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Effect of Chromatic Dispersion of a Lens on Visual Acuity

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ABSTRACT

Materials with a high refractive index have a considerable level of chromatic dispersion which, around the periphery of corrective lenses, may affect the wearer's visual acuity. By measuring visual acuity through prisms of increasing chromatic power we have established the relation between chromatic power and visual acuity. The maximum chromatic dispersion of materials useable in ophthalmic optics can be deduced from these results.

Key Words: chromatic dispersion, optical constringence, ophthalmic lens, visual acuity

The use of high refractive index materials has many advantages for the production of lenses (thinner, flatter, lighter lenses) but generally leads to undesirable lateral chromatic aberration. Most often, high refractive index materials have low optical constringence or coefficient of mean dispersion, and therefore high dispersive power. This causes an increase in chromatic aberrations in ophthalmic lenses that the wearer perceives laterally as iridescence at all the contours. The problems are then to determine the amount of chromatic aberration a patient can accept in his lens and to deduce the minimum value of the optical constringence of the material that can be used in manufacturing lenses.

The chromatic aberration is perceived only at the sides of the lenses because it depends both on the optical constringence of the material and on the prismatic deviation caused by the lens. This deviation depends on the eccentricity and the power of the lens. The iridescence at the contours will be perceived by the wearer with a degree of eccentricity which gets lower as the power of the ophthalmic lens increases and the constringence of the material diminishes.

When the wearer turns his eyes to one side, he is subjected to transverse chromatic aberration, which perturbs the formation of the retinal images. This chromatic aberration spoils perception and, therefore, recognition of details in foveal vision and is also perceived in peripheral vision, although to a lesser degree. Because visual acuity is one means of assessing foveal vision, it has been chosen for evaluating the effect of chromatic aberration on vision; we have measured the loss of visual acuity caused by plano prisms having increasing chromatic aberrations.

The chromatic dispersion of any material is characterized usually by its coefficient of mean dispersion called optical constringence or Abbe's number.

$$\nu_e = \frac{(Ne - 1)}{(Nf' - Nc')}$$

Ne is the refractive index of the material

for the wavelength

λ_e = 546.07 nm (mercury green)

$N_{f'}$ is the index for

$\lambda_{f'}$ = 479.99 nm (cadmium blue)

and $N_{c'}$ is the index for

$\lambda_{c'}$ = 643.85 nm (cadmium red)

The optical constringence ν_e is used especially for ophthalmic lenses and is defined with different wavelengths from those of the standard optical constringence ν_d.

The optical constringence, which is inversely proportional to the dispersive power of the material, is equal to the mean deviation of an incident polychromatic beam divided by the angle of chromatic dispersion. It is determined by the deviation undergone by a monochromatic light ray of wavelength 546.07 nm (λ_e) and the difference between deviations undergone by two

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rays of respective wavelengths 479.99 nm ($\lambda_{f'}$) and 643.85 nm ($\lambda_{c'}$). The constringence is thus independent of the incident beam deviation and characterizes the mean chromatism of the material.

The constringence value is adequate for comparing different materials but cannot be used easily in comparing chromatic aberration and visual acuity because it does not characterize the actual chromatic effect. Therefore we prefer to use the chromatic power:

$$CP = \frac{PE}{\nu_e}$$

PE is the prismatic effect and ν_e the optical constringence, which characterizes the magnitude of the chromatic fringe in prism diopters (Δ or centimeter/meter).

METHODS

A series of prisms of increasing chromatic power was selected among plano prisms of various angles and optical constringences. Their characteristics are listed in Table 1.

The visual acuity of 8 subjects was measured throughout the 12 prisms selected. The measurements were made using a scale of acuity of Landolt rings projected from slides and a psychometric method to determine the threshold of visual acuity. The scale was composed of 19 logarithmically graduated levels of decimal acuity and the rings were presented separately in the four orientations: up, down, right, and left. The psychometric method, operated by a microcomputer, was adaptative and consisted of attempting to narrow the acuity threshold within two consecutive levels of the scale used. The threshold was defined as 62.5% correct responses. For each measurement, presentations of Landolt rings continued until performance showed that one had passed 15 times from below to above the apparent threshold (or vice versa), giving the desired percentage of 62.5% of correct responses. Final visual acuity was interpolated between the two levels that were adjacent to the final threshold. The contrast of the rings was 0.9, the background luminance on which they were presented was 380 cd/m^2 (as measured with a Pritchard light meter), and the ambient illumination of the room was 175 to 200 lux.

