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The Application of Selected Broadband Red Filters for Red-Green Deficiencies*

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Abstract

This paper will review some of the various coloured filters used to aid chromatic discrimination for the red-green deficient. These range from hand-held rapid comparison devices, the so-called 'quick-specs', to daily-wear daytime spectacles or contact lenses.

Also included are a consideration of published reports, some preliminary observations with sample populations, and a discussion of the spectral transmission of selected materials as determined with the Zeiss DMR 21 spectrophotometer.

Abrégé

Ce travail passe en revue certains filtres utilisés pour rehausser la différenciation des couleurs chez les Daltonians souffrant d'une déficience rouge-verte. Ces aides varient d'appareils manuels permettant une comparaison rapide des couleurs à les lunettes ou lentilles de contact pour usage prolongé. Aussi il y a discussion de rapports déjà parus sur ces appareils, des résultats de l'utilisation par certaines populations selectionnées et de l'analyse de la transmission spectrale d'echantillons de materiaux au moyen du spectrophotometre DMR-21 de Zeiss.

Congenital red-green deficiencies have been reported to be present in 8% of the male population and ½% of the female population. Two to 3% of this 8½% are dichromats — 1% protanopic, 1% deuteranopic. Five to 6% are anomalous trichromats — 1% protanomalous, 5% deuteranomalous[1-6]. Statistically, this implies that approximately one million Canadians, or if the U.S. is considered, eleven million North Americans are red-green defective. Not included in these numbers are acquired colour deficiencies which are usually overlooked because the colour defect is secondary to a pathological condition.

Many methods of correction have been attempted throughout the years but as expected there have been no 'cures' for this genetically determined defect[3,5-8]. Proposed 'cures' were most prominent during the World War II years[7-11]. Enlistees were screened for colour deficien-

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cies and not permitted to join military service if a failure was recorded or found on colour vision screening tests. The following is a summary of the methods of correction tried:

- eye exercises[7]
- staring at red and green lights[9,10,12] (which were flashed and/or of high intensity)
- vitamins[4,7,10] (massive doses)
- injections of iodine[7,10]
- electrical stimulation of the eyeballs[7,8,10]
- education[4,9-12] (repeated testing, colour-naming and corrective instruction)
- special diets[4] (include favourable drugs and vitamins, remove unfavourable factors, e.g., excessive tobacco and alcohol)
- change in colour illuminant[7,8,10,13,14] (the effect was to increase the relative brightness of the colours within the spectral emission provided these correspond to the range of spectral reflection of the illuminated object)
- coloured filters[3,4,7,8,10,14-17]

The coloured filters used have been classified by Dr. Schmidt of the Indiana University School of Optometry into the following categories[7,14]:

- filters for successive comparison of brightness relationships
- filters which are used for an immediate evaluation of a change in chromatic experience
- miscellaneous designs.

The first two classifications can be easily demonstrated with the use of Kodak photographic filters — Wratten filter #25 (red)[18] and Colour Correction filter CC50M (magenta)[17] while viewing a colour representation of the C.I.E. chromaticity diagram, a pseudoisochromatic plate (PIP) screening test, or red and green test objects.

For the red filter long wavelengths are passed strongly (transmitted) resulting in an apparent brightening or lightening of any 'reds' being viewed. Short wavelengths are passed weakly (absorbed) causing viewed 'greens' to appear dimmer or darker[3,7,10,14,15,17,19,20]. With the magenta filter most of the blue-green to green wavelengths are absorbed while the 'reds' and 'blues' are transmitted[8,14,17]. This spectrally selective transmission and/or absorption results in an apparent change in the chromatic experience or brightness such that for either filter 'reds' and 'greens' may be discriminated or identified[14] (see plates 1-3). The miscellaneous classification accounts for those filters which ideally could not be placed into the other two types. However, even the red and magenta filters overlap in their classification to a certain degree because all three attributes of colour (hue, saturation, and brightness) appear to be affected.

Since the 1800's coloured filters to aid colour discrimination have been fabricated in various forms — monocle, loupe, lorgnette, spectacle or contact lens[8,10,14,15,18,19]. The first three are usually for quick observations whenever the patient desires to discriminate between 'reds' and 'greens'. The last two were designed to be worn for periods of time throughout the day providing continuous information in identifying colours.

