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COLOUR AND LUMINANCE VISION IN HUMAN OPTIC NEURITIS

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SUMMARY

A comparison of sensitivities to chromatic and luminance stimuli has been carried out in patients with a past history of optic neuritis. Patients were selected with differing degrees of stable residual visual deficits, and with marked interocular differences in sensitivity. Threshold contrast sensitivity was measured to sinusoidal luminance gratings and to chromatic red/green and blue/yellow gratings, all with the same spatial frequency of 1 cycle per degree. A psychophysical criterion was used to ensure that detection of the chromatic grating was determined only by its colour differences. When the difference between the sensitivity to luminance and chromatic gratings was compared between the more and less severely affected eyes of each subject, it was found that, overall, chromatic sensitivity was more severely impaired than luminance sensitivity in the disorder. Sensitivities to the red/green and the blue/yellow stimuli were found to be affected equally.

INTRODUCTION

Abnormalities of colour vision are frequently reported by patients with optic nerve disease. In the earliest clear description of cases of optic neuritis, Nettleship (1884) noted that many patients complained of altered colour vision, 'the hand looking, for example, as if covered by a brownish glove'. He also found that the field of vision might be full to a white target but contracted to red and that 'where the colour was best seen, it appeared much duller than in the same part of the field in the other eye'. He described cases who confused 'greens and greys' and others with 'red/green blindness'. In discussing the frequent occurrence of a central scotoma in retrobulbar neuritis Gunn and Buzzard (1897) pointed out that an absolute scotoma is frequently 'surrounded by an area in which colours are not recognised, the perception of red and green being chiefly involved'. Gunn and Buzzard considered the localized loss of red and green perception to be the most delicate test of interference with optic nerve function.

The introduction of pseudoisochromatic plates into neuro-ophthalmic practice (Sloan, 1942) as a 'refined test of central vision' further emphasized the usefulness of colour vision testing as an adjunct to visual acuity and visual field examination in optic nerve disease. The sensitivity of colour vision abnormalities in providing evidence of a previous attack of optic neuritis can be very high. Lynn (1959) and

Rosen (1965) found 84 and 95 per cent, respectively, of such cases to be abnormal using pseudoisochromatic plates and Griffin and Wray (1978) found 30 eyes with a past history of optic neuritis all to have abnormally high error scores on the Farnsworth-Munsell 100 hue test. Many of Griffin and Wray's cases had normal visual acuity and all were 6/12 or better; a few had cortical visual evoked potentials of normal latency.

The early suggestion that red/green colour vision might be preferentially impaired in optic nerve disease was pursued by Köllner (1912). Köllner found that, if patients were required to name the colour of pigmented objects used to examine the visual field, in choroidoretinal disease there was a selective contraction of the isopter for blue objects whereas in optic nerve disease the isopters for red and green were more affected.

A number of more recent investigators have attempted to determine whether or not there is a selective effect on red/green colour mechanisms in optic neuritis. Using tests of hue discrimination such as, or similar to, the Farnsworth-Munsell 100 hue test, most authors report a predominantly red/green defect both acutely and following recovery of vision (*see* Marré, 1973 and Chisolm, 1979). There is some inconsistency, however, and blue/yellow defects have also been reported (Ohta, 1970). Certainly it seems from the results that the tendency for errors to be more severe in the red/green axis is a small one and is not found in all cases.

In recent years attention has also turned to the question of whether luminance (brightness) and colour vision may be selectively affected in demyelinating optic nerve disease. Hitherto, the notion that chromatic mechanisms may be more severely affected than luminance mechanisms has arisen from the clinical observations, spanning the last century, of the great sensitivity of tests involving the use of coloured stimuli in providing evidence of disordered optic nerve function. However, the stimuli used in these tests contain both luminance and colour differences and it is impossible to know whether, for example, substituting a red target for a white one reveals a greater visual deficit because of its colour difference from the background, or because it has a lower luminance contrast. Similarly, when comparing sensitivity to two targets of different hue (say blue and red) it is very difficult to ensure that there is not also a brightness (luminance) difference between the two targets, which may confound the results.

