test, DAF = deuteranomalous failing the Farnsworth D15 test, PAP = protanomalous passing the Farnsworth D15 test, DAP = deuteranomalous passing the Farnsworth D15 test.

Photograph 4 depicts Summer but the colour vision normal control group was divided over whether it was Summer or Spring, so either answer is taken as correct. One of the control subjects identified it as depicting Winter but none saw it as Autumn. Ninety-five per cent of the colour vision deficient observers correctly identified photograph 4 as depicting either Spring or Summer. One deuteranope, two protanopes and one deuteranomalous who failed the Farnsworth D15 incorrectly identified this photograph as depicting Autumn.

Figure 7 shows the performance of the colour vision deficient subjects at the three tasks when the subjects are grouped according to their severity using the Rich-

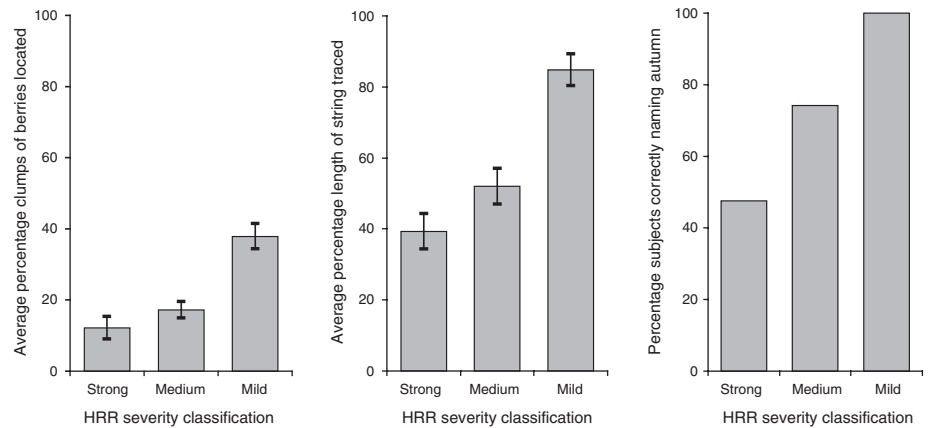


Figure 7. Performance of the subjects with abnormal colour vision at the three tasks when the subjects are classified for the severity of their colour vision deficiency using the Richmond HRR test (a) locating clumps of berries (b) tracing length of red string (c) identifying the season in a photograph depicting Autumn. Vertical lines are standard errors.

mond HRR test. The differences in performance in locating berries and tracing the length of the string among the three severity groups and the normal colour vision group are highly significant (single factor ANOVA, $p < 0.001$). Multiple range tests ($p < 0.05$) show that all three severity groups perform significantly worse than the colour vision normal group for the 'locate the berries' task. The 'medium' and 'strong' groups perform significantly worse than the 'mild' group. For the 'trace the string' task, the 'medium' and 'strong' groups perform significantly worse than the colour vision normal group and the 'mild' group. For the 'name the season' task, the medium and strong groups perform significantly worse than the 'mild' and normal groups, ($\chi^2 = 7.8$, $df = 2$, $p < 0.05$) and the 'strong' group performs significantly worse than the 'medium' group ($\chi^2 = 7.8$, $df = 1$, $p < 0.05$).

The HRR groupings of severity provide more clear-cut differentiation of performance at the three tasks than does the Farnsworth D15 test. In particular, those classified as 'mild' by the HRR test perform clearly better than those classed as 'medium' or 'strong' and all those classed

as 'mild' could identify the Autumn season.

DISCUSSION

All of the colour vision deficient subjects, without exception and regardless of the type and severity of their deficiency, perform considerably less well in locating clumps of red berries than those with normal colour vision. This confirms and provides some quantification of the anecdotal reports made by people with abnormal colour vision of their difficulty seeing coloured berries and flowers in foliage.^{1,2} Even the subjects with abnormal colour vision who performed best saw 30 per cent fewer berries than the worst performing subject with normal colour vision.

Only 38 per cent of anomalous trichromats who passed the Farnsworth D15 test and 55 per cent of those classed as having a mild deficiency by the HRR test could trace the full length of the coloured string, which all the subjects with normal colour vision were able to do without difficulty.

Dichromats seem to have a scant appreciation of the colours of Autumn. Figure 8



Figure 8. Transformation of the photographs depicting Autumn (top) and Summer (bottom) to the colour appearance as seen by a deuteranope. The transformations were made using the algorithms of Vischeck at URL: <http://www.vischeck.com/>. The appearance for a protanope is not greatly different.

makes it easy to understand why this might be so. Figure 8 shows the Autumn and Summer photographs 3 and 4 digitally transformed to the colour appearance as perceived by a deuteranope. Therefore it is not surprising that only three of the 17 dichromats (18 per cent) correctly named the season of the Autumn photograph and it is possible that they did so by guessing. There are four seasons so there is a one in four chance of guessing correctly and as the trees had leaves, Winter was an unlikely choice, so the chance of guessing correctly could well be one in three.

About 20 per cent of the anomalous trichromats who failed the D15 test were also unable to identify the season in the Autumn photograph and it seems that those with moderate to severe anomalous trichromasy will also have a diminished appreciation of Autumn colours.

A severity grading of mild with the Richmond HRR test or a pass at the Farnsworth D15 test are good predictors of the ability to identify autumn colours. All anomalous trichromats who are classified as mild by the Richmond HRR test or who pass the Farnsworth D15 test (with one exception) can identify the colours of Autumn.

These results cannot be generalised too widely: the photographs depicted red berries in foliage, a red string on grass and the reddish hues of Autumn. It does not follow that the same difficulty would be experienced by those with abnormal colour vision for objects having other colours. Theoretical understanding of abnormal colour vision and the evidence of O'Brien and colleagues⁴ and Cole and co-workers⁶ suggest they will have no difficulty searching for and seeing blue and yellow objects.

A practical conclusion that can be drawn is that people with abnormal colour vision, even those with a mild deficiency, have a diminished ability to search for objects in natural surroundings, when those objects are marked by their colour. This has implications for the selection of personnel in occupations that may involve search, for example police officers, who often conduct visual searches for evidence that may be marked out or identifiable by colour and for those who conduct search and rescue operations. The results suggest also that abnormal colour vision may be a handicap in horticultural pursuits.

ACKNOWLEDGEMENT

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