Spectacle mounted filters have been the most diversified throughout the years. They have been presented in the following ways[8,10,14,16,17,18,19,21]:

- one spectacle lens red, the other green
- half of each spectacle lens red, the other half green
- red only (tinted lens, slip-over or clip-on)
- green only (tinted lens, slip-over or clip-on)
- vertical red and green strips mounted above and below a transparent center
- horizontal red and green strips mounted to the sides of a transparent center
- multi-faceted spectacle lens with individual facets of red, violet, blue, green, yellow and/or orange
- mosaic pattern spectacle lens with individual sectors of the primary colours

The contact lenses available are less numerous but have received much more press and interest[3,22-26]. The most widely distributed contact lens is Dr. Harry Zeltzer's X-Chrom[R*] (see plates 4-6). The only other PMMA red-tinted contact lens available in Canada is a ruby red (glassflex) lens from Dominion Contact Lens Laboratories Ltd., Toronto, Ontario(see plates 4 and 7). For both of these red contact lenses the practitioner's standard fitting philosophy[2,3,6,27] is suggested. Only spherical powers are fabricated thus any residual refractive error, presbyopic, or prismatic correction must be incorporated into an adjunct spectacle prescription[3,6,22,27]. Biomicroscopic evaluation of fit, centration and lag is stressed because fluorescein pattern analysis is too difficult if a clear trial lens is not available[3,27] (cobalt blue filtered light — red contact lens — fluorescent green tear film).

The most important part of the fitting evaluation is the screening of potential wearers. This should include a consideration of the patient's motivation and objectives. The device is inappropriate for those who desire it only to pass colour vision screening tests or falsify their results. However, it may be important to others; for example in agriculture to identify when fruits, vegetables, tobacco or other crops are ready for harvest. Other obvious applications are those occupations or avocations involved with photography, art, printing, cosmetics, textiles, etc. The screening procedure should also utilize either a hand-held filter (red spectacle trial lens[3,8,26-28] or X-Chrom screening paddle[16]), slip-over[16], or clip-on[18] to determine if

* The X-Chrom Corporation, Waltham, Massachusetts, U.S.A.; UCO Gordon Contact Lenses, Rochester, New York, U.S.A.; Corneal Contact Lens Co. Ltd., Calgary, Alberta; Plastic Contact Lens Company (Canada) Ltd., Toronto, Ontario

the red-green deficiency is aided by the presence of such a filter(see plates 8 and 9). These screening devices have a high spectral transmission of the long wavelengths and are quite effective in determining whether the practitioner should proceed with providing a contact lens or spectacle mounted filter to aid red-green discrimination.

In 'hard' (rigid) lens fabrication the dye or pigment is added during the polymerization procedure binding it such that the entire lens is tinted permanently.

For hydrogel lenses this procedure cannot be followed because as expected with the larger hydrogel design a clear periphery is desired overlying the limbus and sclera.

As a result, although the concept of a hydrogel red contact lens has had much appeal, its manufacture has been fraught with problems (see plates 11 and 12).

- the dye is not colourfast and results in its leaching out of the lens or into the periphery
- the dye may be poorly or unevenly distributed (nature of the lens matrix?)
- the colour discrimination effect is less than the X-chrom 'model'.

First generation hydrogel lens designs were the Freflex red* and Corneal red designs**(see plates 4,10 and 11). Freflex utilized a procedure where the lens is dyed in the hydrated state while Corneal's process dyes a dehydrated lens. Proprietary techniques and pending patents prevent elaboration on the specifics but the obvious goal is to fix the dye in the polymer matrix such that it wouldn't leach into the periphery or out of the lens(see plates 11 and 12).

These lenses also employed standard fitting philosophies with the only variation being that a specific pupil size is ordered relative to each patient.

The spectral transmittance curves of the four lenses described are shown in plate 13. All lenses have low transmittance throughout most of the spectrum. At the longer wavelengths, transmittance increases as expected, most notably for the X-chrom.