For visual acuity measurement, each subject was seated 5 m from the projection screen and wore a trial frame with his distance correction and the prism to be studied in front of one eye. The other eye was occluded. Each prism had a diaphragm of 7.5 mm on its front surface and was positioned in the frame so that the angle of incidence of the visual axis of the patient was normal to the rear surface. This limited aberrations linked to the angle of incidence on the prism, principally oblique astigmatism and coma, and isolated the effects of chromatic aberration. The base of the prism was also inclined at 45° supero-temporal, i.e., 135° TABO (standard axis notation) on a right eye or 45° TABO on a left eye. The choice of the prism orientation was to imitate the correction of myopes for whom these high refractive index lenses are mainly intended.

Eight subjects took part in these experiments (4 females and 4 males), their average age was 27 years, and all were considered as emmetropes: the maximum spherical ametropia was 0.50 D and maximum astigmatism was 0.75 D. The visual acuity of each subject was measured three times through each of the prisms studied. At the beginning and at the end of each series of measurements, there was a measurement of the maximum visual acuity of the subjects through a placebo plano lens with a 7.5-mm diaphragm, like that of the prisms.

TABLE 1. Characteristics of the prisms selected.

No.	Reference Material: Sovirel/International	Refractive Index, Ne	Constringence, ν_e	Prismatic Effect, Δ (cm/m)	Chromatic Power, CP (cm/m)
1	B2952/529-518	1.5314	51.59	3.5	0.068
2	C2036/620-363	1.6241	36.03	3.5	0.097
3	B2952/529-518	1.5314	51.59	7	0.135
4	D0141/702-411	1.7059	40.82	7	0.170
5	B2952/529-518	1.5314	51.59	10.5	0.204
6	D4445/744/448	1.7479	44.55	10.5	0.236
7	B2952/529-518	1.5314	51.59	14	0.272
8	D4445/744-448	1.7479	44.45	14	0.316
9	D0141/702-411	1.7059	40.82	14	0.344
10	C2036/620-363	1.6241	36.03	14	0.389
11	C8931/689-312	1.6943	30.97	14	0.453
12	E0525/805-255	1.8125	25.30	14	0.570

RESULTS AND DISCUSSION

Fig. 1 shows the mean results obtained from our eight subjects. The abscissa shows the chromatic power in prism diopters (CP) and the ordinate gives the relative visual acuity (RVA); RVA = Measured VA/Maximum VA. Bars show 1 SD on either side of the mean.

The drop in relative visual acuity increases linearly with the chromatic power. The calculation of the regression-correlation line leads to the following equation:

$$RVA = -1.246 \times CP + 1.016$$

This shows that there is excellent correlation between the chromatic power and the RVA: $r = 0.99$ with $p < 0.001$.

Statistical analysis of these results using the Student and Wilcoxon tests (paired samples) shows that, for these eight subjects, the chromatic aberration significantly affects the visual acuity when it reaches a value of about 0.1 Δ (the equivalent of a 6 Δ crown glass prism). This result is in good agreement with the hypothesis made by Morgan[1] in the absence of experimental data, where he assumed that transverse chromatic aberration significantly interferes with sharpness of vision when it is greater than 0.1 Δ. Jalie[2] also uses the value of 0.1 Δ as a tolerance for transverse chromatism in bifocal lenses. Thus, the effect of chromatic aberration on visual acuity can be considered negligible below the value of 0.1 Δ.

The relation established between relative visual acuity and chromatic power cannot be used readily in this form, inasmuch as the chromatic power depends simultaneously on the optical constringence, and on the prismatic effect. This relation can also be expressed by:

$$RVA = -1.246 \times (PE/\nu_e) + 1.016 \qquad (1)$$

where PE is the prismatic effect and ν_e the optical constringence of the material. Fig. 2 shows the relative visual acuity as a function of prismatic effect and for different values of optical constringence.

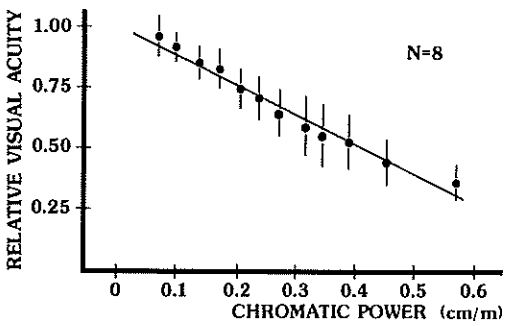

FIG. 1. Mean relative visual acuity of eight subjects as a function of chromatic power (expressed in prism diopters or centimeters/meter). Bars show 1 SD on either side of the mean.

