Performance of the Ishihara, D-15, and City University Colour Vision Test as a function of intraocular straylight

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Abstract

Three colour vision tests, the Ishihara test, the City University Test (CUT) and the D-15 test were studied as a function of induced intraocular straylight, using a commercially available light-scattering filter. Thirty young individuals (aged 17-28 years) with no ocular abnormalities and normal colour vision participated in the study. Intraocular straylight was estimated in all individuals using a psychophysical compensation method with the C-Quant straylight meter, with and without the light-scattering filter which caused an increase in intraocular straylight typical of that found for cataract. Under normal viewing conditions all the subjects passed each of the three tests with no errors. When viewing the Ishihara test plates through the filter, 10 out of the 30 observers made at least one error. Three subjects also made errors on the desaturated CUT test plates, but all subjects still passed the D-15 test with the filter. The errors in the Ishihara test correlated with the amount of intraocular straylight, as measured with the C-Quant. This study indicates that interpretation of the Ishihara test in a clinical environment will be made more difficult in individuals with higher levels of straylight.

Introduction

A variety of tests are available for the assessment of congenital and/or acquired colour vision defects. The outcome of these tests can be affected by several factors that have previously been shown to influence the results. Changes in spectral and photometric characteristics can affect colour vision test results, as can changes in retinal illumination e.g. Colour and luminance contrast, the design and difficulty of the particular test can also impact upon the results. It has been well documented that age is an important factor affecting the results from colour vision tests with an increase in colour vision errors being associated with increasing age. Such changes might be due to crystalline lens aging which can cause an increase of the light scatter and absorption in the eye. The change of lens spectral absorption observed with age has not been found to affect colour discrimination significantly.
The increase in the amount of straylight in the eye can be caused by the normal aging of the lens due to senile structural changes, or by cataract. Although the removal of the lens undoubtedly reduces the amount of straylight in the eye, implantation of IOLs can also cause glare\textsuperscript{15,16,17} and posterior capsular opacification (PCO) can often arise after cataract surgery giving rise to a glare problem similar to cataract. Increased intraocular straylight is also associated with a variety of other ocular pathologies including corneal dystrophies, corneal oedema, lack of iris pigmentation as in albinism\textsuperscript{18} and laser refractive surgery\textsuperscript{19}, etc.

It is well known that the straylight in the eye creates a veiling luminance covering the retina which can reduce the colour contrast and saturation of the retinal image.\textsuperscript{20} However, the effect of the intraocular straylight on commonly used clinical colour vision tests has not been studied systematically. The aim of this paper is to individually study and compare the performance of three commonly used colour vision tests as a function of the amount of intraocular straylight present.

The Ishihara test is one of the most widely used tests for the detection of red/green colour vision deficiencies and for helping in the occupational assessment of colour vision.\textsuperscript{2} The Ishihara is often used in combination with either the Farnsworth Panel D- 15 Test or City University Test (CUT), which can be used to help determine any defect\textsuperscript{21} and to assess for both red-green and blue-yellow defects. The performance of all three tests under conditions of induced straylight was tested in young healthy individuals. This allowed us to examine each test individually and to compare any differences between test results under simulated straylight conditions.

**Materials and methods:**

**Subjects**

30 young individuals (age range 17 - 28 years; 14 female) with normal vision, recruited from a regional university, took part in the study. This age range was specifically chosen as individuals in this age group demonstrate the best colour discrimination and none of the participants had any ocular history which would significantly increase their straylight in the eye. All participants had normal visual acuity (at least 6/6 Snellen acuity) and had no self-reported ocular abnormality,
diabetes or other disease that might affect colour vision. None of the participants were taking medication which is known to impact upon colour vision. A preliminary colour vision screening was performed monocularly on each eye using the CUT (3rd edition, 1998) to exclude individuals with colour vision defects. According to the screening results, one male was diagnosed as having red-green deficiency and was excluded. The rest of the participants had normal colour vision.