The task of designing experiments to test independently luminance and chromatic mechanisms is not an easy one. A number of clinical studies have used experimental paradigms which exploit the different temporal and/or spatial properties of the luminance and chromatic mechanisms (Alvarez and King-Smith, 1984; Foster *et al.*, 1983). Others have compared thresholds for the detection of a chromatic change from white, with thresholds for a change in luminance (Fallowfield and Krauskopf, 1984). The results of these studies conflict, and problems may arise if stimuli used to test colour vision differ in their spatial or temporal properties from those used to test luminance vision (*see* Discussion).

In our present experiments a stimulus is used which is a sinusoidal grating

consisting of alternating bars of either red and green, or blue and yellow. The stimulus is arranged so that there are no brightness differences between the two colours in the grating, which therefore cannot be detected by visual mechanisms sensitive to luminance contrast but only by mechanisms sensitive to colour contrast. The method used to establish that the grating is detected by chromatic mechanisms alone can be applied to any spatial or temporal arrangements of the stimulus. Furthermore, this luminance match is established separately for each eye of each subject. We have chosen two chromatic stimuli which are maximally detected by either the red/green or blue/yellow chromatic pathways in the visual system. All the patients have sustained one or more attacks of optic neuritis in the past and have been left with a stable residual deficit. The acute phase of the condition was not studied.

METHODS

Stimuli and Apparatus

A red/green or a blue/yellow sinusoidal chromatic grating, with a spatial frequency of 1 cycle per degree (cpd) and sinusoidally phase reversed at 0.5 Hz was produced by displaying two gratings varying in luminance, each on specially constructed oscilloscope screens with white (P4) phosphors. A diagram of the apparatus is shown on the left side of fig. 1. A fuller description of the stimuli and methods is given elsewhere (Mullen, 1985).

The two screens, placed at right angles, are each viewed through a narrow band interference filter. Interference filters with peak wavelength transmissions at 526 nm and 602 nm are used in the red/green grating, and 470 nm and 577 nm for the blue/yellow grating. The wavelengths in the red/green pair lie at the peaks of the human opponent colour spectral sensitivity function (Sperling and Harwerth, 1971) and the peaks of the red/green chromatic response function (Hurvich and Jameson, 1955); this pair is likely to produce little modulation in the blue/yellow opponent system. The blue/yellow pair was also selected on the basis of their positions on the human opponent colour spectral sensitivity function and blue/yellow chromatic response function and, as such, this stimulus will modulate the blue/yellow opponent system much more than the red/green opponent system.

The two monochromatic gratings are combined optically 180 deg out of phase to form the composite red/green or blue/yellow chromatic grating. The grating patch viewed was circular and subtended 6.5 deg in diameter. Viewing was monocular and with a natural pupil. The subject's head was lined up with the stimuli and the alignment was maintained both by use of a chin rest and by using a visual marker. A V-shaped marker was placed on each screen; when the stimulus was lined up, the points of the two Vs were also adjusted to line up exactly. Subsequently, the subject only made threshold settings when the markers were aligned and indicating, even at subthreshold contrasts, when the stimulus was correctly aligned. Both types of chromatic aberration of the eye, the chromatic differences of focus and magnification, were corrected. These corrections had been established previously using normal subjects (Mullen, 1985).

The contrast of either component grating was defined by the usual formula:

$$C = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

where I_{max} and I_{min} are the peak and trough luminance values, respectively. The contrasts of the two component monochromatic gratings were yoked together electronically so that they were always equal, even though their respective mean luminances may differ. Henceforth these contrasts are used to describe both the monochromatic and the chromatic gratings. The mean luminances of the composite red/green or blue/yellow gratings are both fixed, although the ratio of the luminances of the

two component colours in each is variable. The mean luminance of the red/green stimulus is 15 cd/m^2 and that of the blue/yellow stimulus is 2.1 cd/m^2 (*see* fig. 1). Output contrasts were calibrated using a UDT (United Detector Technology) light meter. All mean luminances were measured with a calibrated SEI spot photometer. A 6809 Motorola microprocessor was used on-line to control the stimulus production and presentation.

Procedure

A method of adjustment was used. The subject was able to increase or decrease the contrast of the stimulus by pressing an appropriate button. A third button could be pressed to indicate the chosen threshold value. A jump in contrast either above or below threshold occurred after each threshold setting. Threshold was described to subjects as being when a vertical bar pattern could just be seen, and all subjects were given several practice runs before beginning the experiment. Each data point represents the mean of at least two thresholds set nonsequentially. Generally, however, the mean of 3 to 5 threshold settings is taken for each plotted point. Error bars show the largest standard error of the mean unless described otherwise.