Theories or hypotheses on how this optical device enables a patient to discriminate colours that they previously couldn't can be summarized as:

- intensity (brightness) discrimination: The appearance of objects and their surround is compared before and after a filter is passed in front of one or both eyes. The two differently illuminated percepts are compared. Binocular vision is not necessary[3,19]
- retinal rivalry: A brightness comparison is made of dissimilar monocular impressions transmitted from one eye with a filter in place and the other eye without. The retinal images are alternately suppressed and a comparison can be made of the different inputs[1,3,4,14,18,20]
- stereoscopic lustre: The lustre phenomenon varies with hue, and colours can thus be discriminated by learning the lustre of 'reds' and 'greens' when observed with a monocularly worn filter. The fused lustre colour mixture of the two different monocular impressions depends on the hue, saturation and brightness of the objects and their surround[4,10,12, 14,15,18,20]
- isochromatic lines: Are the isochromatic lines shifted or altered in some way? A preliminary investigation indicated that the isochromatic (confusion) lines may be modified to some extent[29]

The effect could also be a combination of these phenomena. As a result it is obvious that this type of monocular correction in the form of a daily-wear spectacle or contact lens is contraindicated for patients who are monocular, have poor binocular development, or are usually exposed to reduced illumination levels[2,3,6,19,27]. The filter is typically prescribed to be worn over the non-dominant eye[2,3,6,10,26,27].

Numerous studies of the effect of red filters worn for periods of time by binocular patients are reported in the literature, most concentrating on the X-Chrom contact lens. These along with some observations at the University of Waterloo School of Optometry are summarized below:

Visual acuity — unchanged[13,19, 30-33] to 'minimal'(?) decrease[1,2,3,27,30,31,33] (20/25 - 20/40)

Binocular vision/stereopsis — unchanged or rapid adaptation[1,3,18,19,32,33] to decreased response[34]

Fixation disparity — none induced/no effect[3,19,32]

Aniseikonia — inconclusive - Ciuffreda[35] found the image size for the filtered eye (X-Chrom) of a 'normal' subject to be 0.2% smaller than the non-filtered fellow eye

Pulfrich stereophenomenon — observed[1,3,19, 29,33,35] – some reports suggest a reorientation or adaptation of the visual system[3,35,36] occurs while others demonstrate a decreased response[32] or very little adaptation[33]

Distortions of speed, distance and size — When a filter is placed over one eye the visual latency results in moving objects viewed on that side appearing to be closer, smaller and moving slower than they actually are. The opposite is apparent for the non-filtered side. Though discussed in the literature[14,20,37,38] this phenomenon has not been investigated with red filters.

Performance on colour vision screening tests — Mixed reports fail to totally support or not support claims on the ability of red-green defectives to

Text Cont'd on p. 56

* Freflex Canada Contact Lenses, Toronto, Ontario
** Corneal Contact Lens Co. Ltd., Calgary, Alberta