All colour vision tests were performed monocularly with natural pupils (average size 4 mm). The eye with better acuity was the study eye (or one eye was chosen randomly when VA was the same) and the non-tested eye was patched. All subjects with refractive error were required to wear their glasses during the tests. Tinted lenses and contact lens wear were not permitted.

The study was approved by the Biomedical Sciences Ethics Filter Committee of the University of Ulster. Prior to carrying out tests all subjects gave written consent to take part in the study by signing a consent form. The study adheres to the tenets of the Declaration of Helsinki.

**Materials**

Colour vision performance was evaluated as a function of induced intraocular straylight created by a commercially available white opacity filter, Lee Fog 4 (Lee Filters, Andover, England) with a transmittance level of 60% at all wavelength, source C, as specified by the manufacturer. We qualified the light scattering properties of the filter both by measuring the angular distribution of the light scattered by the filter and by measuring the amount of the intraocular straylight light induced by the filter.

The angular distribution of the scattered light has been measured and the resulting curve has been published in our previous paper 22. The collimated beam of light emitted from 1000 W tungsten-halogen source was passed through the filter. All optical elements were mounted on an optical bench. The luminance of the light transmitted through the filter was measured by the spectrophotometer Spectrascan (PR-650; Photo Research, Inc., Chatsworth, CA, USA) at different angles in the range 4-15 deg, using its rotatable facility. The measured straylight level followed an
inverse power law as a function of the scattering angle with an exponent of -2.02 which is the well-established inverse square law for intraocular straylight (e.g. \(^{23, 24}\)). In addition, contrast sensitivity measurements with glare demonstrated that this filter caused significant visual loss in the range reported for cataract patients.

In the present study, we determined the amount of the intraocular straylight induced by the scattering filter, by estimating the straylight for each subject without and with the filter. The commercially available C-Quant straylight meter (Oculus GmbH, Wetzlar, Germany) was used for these measurements.

The filter was placed into a pair of adapted welder goggles which the subject was able to wear comfortably over their refractive correction.

_Ishihara Pseudoisochromatic Plate test_

The Ishihara test belongs to the group of pseudoisochromatic plate tests, consisting of a series of plates that contain coloured figures, usually one- or two-digit Arabic numeral embedded in a differently coloured background. Both the figure and background consist of spots that vary randomly in size and lightness. The whole pattern is superimposed on a white background. The observers have to identify the figure which differs systematically from the background only in its colour since the spots luminance and size vary randomly to mask any luminance differences. The plates design is based on the confusion axes assuming that the colour defective individuals cannot discriminate colours along these axes. Any colour vision deficiency can be identified on the basis of the number of incorrect responses. According to the original instructions, up to two errors can be considered as normal while six or more errors can be regarded as an indication of a definite colour vision defect. \(^{25}\) However, it has been stressed that this pass/fail criterion can be more or less stringent depending on the specific aim of the test e.g. \(^{26}\)

_Farnsworth Panel D-15 test_

This is an arrangement test, a subset of the Farnsworth Munsell-100 hue test. It consists of 16 Munsell hues from an incomplete colour circle which are mounted on small caps subtending 1.5 degrees at a distance of 50cm. The 15 movable caps have to be arranged on a dark matt surface starting with the fixed pilot cap so as to produce gradual progression of hue between adjacent caps.
This test provides a rapid assessment of moderate to severe protan, deutan and tritan defects. Since some hues from the opposite parts of the colour circle lie on dichromatic confusion lines, they can be confused and placed next to each other by a colour deficient observer. The colour arrangement made by each observer is drawn in a circular diagram made up of 15 dots, each dot corresponding to a different hue. A colour defect is characterised by the number of crossing (2 or more) on the circular diagram based on their orientation. Two or more major crossing are considered as a failure according to the instructions although more stringent criteria can apply. The assessment is performed by visual inspection as originally proposed by Farnsworth, but methods of quantitative scoring have also been developed.