Subjects

The clinical details of the 10 patients studied and criteria for the diagnosis of optic neuritis are given in the Table. All patients had had an episode of optic neuritis in the recent past which had left them with a stable residual visual deficit. The patients do not represent a random sample with respect to the severity of the visual deficit, but were selected to provide examples of the many degrees of visual loss that may be seen. Apart from the one subject who had virtually no residual loss (Case 5), patients were also selected who showed a marked asymmetry between the two eyes. This has permitted a comparison of luminance and chromatic sensitivities between the two eyes of each subject. It is assumed that any postchiasmal lesions in these patients will affect both eyes more or less equally. The comparison

TABLE. CLINICAL DETAILS OF PATIENTS

Case	*Diagnosis*	*Eye*	*Snellen acuity*	*Ishihara, no. of errors*	*Farnsworth-Munsell 100 hue total error score*	*RAPD*	*Optic disc*	*Visual field***
1 (I.N.)	Left ON*	L	6/9	11	ND	+	Pale	Normal
		R	6/5	0		0	Normal	Normal
2 (J.S.)	Bilateral ON	L	6/9	3	194	+	Pale	Normal
	Definite MS	R	6/6	0	138	0	Normal	Normal
3 (E.R.)	Right ON	L	6/5	0	ND	0	Normal	Normal
	Definite MS	R	6/6	0		+	Pale	Normal
4 (P.S.)	Right ON	L	6/5	0	19	0	Normal	Normal
		R	6/9	12	319	+	Pale	Normal
5 (M.A.)	Right ON	L	6/5	0	3	0	Normal	Normal
		R	6/5	0	4	0	Normal	Normal
6 (E.O.)	Right ON	L	6/60	12	618	0	Pale	Relative central scotoma to red target
	Definite MS	R	6/5	0	106	+	Normal	Normal
7 (C.S.)	Left ON	L	6/9	6	88	+	Pale	Normal
		R	6/6	0	39	0	Normal	Normal
8 (B.F.)	Bilateral ON	L	6/5	0	124	0	Pale	Relative paracentral scotoma
	Definite MS	R	6/18	10	561	0	Pale	Relative paracentral scotoma
9 (C.R.)	Bilateral ON	L	6/12	10	ND	+	Pale	Relative paracentral scotoma
		R	6/9	6		0	Pale	Normal
10 (M.M.)	Bilateral ON	L	6/9	13	241	+	Pale	Relative paracentral scotoma
	Definite MS	R	6/6	3	50	0	Pale	Normal

* Optic neuritis is defined as an episode of unilateral or bilateral visual failure of rapid, but not sudden, onset for which no evidence for a toxic, vascular or compressive aetiology has been discovered. All the patients had been seen by one of us (G.T.P.) in the acute phase of the disorder and in no case has the diagnosis been based on a retrospective history. The cases of bilateral optic neuritis were in all instances sequential. Those patients classified as having MS have had remitting and relapsing symptoms and physical signs of at least two distinct lesions of the CNS outside the visual system. ON = optic neuritis; MS = multiple sclerosis; RAPD = relative afferent pupillary defect; ND = not done; ** visual field assessed using Bjerrum screen 5/2000 white and red targets only.

between eyes in the same subjects therefore both insulates the results from the variability between individuals in the threshold settings, and allows us to draw conclusions related to the disease process as it affects the optic nerve without the added complication of any more central pathology.

The results of the Ishihara tests for colour blindness and the Farnsworth-Munsell 100 hue test are shown in the Table. The latter are discussed further later.

