Colour perception in pseudophakia

JEFFREY L. JAY, VIJAY B. GAUTAM, AND DONALD ALLAN

From the Tennent Institute of Ophthalmology, University of Glasgow

SUMMARY Minor differences in colour perception between pseudophakic, phakic, and spectacle aphakic eyes were identified by the Pickford-Nicholson anomaloscope and the Farnsworth-Munsell 100-hue test. The results suggest that pseudophakic eyes are more sensitive to red and less sensitive to blue than aphakic eyes corrected with spectacles. Spectrophotometer measurements reveal that the Rayner-Pearce posterior chamber intraocular lens used in this study transmits an evenly balanced colour spectrum, whereas an aphakic spectacle lens exhibits significant colour distortion, reducing the red and enhancing the blue transmission. This distortion may possibly be attributed to the increased chromatic aberration in the spectacle lens compared with the intraocular lens.

Many surgeons now consider intraocular lenses to be the best form of optical correction following cataract extraction. These lenses avoid the image magnification and distortion caused by spectacle lenses without introducing the disadvantages of contact lenses. There is, however, no published information about colour vision in pseudophakia, and the comments of some of our patients with intraocular lenses suggested that their colour perception might not be equivalent to the recognised changes in colour vision after cataract extraction when removal of the yellow-brown crystalline lens increases the appreciation of blue and produces an overall loss of colour warmth.[1][2]

This study was therefore carried out to determine the nature and cause of the possible differences in colour perception between pseudophakic and spectacle aphakic eyes.

Subjects and methods

The Pickford-Nicholson anomaloscope and the Farnsworth-Munsell 100-hue test were used to test colour perception in 3 groups of subjects: (i) a pseudophakic group who had undergone unilateral extracapsular lens extraction with insertion of a Rayner-Pearce posterior chamber intraocular lens made of CQ Perspex of +21·0 dioptre power in aqueous equivalent to +11·5 dioptres at the spectacle plane (mean age 70 years, range 48 to 87 years); (ii) one eye of each individual from a group of patients of

Correspondence to Dr Jeffrey L. Jay, Tennent Institute of Ophthalmology, University of Glasgow, 38 Church Street, Glasgow G11 6NT.

similar age distribution (mean age 72 years, range 46 to 90 years) with surgical aphakia corrected by spectacles; and (iii) a paired control group comprising the contralateral healthy phakic eyes of the patients in group (i). There were 30 eyes in each group, and they showed an almost identical distribution of visual acuities between 6/6 and 6/18 (Snellen).

Colour matching with the Pickford-Nicholson anomaloscope was performed with glass filters of dominant wavelengths 680 nm and 525 nm for the red-green test, 580 nm and 400 nm for the yellow-blue test, and 400 nm and 490 nm for the blue-green test. The mean mid match point and the matching range for each of the 3 tests was calculated for 5 attempts.

The 100-hue test was administered under illuminant C conditions in a Hubble Veri Vide cabinet by Aspinall's procedure,[3] and the graph of error scores was plotted according to the method suggested by Kinnear.[4] The total error scores and the error scores in the 4 individual boxes were calculated.

Results for both anomaloscope and the 100-hue test were analysed statistically for changes with age and for differences between the 3 groups by several of the standard facilities of the Minitab statistical package on the University of Glasgow ICL 2976 computer. The changes with age were tested by calculation of the Pearson product moment correlation coefficients, and the following nonparametric methods were used to compare the medians of the 3 groups. For unpaired results (pseudophakic versus spectacle aphakic and phakic versus spectacle aphakic) the Mann-Whitney 2-sample rank procedure was used, and for paired

data (pseudophakic versus phakic eyes) a single-sample sign test was performed. The results were also analysed to compare aphakic eyes corrected by glass spectacle lenses (19) with those corrected by Perspex spectacle lenses (11).

In an attempt to explain observed differences in colour perception between the groups the spectral transmission characteristics of CQ Perspex and crown glass were measured between 190 nm and 800 nm (band width 1 nm) with a Pye Unicam SP8 100 spectrophotometer. Transmission curves were obtained for both these materials in plano form between 1 mm and 5 mm in thickness, for glass and Perspex spectacle lenses of +6·0 dioptres and 10·5 dioptres, and for the Rayner-Pearce intraocular lens of +21·0 dioptres in aqueous equivalent to +11·5 dioptres in the spectacle plane. In addition, the linear chromatic aberration of the +10·5 dioptres spectacle lens and the Rayner-Pearce intraocular lens was measured directly on an optical bench.