Description of Colour Photographs

1. Plate 14 of the Ishihara pseudoisochromatic series of plates designed as a test for colour blindness.
2. Ishihara plate 14 photographed with a Kodak #25 Wratten filter. Long wavelengths are transmitted resulting in an apparent brightening or lightening of 'reds' while absorbed short wavelengths cause 'greens' to appear dimmer or darker.[14]
3. Ishihara plate 14 photographed with a Kodak CC50M colour correction filter. A chromatic shift to yellow or a lightening is expected if red is present while a chromatic shift to gray or a darkening occurs if green is present[14].
4. Samples of red contact lenses. From left to right: X-Chrom, Freflex red and Ruby red.
5. Monocular view of a subject wearing An X-Chrom contact lens.
6. Binocular view of a subject wearing an X-Chrom contact lens.
7. Binocular view of a subject wearing a ruby red contact lens.
8. Red spectacle trial lens common to most trial sets.
9. An X-Chrom screening paddle available from the X-Chrom Corporation, 57 Grant St., Waltham, Massachusetts, U.S.A. 02154.
10. Binocular view of a subject wearing a Freflex red contact lens.
11. A 12 month old Corneal red hydrogel contact lens when the dye has leached into the periphery and is poorly distributed centrally.
12. A 12 month old Freflex red hydrogel contact lens from which some of the dye has leached out of the lens.
13. Spectral transmittance of represented lenses (X-Chrom/-Dominion Ruby Red/Freflex Red/Corneal Red) as determined with the Zeiss DMR 21 spectrophotometer. These transmittance values should be adjusted 3-5% higher to compensate for the reflectance difference when the lens is worn on the eye vs. measurements in the air with the spectrophotometer.
14. Plate 2 of the Ishihara pseudoisochromatic (colour confusion) test. The normal trichromat response is the number 8. Persons with red-green deficiencies report a 3 or cannot read a number[43].
15. Plate 2 of the Ishihara pseudoisochromatic test photographed with a Kodak #25 Wratten filter.
16. Plate 25 of the Ishihara pseudoisochromatic test. This plate is one of those included to classify the degree of the defect. The normal trichromat response is the number 96. Persons with protanopia and strong protanomalia report only the 6 or if mild protanomalia both numerals but the 6 is clearer. In the case of deuteranopia and strong deuteranomalia only the 9 is reported or if mild deuteranomalia both numerals but the 9 is clearer[43].
17. Plate 25 of the Ishihara pseudoisochromatic test photographed with a Kodak #25 Wratten filter.
18. Plate 13 of the AO H-R-R pseudoisochromatic (saturation discrimination) plates. This plate is one of those included to classify the defect as medium. A circle and triangle are reported by the normal trichromat while the protan reports only a circle and the deutan ony a triangle.
19. Plate 13 of the AO H-R-R pseudoisochromatic plate photographed with a Kodak #25 Wratten filter.
20. Plate 15 of the AO H-R-R pseudosiochromatic plates. This plate is one of those included to classify the defect as strong. An X and circle are reported by the normal trichromat while the protan reports only an X and the deutan only a circle.
21. Plate 15 of the AO H-R-R pseudoisochromatic plates photographed with a Kodak #25 Wratten filter.
22. Farnsworth Dichotomous or Panel D-15 (colour confusion) test.
23. Farnsworth Dichotomous or Panel D-15 test photographed with a Kodak #25 Wratten filter.
24. Farnsworth-Munsell 100-Hue (hue discrimination) test.
25. Farnsworth-Munsell 100-Hue test photographed with a Kodak #25 Wratten filter.
26. Farnsworth F2 Pseudoisochromatic Plate. The normal trichromat reports two overlapping diamonds or squares with the yellow-green one appearing clearer or brighter than the blue one. Red-green defectives only report the yellow-green square[7,44].
27. Fransworth F2 Pseudoisochromatic Plate photographed with a Kodak #25 Wratten filter.
28. Holmgren Wool (colour confusion) test Set No. 235. Seventy-two small skeins are matched by their resemblance (lighter or darker shades) to 3 large control skeins (green/-lavender/red). Confusion colours are present so that a poor red-green discriminator is easily identified.
29. Holmgren Wool test Set No. 235 photographed with a Kodak #25 Wratten filter.
30. Plate 3 of the City University Colour Vision (colour confusion) test. Each plate consists of 5 coloured dots on a matte black background. The subject is instructed to select from the 4 surrounding dots the one that most resembles the central dot. The normal trichromat selects the top one while the protan selects the bottom dot and the deutan the dot to the right[45].
31. Plate 3 of the City University Colour Vision test photographed with a Kodak #25 Wratten filter.
32. Suggested spectral transmittance of protective devices for 'RP' patients[40].
33. Samples of Ciba's "first generation" of red hydrogel contact lenses.