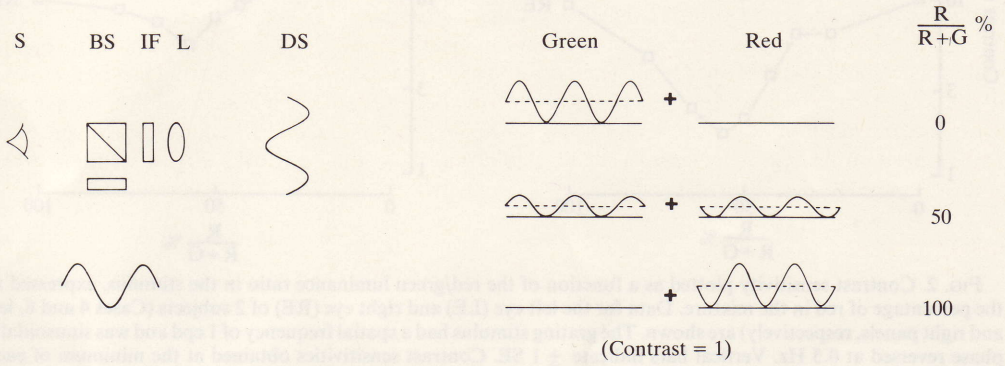

FIG. 1. *Left*, apparatus used to produce the stimuli. DS = display screen; L = lens for correction of chromatic aberrations; IF = interference filter; BS = beam splitter; S = subject. *Right*, diagram of the luminance profiles across space of the red and green component gratings which, when added together 180 deg out of phase, produce a sinusoidal red/green chromatic stimulus. The ratio of the red (R) to green (G) mean luminances in the chromatic grating is variable, and is expressed as the percentage of red light in the mixture. Three ratios in the range are shown. The mean luminance of each stimulus (R + G) is constant. The contrasts of the red and green component gratings are always equal to each other and have a value of 1 in this example. Contrast is varied to determine threshold. The same method is used to produce a blue/yellow grating.

RESULTS

The principle of the experiment is illustrated on the right side of fig. 1. The ratio of the mean luminances of the two component gratings in the stimulus is varied over a wide range. The ratio is expressed as the percentage of red in the red/green mixture, or as the percentage of blue in the blue/yellow mixture. Three points in the range are shown in the figure for a red/green stimulus. The range begins and ends with a green or a red monochromatic grating (at 0 and 100% red, respectively). These stimuli are of uniform colour but vary sinusoidally in luminance, thus detection of the bar pattern must be based solely on the luminance contrast in the stimulus. At a point in the midrange, however, the grating will contain colour differences but be of uniform luminance, thus detection thresholds will be based on its colour contrast. Contrast sensitivity was measured at seven points in the complete range for both blue/yellow and red/green gratings, for each eye.

Results for 2 subjects for red/green gratings are shown in the two panels of fig. 2. Each subject has had an attack of optic neuritis which has more severely affected their right eye, and in each case this eye has the lower overall contrast sensitivities. First, it is worth considering the results of the left eye of Case 4, since these illustrate

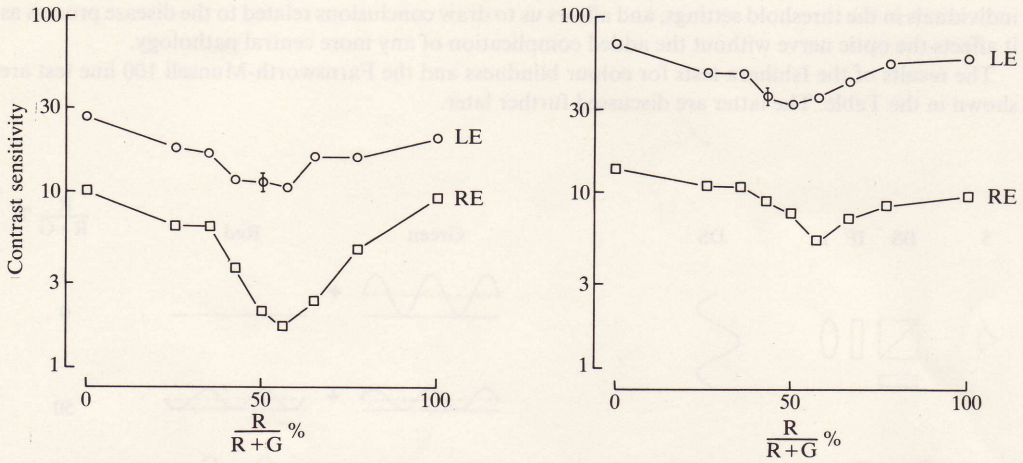

FIG. 2. Contrast sensitivity plotted as a function of the red/green luminance ratio in the stimulus, expressed as the percentage of red in the mixture. Data for the left eye (LE) and right eye (RE) of 2 subjects (Cases 4 and 8, left and right panels, respectively) are shown. The grating stimulus had a spatial frequency of 1 cpd and was sinusoidally phase reversed at 0.5 Hz. Vertical bars indicate ± 1 SE. Contrast sensitivities obtained at the minimum of each function represent the contrast sensitivity of the eye to red/green chromatic gratings. Data points occurring at 0 and 100% red show contrast sensitivities to green and to red luminance gratings respectively.