Results

In both tests of colour vision all groups showed the expected deterioration in performance with increasing age,[5-7] but the results for each group fell within the normal range corrected for age. There were, however, significant differences between the groups, although the observed anomalies did not amount to pathological abnormalities in colour vision. Differences between those spectacle aphakics wearing glass lenses and those wearing Perspex lenses were negligible.

PICKFORD-NICHOLSON ANOMALOSCOPE (Fig. 1)
Red-green test. The mid match point was significantly different for each group. The pseudophakic group lay closest to green and the spectacle aphakic group closest to red (pseudophakic versus spectacle aphakic p=0·001, pseudophakic versus phakic p=0·012, phakic versus spectacle aphakic p=0·049). Fig. 1 demonstrates the mid match point for the phakic group between that of the pseudophakic and the spectacle aphakic groups.

Yellow-blue test. There were no significant differences between the 3 groups (pseudophakic versus spectacle aphakic p=0·607, pseudophakic versus phakic p=0·405, phakic versus spectacle aphakic p=0·491).

Blue-green test. There were significant differences between each group. The mid match point for pseudophakic eyes lay closest to blue and that for aphakics closest to green with the phakic group in an intermediate position (pseudophakic versus spectacle aphakic p=0·022, pseudophakic versus phakic p=0·0007, phakic versus spectacle aphakic p=0·043).
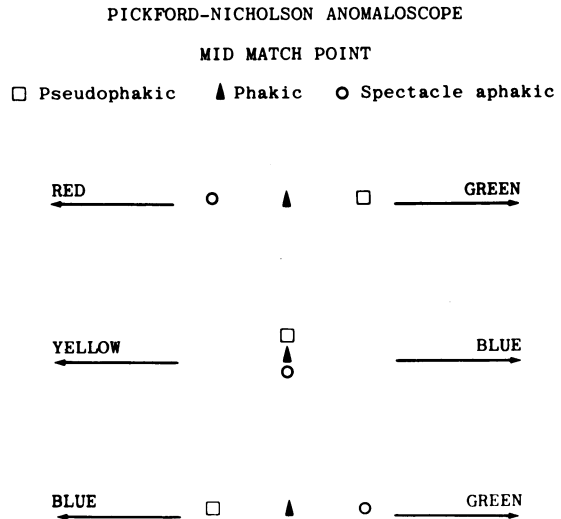

Fig. 1   *Diagram showing qualitative changes in colour discrimination on the Pickford-Nicholson anomaloscope. Compared with healthy phakic eyes the pseudophakic eyes require less red and more blue to make the appropriate match and the spectacle aphakics require more red and less blue.*

100-HUE TEST
Fig. 2 shows the composite 100-hue test diagram for each group with the group mean error score at each cap. No significant differences were found between the normal phakic eyes and the spectacle aphakics. The pseudophakic group did, however, show a significant difference compared with the other 2 groups with increased errors in box 3 (pseudophakic versus spectacle phakic p=0·038, pseudophakic versus phakic p=0·001), box 4 (pseudophakic versus spectacle aphakic p=0·003, pseudophakic versus phakic p=0·007), and total error score (pseudophakic versus spectacle aphakic p=0·009, pseudophakic versus phakic p=0·001). Inspection of Fig. 2 shows the source of increased error in pseudophakic eyes to arise in areas of confusion, suggesting anomalous red/green and blue/violet discrimination.

SPECTRAL TRANSMISSION CURVES
Fig. 3 shows the spectral transmission characteristics of plane CQ Perspex compared with plane crown glass. Perspex transmits a wider spectrum extending further into the shorter wavelengths below 350 nm, but the transmission at other wavelengths is identical. Increase in thickness of the plane materials between 1 mm and 5 mm has a negligible effect on the transmission of visible light, causing less than 1% reduction without distorting the spectral balance.