*City University Test (CUT)*

The CUT can be used to identify moderate to severe protan, deutan and tritan defects. The test consists of 11 plates using Munsell hues that are derived from the colours of D-15 panel test. Each plate contains circular coloured spots superimposed on black matt background. The first part of the test is designed to detect colour vision defects and the second part is used to help classify the type and the degree of the defect. In the first part, observers are asked to identify which spot in a row is different in colour from the rest of coloured spots and in part two, to identify which of four coloured spots around a central spot is most similar in colour to the central standard colour. The colours that are to be resolved lie on protan, deutan and tritan confusion axes i.e., the colours will look similar to an individual with colour vision defect, while an individual with normal colour vision would be able to differentiate between the colours. The principle and the aim of the CUT are similar to the D-15 test but the examination procedure is simplified and easier to be implemented. The small size of the colour spots subtending 0.716 deg at 40 cm and the desaturated colours used in the 2nd and 3rd edition of the test make it more difficult similarly to desaturated D-15 test to allow better classification of colour defective individuals. A single error is qualified as a failure of the test. The number of errors can be used to indicate the severity of the defect.

*Procedure*
The colour vision tests used were Ishihara Pseudoisochromatic Plate Test (38-plates edition, 2002), Farnsworth Panel D-15 Test and CUT (3rd edition, 1998).

Prior to beginning of the experiment all subjects were given an information leaflet regarding the nature of the study. The CUT used for screening was performed first. Following the screening, the participants who passed the inclusion test performed Farnsworth D-15 test and the Ishihara Test twice, with or without the diffusing filter placed in front of the eye. The CUT was repeated using the filter. The order of the colour vision tests under the two conditions was randomised across subjects with the exception of the CUT without the filter, which was always performed first as an inclusion test.

The 38-plates edition Ishihara test was used since it has been recommended for clinical use. Plates 1-17 should be seen by all individuals with normal colour vision while individuals with colour vision defects may fail to read the figures or read them incorrectly (plate one is a demonstration plate so will be seen by all). In the present study, only plates 1-17 were presented to the observers and no more than 3 seconds per plate was allowed as stated in the instructions.

For the D-15 test, the positions of the caps were mixed up by the researcher and the subjects were asked to arrange the caps so that they formed a gradual transition in colour. There was no time constrain although the subjects were advised to perform the tests as quickly as possible. The colour arrangement made by each subject was drawn in a circular pattern made up of 15 dots, each dot corresponding to a different hue.

For the CUT, there were no time constraints but it never took longer than 6 seconds per page which was adequate time according to the instructions. Scoring of the test was done using a score sheet which was provided within the test.

The tests were performed under conditions according to the manufacturers' instructions. All the experiments were carried out under conditions of natural daylight illumination next to a north facing window which are among the recommended viewing conditions for the tests used. Subjects were seated at a table and room lights were turned off. Room Illumination of the test area was always above 225 lx.
Intraocular straylight was measured with each subject once without and once with the filter using the C-Quant straylight meter. This device employs a psychophysical compensation comparison method devised by Van den Berg and co-authors and described in details elsewhere (e.g. 32). The technique has become a standard method for assessment of the intraocular straylight due to its rapidity and repeatability as confirmed in a variety of cohorts including a large number of subjects. 33, 34, 35

A short practice session with C-Quant was given prior to beginning the test to make sure that the subject understood the task. It has been shown that this procedure increases the reliability of the measurement. 36 The C-Quant Test lasted approximately 3 minutes. Each experimental session lasted approximately 45 min. No more than one visit was required to complete the experiments.