the type of function which is obtained from normal subjects (Mullen, 1985). The results show that contrast sensitivity is greatest for the monochromatic luminance gratings at 0 and 100 per cent red, whereas as luminance contrast is removed from the stimulus, sensitivity to it declines to a minimum. The value at the minimum indicates the contrast sensitivity of the subject to chromatic gratings when thresholds are based solely on colour contrast detection, thus the appropriate match of the intensities of the two colours in the stimulus is determined for each eye of each subject. The depth of the minimum corresponds to the difference between the logarithms of contrast sensitivity to luminance and chromatic gratings.

Normal subjects show such a minimum for both red/green and blue/yellow gratings at this spatial and temporal frequency (Mullen, 1985). However, since the experiment is concerned with the relative effects of optic neuritis on chromatic and luminance sensitivity, the question is whether the depth of these minima, representing the differences between colour and luminance sensitivity, are greater than normal in eyes affected by the disease.

The results for the 2 subjects shown in fig. 2 are representative of the extremes of the range of results. For Case 4, there is a marked difference between the two eyes in their contrast sensitivity to monochromatic gratings; the sensitivity of the right eye is lower by 0.4 log units. Moreover the minimum in this eye is deeper than that in the left eye, indicating that in this subject colour sensitivity has deteriorated more than luminance contrast sensitivity. For the other subject (Case 8) there is a difference in contrast sensitivity to monochromatic gratings between the two eyes of 0.5 log units.

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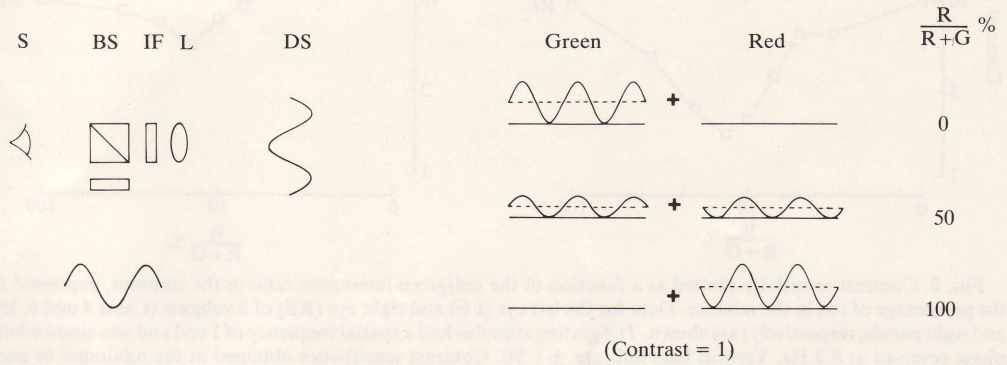

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However, in this subject the depths of the minima in the two eyes are about equal, indicating that colour sensitivity has fallen in proportion to the loss of luminance contrast sensitivity.

The results for our population were analysed by comparing this ratio, of luminance to colour contrast sensitivity, between the two eyes of each subject. This method helps to control for the effects of the variability in the normal population of colour and luminance contrast sensitivities. The eyes of each subject were divided into 'better' or 'worse' depending on which eye had the higher or lower contrast sensitivity to chromatic gratings at its minimum of sensitivity. Substantially the same results would have been obtained if this division had been made on the basis of the contrast sensitivity to luminance gratings. Luminance contrast sensitivity was taken as the average of the contrast sensitivities found for the two monochromatic gratings occurring at each end of the red/green or blue/yellow range. For each eye, the difference between the logarithms of the luminance contrast sensitivity (L) and colour contrast sensitivity (C) was calculated: $\log L - \log C = \log L/C$. The ratio L/C, expressed in log units, corresponds to the depth of the minima shown in fig. 2.