The curves for CQ Perspex in the form of a Rayner-Pearce posterior chamber lens and for glass spectacle
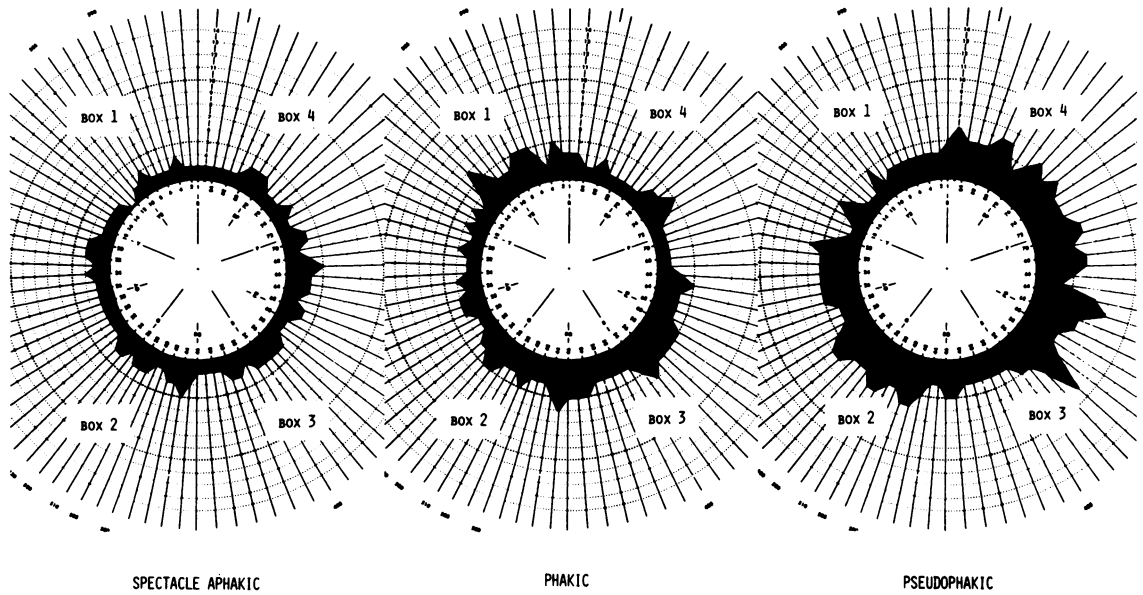
SPECTACLE APHAKIC   PHAKIC   PSEUDOPHAKIC

Fig. 2   Composite diagram of the group mean error scores at each cap for the Farnsworth-Munsell 100-hue test.

lenses of +6·0 dioptres and +10·5 dioptres are shown in Fig. 4. The same difference between glass and Perspex is evident at wavelengths shorter than 350 nm but there are also considerable differences in large areas of the spectrum between 350 nm and 800 nm.

The spectacle lens forms show reduced transmission of red and increased transmission of blue, and these distortions are more marked with lenses of increasing dioptric power. The same distortions can be increased for a specific power of lens by decentering it. Glass
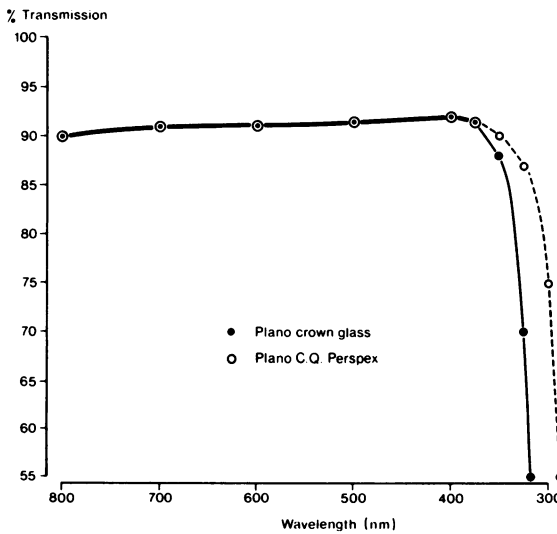

Fig. 3   Spectral transmission characteristics of Perspex and glass showing identical values in the visible spectrum. Increase in thickness of plane material between 1 mm and 5 mm reduces transmission by less than 1%.
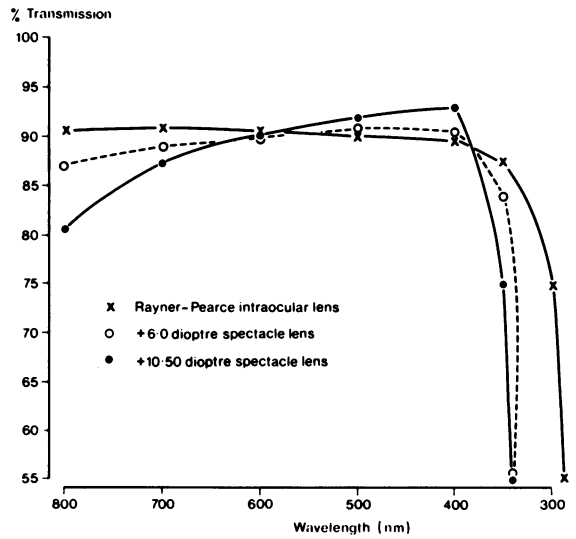
Fig. 4   Spectral transmission characteristics of intraocular and spectacle lenses. The differences are compatible with the observed differences in colour vision. The curves for spectacle lenses are similar for glass or Perspex of equivalent power.

and Perspex spectacle lenses of equivalent power displayed identical transmission characteristics in the visible spectrum.