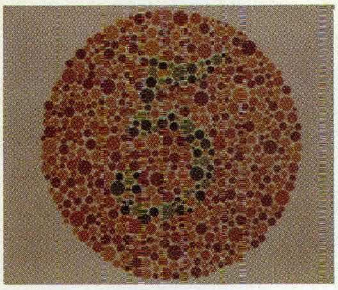


Fig. 1

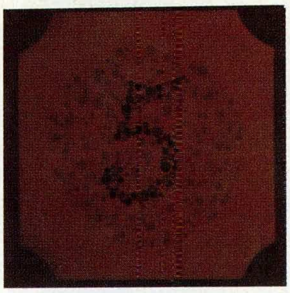


Fig. 2

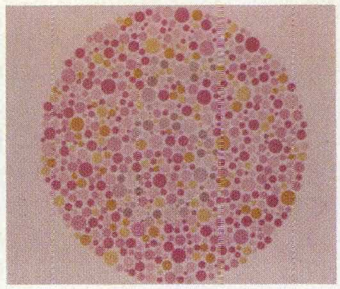


Fig. 3

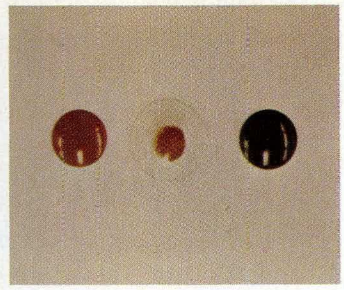


Fig. 4

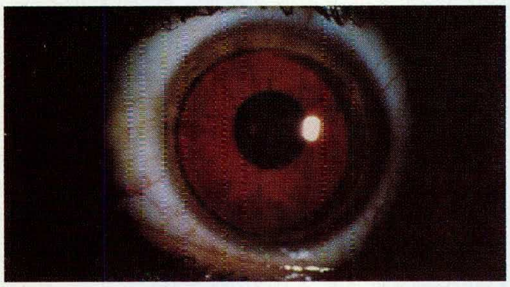


Fig. 5

Fig. 6

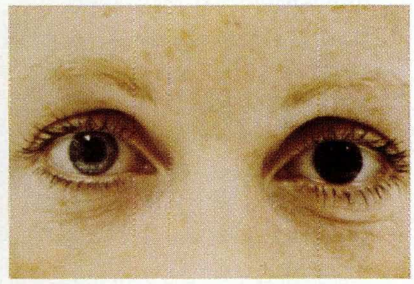


Fig. 7

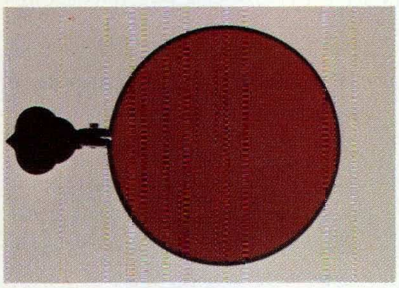


Fig. 8

Fig. 9

Fig. 10

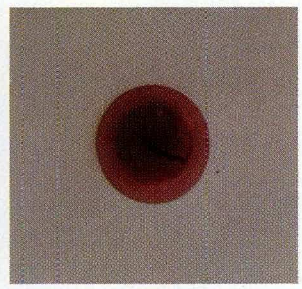


Fig. 11

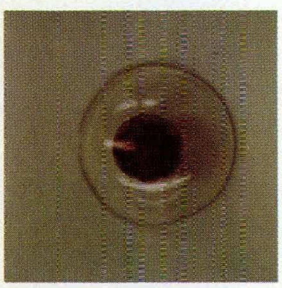


Fig. 12

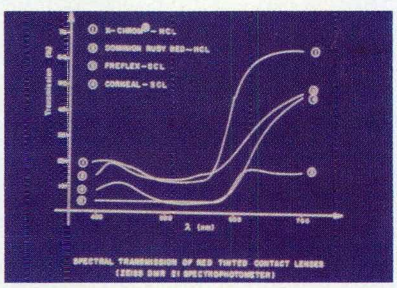


Fig. 13

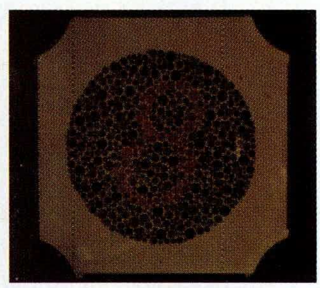


Fig. 14

Fig. 15

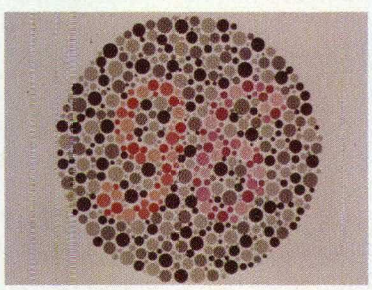
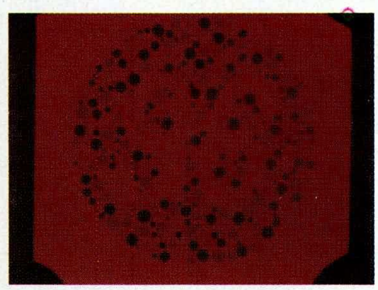


Fig. 16



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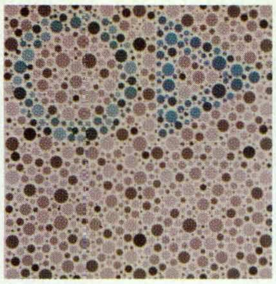
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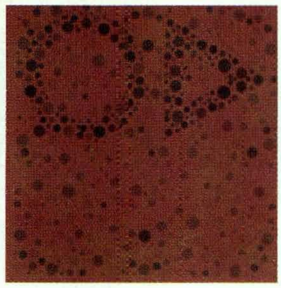