Results

All participants performed all three tests without any errors when the opacity filter was not in use. With the filter in its place, some mistakes were made, more markedly in the Ishihara test. 10 out of 30 observers made at least 1 mistake in Ishihara test with the filter, including 4 observers who made 3 mistakes each (Table 1). The most frequent mistakes were made on the plates 2, 6, 7 and 9 of the transformation design which the normal trichromats should read as 8, 5, 3 and 74. The performance on the CUT was also affected by the scattering filter with 3 participants making one mistake each and failing the desaturated plates. For the D-15 test, only one inversion of the caps was observed which was not qualified as a failure. Only one individual made mistakes in both Ishihara test and CUT. The rest of the participants made mistakes in only one test but had a faultless performance in the other two tests. If we simply compare the total number of mistakes across the tests then it appears that the Ishihara test is most affected by the induced straylight. However, the number of mistakes made on one colour test is not equivalent to the same number in another test due to differences in the scoring techniques, design, colour vision characteristics tested etc. In order to compare the performances across the tests, the number of observers who failed the Ishihara test were compared with the number of observers who failed the CUT. Figure 1 shows the number of failing observers on Ishihara test,
at different number of errors used, as a fail criterion with varying stringency. These values can be compared with the number of fails from CUT accepting a single error as a failure. The difference between the number of observers failing the two tests did not reach statistical significance (p > 0.05) at any of the assumed criteria using related-samples non-parametric McNemar's Test. However, if two errors are set as a fail criterion for CUT test, all observers would pass CUT test and the difference between failures in the Ishihara and the CUT test was statistically significant if we accept two errors (p < 0.031), or one error (p < 0.001) as a criterion for failing the Ishihara test. This is an illustration that the comparisons between tests are criterion-dependent.

It is important to know if the amount of the straylight in the eye with the filter caused the mistakes. The box-and-whiskers plot in Figure 2a shows the medians, the IQR, and the range of the straylight parameter measured by C-quant for each observer for baseline and also with the light-scattering filter.

The median of the baseline values is higher than the average for this age group (e.g. 19, 39) but lies within the normal range indicated by the grey band. The filter causes an increase of the straylight which lies above the range determined for 80-90 years old individuals (19,39). Previous population studies 39,40 have shown that the average log straylight parameter can be 1.4 or more after the age of 80 and can reach 2.0 or more in moderate or severe cataract. Since some baseline values lie above the normal range, it would be useful to consider the increase in the straylight caused by the filter relative to the baseline values or the straylight addition. 41 Figure 2b shows the histogram of the straylight addition, calculated as a difference between the log straylight parameter with and without the filter. According to the study of deWit et al.41, the straylight addition necessary to simulate cataract varies within the range 0.6 and 1.6. Figure 2b shows that our data lie within this range. Therefore, the filter used by us simulates the light scattering properties of cataract.

To determine if the errors made by each participant with the filter are related to the individual level of the intraocular straylight, we examined the relationship between the total number of errors made in Ishihara and the straylight level in the eye as qualified by the straylight parameter measured by C-quant for each individual (Figure 3). Despite the considerable interindividual variation, it is seen that people with
higher intraocular straylight level tend to make more mistakes. This tendency was statistically significant as shown by the Spearman’s rank-order correlation ($r_s = 0.393$, $p < 0.04$).

**Discussion**

The aim of the present investigation was to evaluate the effect that the induced straylight, similar to that typical of cataract, has on some commonly used colour vision tests. The results showed that the outcome of the D-15 arrangement test was not significantly affected but some errors were made on the desaturated part of the CUT. In addition, several individuals made mistakes on the Ishihara test with the filter and the number of mistakes was positively associated with the amount of induced straylight (Figure 3).

It has been well documented that normal trichromats can make as many as 6 misreading errors on the Ishihara plates. Our results showed that most of the plates read incorrectly contained numbers that the normal trichromats should read as 8, 5, 3 and 74. Previous studies have shown that these are the most frequently misread plates, for example 3 can be read as 8 or 5 or 6. The serifed design of the numbers in Ishihara test is often given as a cause for digit confusion or misreadings of individual plates caused by poor legibility. The errors such as digit confusions are classified as non-typical errors and differ from the typical errors made by colour deficient individuals. An example of this would be where a colour normal reads 46 rather than 45 on a vanishing design plate, where a true colour deficient would not see any number on this plate. This type of situation can confuse a poorly informed examiner and may result in an increase in the number of false positives, i.e. normal trichromats incorrectly identified as colour deficient would increase.