CHROMATIC ABERRATION

Measurements on the optical bench showed the spectacle lens form to have linear chromatic aberration (Δf) 10 times greater than that of the intraocular lens in the separation of red (656 nm) and blue (486 nm). For the $+10.5$ dioptre spectacle lens $\Delta f \approx 10$ mm and for the intraocular lens $\Delta f \approx 1$ mm.

Discussion

This study suggests that, although each test group shows colour perception within the physiological range with respect to age, there are nevertheless real differences between the groups. Both the anomaloscope and the 100-hue test results can be interpreted as indicating that the pseudophakic eyes are more sensitive to red and less sensitive to blue than healthy phakic eyes and that the spectacle aphakics are conversely less sensitive to red and more sensitive to blue than the phakic eyes. Colour perception in pseudophakia has not previously been reported, but the differences between the phakic and spectacle aphakic groups in this study are qualitatively similar to those reported by Lakowski,[5] and as they remain after allowance is made for the transmission characteristics of the optical correction worn by the subject[8] they are probably due to the absorption characteristics of the crystalline lens.[9][10]

The observed differences in colour perception between pseudophakic and spectacle aphakic eyes are consistent with the spectral transmission curves for the respective types of lens (Fig. 4). Thus the enhanced appreciation of red in pseudophakia matches the increased transmission of red of the intraocular lens compared with the spectacle lens, and the enhanced appreciation of blue in spectacle aphakia matches the increased transmission of blue of the spectacle lens compared with the intraocular lens. These distortions of transmission in the spectacle lens are reduced with lower power lenses and enhanced by decentering the lens in the spectrophotometer. In contrast the trace for the intraocular lens is virtually free of distortion in colour transmission, and these differences may be related to the reduced chromatic aberration of the intraocular lens.

Our measurements demonstrate that the linear chromatic aberration for the intraocular lens is approximately one-tenth that for the aphakic spectacle lens, and this agrees with the theoretical calculation for the same lenses where Δf (linear chromatic aberration) for a $+10.5$ dioptre lens is 16.1 mm (glass) or 16.5 mm (Perspex), and Δf for the Rayner-Pearce

intraocular lens of $+21.0$ dioptres in aqueous is 2.0 mm. This discrepancy in chromatic aberration will be reduced when these lenses are included in the compound lens system of the aphakic eye, but as the displacement of the nodal point in the spectacle aphakic eye still produces an image magnification approximately 30% greater than the pseudophakic eye, the chromatic aberration will remain correspondingly greater in aphakia corrected with spectacles. Chromatic aberration has been shown to have an effect on threshold contrast sensitivity,[11] but its effects on colour vision remain uncertain. Wienke and Schwartz[12] summarise the limited work in this field, but their own measurements comparing spectacle lenses to contact lenses are inconclusive, as they are limited to 4 subjects with small errors of refraction. It is also conceivable that some unquantifiable spectral scatter or reflection in the artificial optical elements is responsible.

Whatever the origins of the differences in colour vision, they are unlikely to be caused by the transmission characteristics of the Perspex or glass, as at the thicknesses used for aphakic spectacle lenses and intraocular lenses the transmission of the visible spectrum is similar (Fig. 3). The discrepancy in transmission of ultraviolet between Perspex and glass is beyond the visible spectrum of even the aphakic eye, as these wavelengths are absorbed in the cornea.[13] This is therefore unlikely to contribute to the differences in colour perception in the clinical tests used in this study.

The higher error scores noted in the 100-hue test in the pseudophakic subjects should not be interpreted as deterioration in colour vision. This is a subjective test, arbitrarily constructed on a sequence of colours chosen to represent a series of just noticeable differences in 20 to 30 year olds with healthy crystalline lenses. Thus either increase or decrease in chromatic aberration will increase the error score because in either case the colour balance of the light reaching the retina will be different from that for which the test is standardised.

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