No strict conclusion can be drawn from these results concerning the maximum acceptable chromatic power in an optical correction, and no strict decision can be taken on the optical constringence of the material to be used.

But let us consider a 10 D myope looking at an object at an eccentricity of 9° where the prismatic effect is about 4 Δ. Fig. 2 and equation 1 show that for the current constringence values of 60 and 40 the myope's visual acuity would be preserved at 93.3 and 89.1% respectively. For the unusual constringence of 30, 85.0% of the

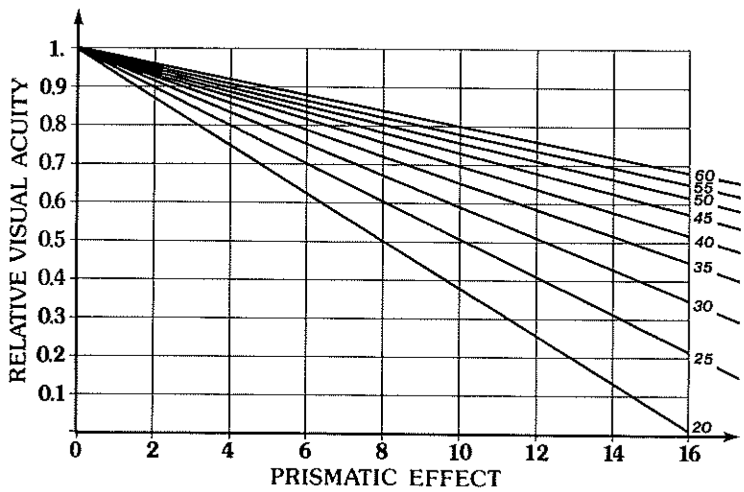

FIG. 2. Relative visual acuity as a function of the prismatic effect (in prism diopters or centimeters/meter) and for different values of the optical constringence.

visual acuity would be preserved. Our 10 D myope would, at an eccentricity of 9°, be exposed to a chromatic power of 0.13, which would cause his relative visual acuity to drop from 1.0 to 0.85 but would retain his maximum visual acuity in the center of the lens.

Ophthalmic lenses are usually fitted so that the optical centers are 3 to 4 mm below the center of the pupil.[3] In the primary position, the eye is, thus, subjected to a small amount of chromatic aberration. Because most vertical eye movements are downward, the eye utilizes the area around the optical center and is subjected to a minimum of chromatic aberration.

It is worth pointing out that no disturbing chromatic aberrations should be present in the central area of the ophthalmic lens because it is used by the patient for foveal vision where the acuity has to be maximum. Thus, the coordination of the patient's eye and head movements is of great importance because it determines the field of gaze the patient normally uses and therefore defines the optical zone of the lens, which should be clear of any chromatic aberrations. Afanador and Aitsebaomo[4] measured a mean range of eye movement of about 13° (±7.5°) on 40 prepresbyopic and presbyopic subjects. Gresty[5] found that for 14° peripheral viewing a great deal of head movement occurred. Thus the peripheral parts of ophthalmic lenses appear to be utilized rarely by the eyes during normal use of glasses.

Our results show that material with lower constringences than those used generally could be acceptable for the manufacture of ophthalmic lenses. This is confirmed by the lack of complaints from patients wearing such lenses.

Furthermore, the fact that the wearers can accept low constringence is supported by the ability of the visual system to adapt to chromatic dispersion. Held[6] reviewed this phenomenon. Color-fringe adaptation has been observed in patients wearing lenses or prisms producing appreciable chromatic dispersion; the iridescence of contours, which is very noticeable on the first day the lenses are worn, is no longer observed by the wearer after a few weeks.

CONCLUSION

Our measurements of visual acuity through prisms of increasing power reveal the effect of chromatic aberration on visual acuity. The relation established between chromatic power and visual acuity shows the influence that the constringence of ophthalmic lens materials may have on the wearer's visual acuity. It appears that aberrations linked to the chromatic dispersion of lenses are less important than expected. We conclude that materials with lower constringences could be used for the design of ophthalmic lenses. This would allow manufacturers to use new optical materials and produce thinner, flatter, and lighter lenses, which would be more comfortable for the wearers.

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