In fig. 3 this ratio in log units is plotted for the better eye as a function of the ratio for the worse eye of each subject. Data for both red/green and blue/yellow gratings are included. The dashed line in the figure has a slope of unity and passes through the origin. The data would be fitted by this function if, in the worse eye of each subject,

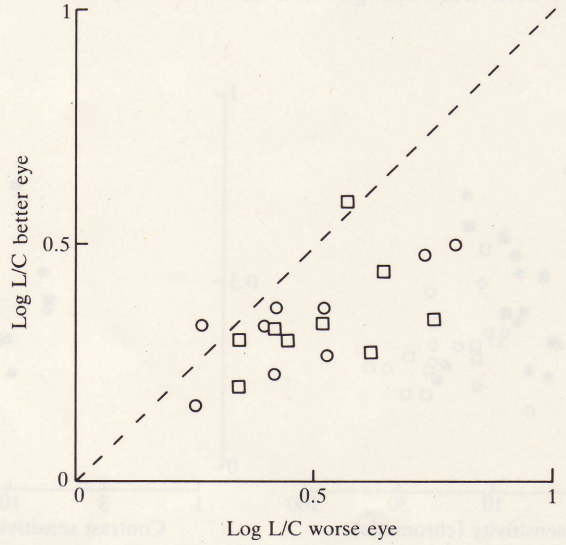

FIG. 3. The ratio of the contrast sensitivity for luminance gratings (L) to the contrast sensitivity for chromatic gratings (C), expressed in log units, is shown for the better eye as a function of that for the worse eye of each subject. The method of obtaining this ratio is explained in the text and fig. 2. The eyes of each subject were categorized as 'better' or 'worse' depending on which had the greater or lesser contrast sensitivity to chromatic gratings, respectively. The dashed line has a slope of unity. Data for red/green gratings (squares) and blue/yellow gratings (circles) are shown. Typical standard errors are 0.1 log units.

the contrast sensitivity to chromatic gratings was reduced in proportion to the loss of luminance contrast sensitivity. In other words, the depth of the minima would be the same in the two eyes; an example of this in one subject is shown in the right panel of fig. 2. However, the data shown in fig. 3 deviate from the dashed line and are fitted by a linear regression which is considerably shallower than unity. (The slope of the linear regression line is 0.42 and the correlation coefficient is 0.63 which is significantly different from zero at the 95% confidence level.) Thus, first, the results show that the gap between colour and luminance contrast sensitivity tends to be wider in the worse eye than in the better eye. This indicates that colour sensitivity has fallen further below luminance sensitivity in the worse eye than it has in the better eye; the sensitivity to chromatic gratings has been more severely impaired than luminance sensitivity. Secondly, since the data do not lie along a slope of unity, the luminance to colour contrast sensitivity ratios in the two eyes do not have a fixed constant of proportionality. Instead, the results show that the larger ratios (deeper minima) found in the better eyes tend to be associated with disproportionately larger ratios in the worse eyes. That is, the relationship on linear coordinates is a power function.

One question concerns how the luminance to colour contrast sensitivity ratios (the depth of the minima) are related to the actual colour and luminance contrast sensitivity values. Fig. 4 shows L/C, in log units, as a function of luminance contrast sensitivity (right panel) and colour contrast sensitivity (left panel). Data for all eyes are shown for both red/green and blue/yellow gratings. Hollow and filled symbols show data for eyes which were categorized as better and worse respectively.