Fig. 19

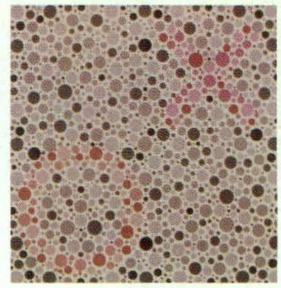


Fig. 20

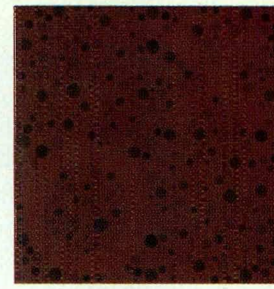
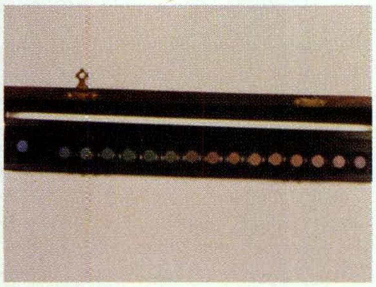


Fig. 21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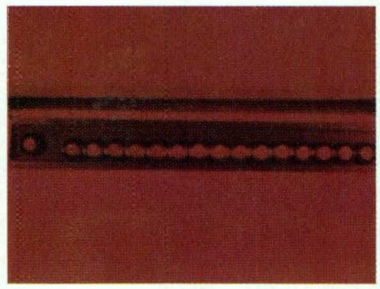
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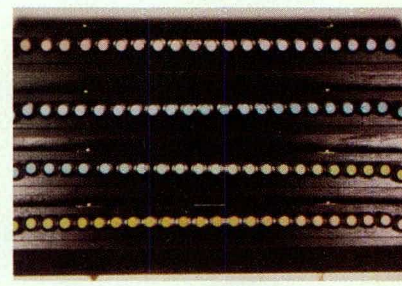
Fig. 24