There are some reasons why induced straylight might affect the Ishihara test more than the other colour tests. Lakowski has published the spectrophotometric curves for several colour vision tests and it has been shown that the reflectance curves for both the figure and the background in the Ishihara test don’t have narrow spectral bands but rather show a complex shape with more than one maximum at different
wavelengths. The secondary peaks which are of lower height can become sub-threshold due to the increased straylight and it can be predicted that the hue and saturation of the retinal image would undergo a shift for both figure and background. The luminosity also will change due to the filter absorption. The colours in Ishihara plates lie close to the centre of the CIE diagram and the scattered light from the surrounding white areas will shift the colours even closer to the white point of the diagram. This is not the case with the pigments in D-15 which show broad band spectral characteristic with a single maximum. In addition, the caps in D-15 and CUT lie on black matt surface which minimizes the effect of the light scattered from the surrounding areas, while in the Ishihara test both figure and background are superimposed on white background and the scattered light will cause overlap of colours and a reduction of the colour contrast.

In addition, the more complex perceptual task in Ishihara involves separation of a figure from the background and this recognition requires large colour differences. The colours used in some plates are very close in terms of delta E colour difference units and can become even closer if the straylight is added to the retinal image. For example, in the plate containing the number 74, the colour differences in some of the dots in the digit 4 are very small and many colour normals read it as 71. This was one of the most common mistake in the present experiment with the introduction of the filter.

Ishihara plates have sensitivities and specificities close to 1, making it very efficient as a screening test. Although Ishihara errors increase with induced straylight our results showed that even a significant amount of straylight falling on the retina does not cause more than 3 individual errors, below the advised minimum fail criterion of 4 errors in order to maintain good sensitivity/specificity. We cannot directly compare the performance on Ishihara test and CUT tests since the differences in performance are criterion dependent as shown in the Results.

In the present study, we have used the 38 plate edition. The effect of the straylight could be different if the 24 plate, 14 - plate editions or subsets of them are used but it is likely that the same errors will be observed, since the most frequently mistaken plates are present in both editions. The present study concentrates on the straylight effect of cataract, although another effect of the cataractous lens is the reduction of
the retinal illuminance and change in the spectral transmission due to light absorption especially at the short wavelength part of the spectrum. In our previous study we did not find an effect of this factor on colour discrimination even at high levels of short wavelength light absorption. Similar result has been demonstrated in a study with yellow intraocular lenses. The reduced retinal illuminance is known to affect the performance in colour vision tests but at much lower levels (e.g. 45, 46) than the level resulting from our scattering filter which reduced the illuminance with 0.2 log units.

To conclude, the increased level of straylight in the eye had little effect on the overall outcome of three commonly used clinical colour vision test. The increased number of errors found on the Ishihara test could potentially cause some false positive screening fails. This could be important when using the test for helping advise individuals on their colour vision eligibility for some occupations, where the fail criterion is much more stringent than the normal limits of errors accepted for this test.

References


Captions

Figure 1
Number of observers failing the Ishihara test with the light-scattering filter as a function of the fail criterion set at 3, 2 or 1 errors. Dashed line – Number of observers failing CUT if one error is accepted as a failure.

Figure 2
(a) Box-and-whiskers plot showing the change in intraocular straylight as characterized by log straylight parameter without and with the light-scattering filter. The lines across the inside of each box represent the median values. The dashed and the dotted lines show the published average value of straylight for young healthy observers and for 80 years old observers (see the text). Grey band - 95 % confidence interval. (b) Frequency distribution of the differences between the log straylight parameter with and without the filter (straylight addition).

Figure 3
The total number of errors made in Ishihara test by each individual with the scattering filter vs the log straylight parameter s with the filter.
Figure 1.

Figure 2
Figure 3
Table I. The number of errors in Ishihara test made by young observers with normal colour vision under conditions of induced intraocular straylight.

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