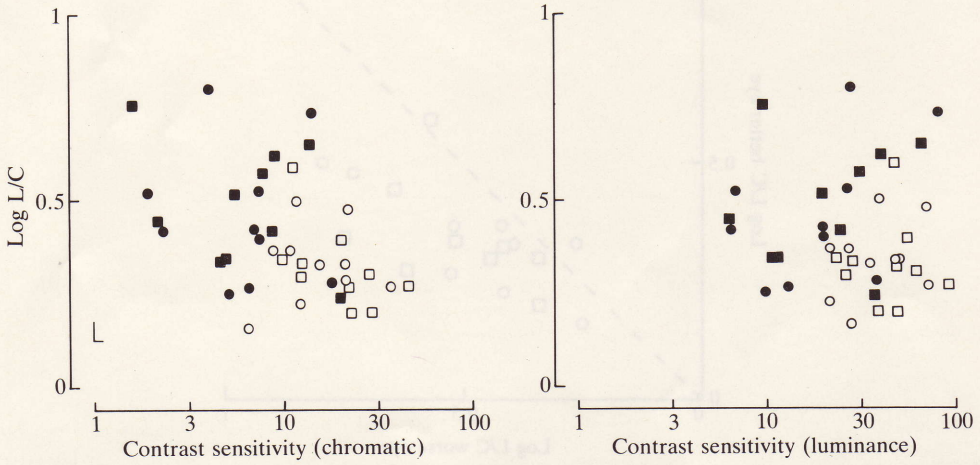

FIG. 4. *Left*, the ratio of contrast sensitivity for luminance gratings to contrast sensitivity for chromatic gratings (L/C), expressed in log units, is plotted as a function of the contrast sensitivity to chromatic gratings. Open and filled symbols show data for the better and worse eyes of each subject respectively, for red/green gratings (squares) and blue/yellow gratings (circles). The vertical and horizontal bars each show one typical standard error. *Right*, the ratio of contrast sensitivities to luminance and chromatic gratings (L/C), expressed in log units, is plotted as a function of the contrast sensitivity to luminance gratings.

The results in the right panel show that there is no association between the L/C ratio and luminance contrast sensitivity. The results in the left panel are suggestive of a very weak association where eyes with the lowest sensitivities to chromatic gratings tend to have the larger L/C ratios; however, the correlation is not significantly different from zero (slope = -0.11; r = -0.28, not significant at the 95% confidence level). Thus the association between the L/C ratios in the better and worse eyes (fig. 3) occurs independently of the contrast sensitivity values. The possible implications of these results are considered in the Discussion.

Finally, we have considered whether there is any evidence for a differential effect of optic neuritis on red/green or blue/yellow stimuli. Fig. 5 shows the luminance to colour contrast sensitivity ratio for blue/yellow gratings as a function of the ratio for red/green gratings. The data lie close to a slope of unity (slope = 0.82; r = 0.81, significantly different from zero at 95% confidence limits). These results thus suggest that in our population of subjects, overall, the deficit in colour sensitivity occurs equally for red/green and blue/yellow stimuli.

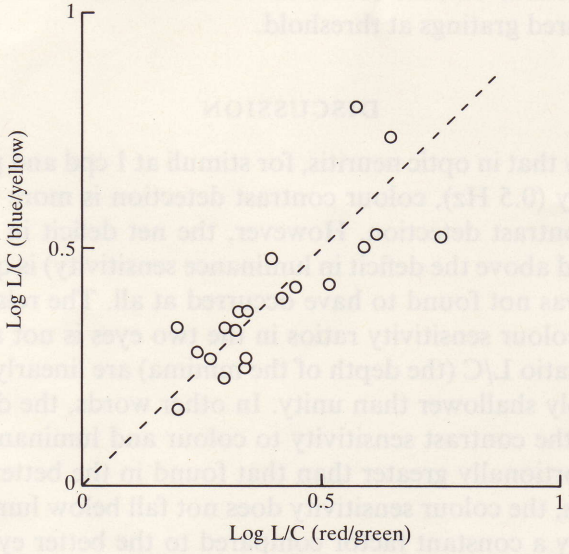

FIG. 5. The ratio of luminance to colour contrast sensitivities (L/C) expressed in log units is shown for the blue/yellow stimuli as a function of the ratio for red/green stimuli. Data are shown for each eye of each subject. The dashed line has a slope of unity. Typical standard errors are 0.1 log units.

Results from the Farnsworth-Munsell 100 hue test of colour discrimination were obtained for 7 of the subjects and are shown in the Table. Error scores for most of the subjects are much greater than average. Average error scores in the normal population are 20–30 and 16% of the population have 'low' discrimination showing an error score of over 100 (Farnsworth-Munsell 100-hue test manual, 1957). The highest error scores were obtained from subjects with the lowest contrast

sensitivities to chromatic gratings. The errors were not found to be distributed along any particular colour axis, but in most subjects were evenly distributed across all the colours tested.

Comments on Colour Appearance

All our subjects were asked to describe the appearance of the colours. Red/green and blue/yellow square-wave gratings of maximum contrast were displayed, and the subject asked to compare the appearances of the stimuli between their two eyes. In most cases the colours were reported to be duller or paler in the worse eye. For example, colours were described as fluorescent in the better eye but less so in the worse eye, or glossy in the good eye compared to matt in the worse eye. Generally, the greatest differences in colour appearance were noted by subjects with the greatest colour contrast sensitivity losses. For these subjects the red appeared either 'orangey' (Case 1) or pink (Cases 4, 8), the green tended to look grey (Cases 4, 6, 8) and the yellow looked orange (Cases 1, 4) or orange-grey (Case 8). The blue was not reported to be anything other than pale blue. Thus the paler or duller appearances of these suprathreshold colours seems to be associated with a loss of contrast sensitivity to coloured gratings at threshold.