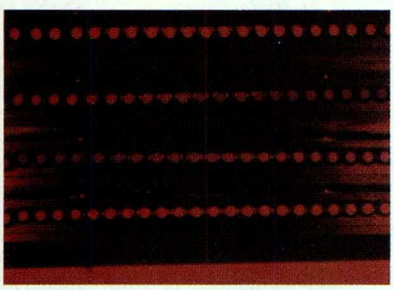
Fig. 25

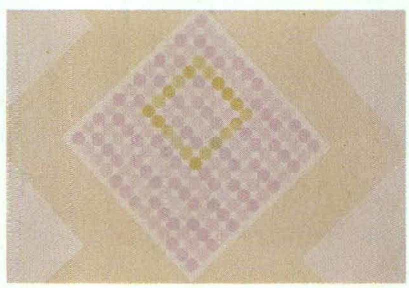
Fig. 26

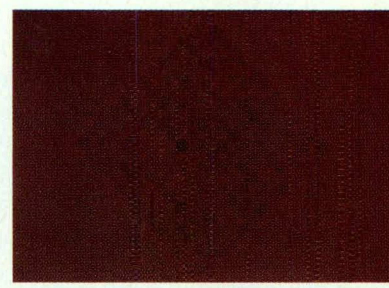
Fig. 27


Fig. 28

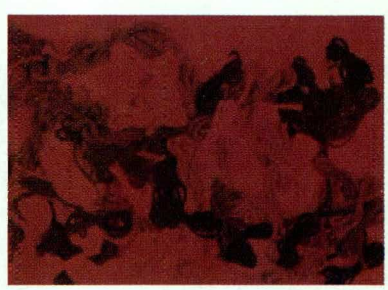
Fig. 29

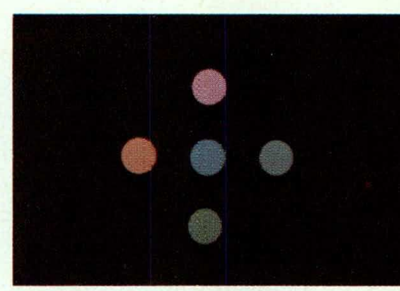
Fig. 30

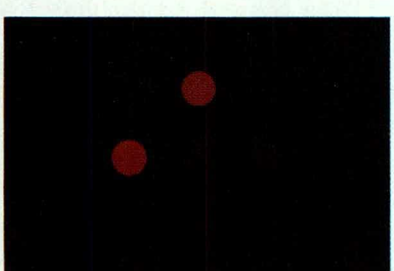
Fig. 31

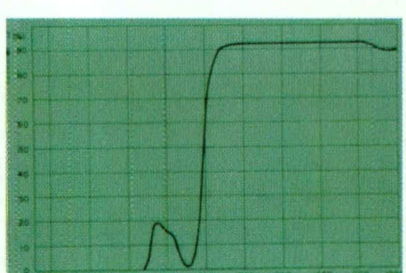
Fig. 32

Fig. 33

discriminate or identify previously confused colours[2,3,10,14,16,18, 19,26,28,30-34]. In summary, the overall performance on pseudoisochromatic plate tests usually demonstrated some improvement (fewer mistakes or reclassification to a less severe defect) whereas results on hue discrimination or colour confusion tests and lantern tests demonstrated little improvement, no change, or a poorer performance. In essence, the results seem to indicate no real increase in the number of colours or shades a red-green defective can discriminate.

The effect of a red filter when viewing typical colour discrimination tests is as expected. Recall that for the wavelengths transmitted viewed objects of comparable colours will appear brighter or lighter. For wavelengths absorbed, objects of comparable colours will become dimmer or darker. Readers are asked to judge for themselves by inspecting plates 14 - 31 what happens when one views the Ishihara, AO-HRR, D-15, 100 Hue, F2, Holmgren yarn, and City University colour vision screening tests with a red filter. Are the confused colours easier to sort out? It can be readily seen that some changes do occur and if these are put into a proper perspective the following statement seems appropriate — any change in colour vision may be interpreted by a patient as an improvement when, in fact, there is no improvement in colour discrimination.

A review of the above observations and studies indicates the need for further investigation, more specifically, a scientific study of the effect of red filters on the isochromatic lines, contrast sensitivity function, stereo acuity, stereoscopic thresholds, chromatic aberration and dissimilar retinal luminances, i.e. Pulfrich stereophenomenon, distortions of speed, distance, and size, etc.

Just as red hydrogel lenses were starting to look promising both companies due to other priorities decided to shelve their development. Fortunately, Ciba Vision Care has developed a "new generation of dyes and a non-leachable process"*. Their interest in red lenses was initiated by reports of using red lenses as an aid in the treatment of pigmentary retinal degeneration (retinitis pigmentosa)[39-42]. The hypothesis is that the rods' rhodopsin breakdown-photoresynthesis process is defective because of rhodopsin's exaggerated sensitivity to normal levels of illumination[42]. To decelerate or even possibly halt the degenerative process a filter is suggested which will reduce the overall illumination providing maximum rod protection while maintaining adequate colour vision and visual acuity[40,42]. Because the rods are extremely sensitive to wavelengths less than 540 nm Adrian and Schmidt suggest a filter that provides no transmission less than 540 nm, minimal transmission from 540-640 nm for colour vision and maximum transmission at the red end of the spectrum[40](see plate 32). This spectral transmission being high in the long wavelengths may have application as a red filter for red-green deficients but more importantly Ciba hopes they will be able to match any transmission curve thereby providing any shade red lens desired(see plate 33).

* Personal communication from Mr. Syl Ghirardi, Marketing Director, Ciba Vision Care Inc., Mississauga, Ontario

In conclusion, I wish to stress that the purpose of this paper has not been to advocate or discourage the use of red filters for red-green deficiencies but rather to supply information to those practitioners interested in them.

Note: Subsequent to this initial presentation Veracon Inc. of Sherbrooke, Quebec has informed the author that they will provide upon request a ruby red tinted rigid (PMMA) contact lens which can be used as an aid for red-green colour discrimination. The spectral transmittance as determined with the Zeiss DMR 21 spectrophotometer of a sample lens was approximately 35% for the long wavelengths of the visible spectrum.

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Erratum

There were two errors in the article *Chemical Components of Contact Lens Solutions*, by V.J. Lum and W.M. Lyle, published in the December, 1981 C.J.O.:

i) P.143, Table 2: Soaking solutions should read 5 ml/day instead of 5 ml/week.

ii) P.147: Soft Lens Comfort Drops are made by Barnes-Hind, and not by Alcon/BP as shown.