DISCUSSION

Our results show that in optic neuritis, for stimuli at 1 cpd and presented at a low temporal frequency (0.5 Hz), colour contrast detection is more severely impaired than luminance contrast detection. However, the net deficit in colour sensitivity (occurring over and above the deficit in luminance sensitivity) is quite variable, and in some subjects was not found to have occurred at all. The relationship between the luminance to colour sensitivity ratios in the two eyes is not a simple one. The logarithms of the ratio L/C (the depth of the minima) are linearly related, but with a slope considerably shallower than unity. In other words, the difference between the logarithms of the contrast sensitivity to colour and luminance gratings in the worse eye is proportionally greater than that found in the better eye. This means that in linear terms, the colour sensitivity does not fall below luminance sensitivity in the worse eye by a constant factor compared to the better eye, but rather that the relationship is a power function: the larger ratios of luminance to colour sensitivity in the better eyes are associated with disproportionately greater colour losses in the worse eyes.

Potential explanations for this relationship are obscure. Generally the 'better' eyes were not normal but showed signs of the pathological process (*see* Table). Possibly some aspect of this process in some subjects causes colour sensitivity to be more affected than luminance sensitivity, and so is manifest in the better eyes by greater colour/luminance differences. In this case, the results suggest that this process occurs in both eyes of the subject, but has advanced further in the worse eye. Possible causes of such a selective deficit in colour sensitivity are discussed later. Our

results also show that the actual contrast sensitivities to either chromatic or luminance gratings are not good predictors of this 'net' colour loss since large differences in colour and luminance sensitivities occur independently of the subject's actual contrast sensitivities. These results differ from those obtained from several previous studies, and explanations for these discrepancies should take into account the different methods and stimuli which have been used to reveal and compare colour and luminance thresholds.

Alvarez *et al.* (1982) and Alvarez and King-Smith (1984) used a 1 deg monochromatic test-spot presented on a white background and temporally modulated at 1 Hz. This arrangement has been shown to isolate opponent colour mechanisms at threshold (Sperling and Harwerth, 1971; King-Smith and Carden, 1976). Responses based on luminance detection were elicited by flickering the spot at 25 Hz. It was found that luminance thresholds (obtained at high temporal frequencies) showed a considerably greater loss than colour thresholds in retrobulbar neuritis. However, as Foster (1986) has pointed out, since the colour and luminance thresholds are compared at different temporal frequencies, the results are also likely to reflect any temporal frequency dependent threshold deficits. These may be greater at high temporal frequencies.

Foster (1986) has used a method of isolating colour and luminance detection thresholds which allows them to be compared under identical temporal conditions (200 ms presentation time). Small spots (0.25 deg) are superimposed on an auxillary field, all on a large white background (Foster and Snelgar, 1983). Thresholds based on either colour or luminance detections can be obtained by manipulating the colour of the test spot and size of the auxillary field. Results show that, compared with normal subjects, the deficits in colour and luminance thresholds are about equal.

A different approach was used by Fallowfield and Krauskopf (1984), more closely resembling the one used here. A uniform field (2 deg) was modulated in saturation, from white to coloured, while the luminance of the field remained unchanged. The results show that, compared with normal subjects, thresholds for detecting a change in saturation (chromatic thresholds) were elevated more than those for detecting a change in brightness of the field (luminance thresholds). The effect was slightly greater for changes towards green, as opposed to red, yellow or blue. However, direct comparisons between colour and luminance thresholds in this study are tenuous since each is measured using a different scale. Furthermore, the removal of brightness differences was established using flicker photometry measurements made by normal subjects; this method of removing brightness differences may not apply to subjects suffering from optic neuritis. For example, Alvarez and King-Smith (1984) showed abnormal spectral sensitivity functions obtained using flickering spot stimuli.

The approach reported here overcomes these problems since the same contrast scale is used to measure both colour and luminance sensitivities. Furthermore, the appropriate match of the intensities of the two colours in the chromatic stimulus is

determined, for the spatial and temporal conditions used, for each eye of each subject. Despite these differences in technique, the results of Krauskopf and Fallowfield show the same type of effect as ours, namely, a greater deficit in colour sensitivity than luminance sensitivity. However, we find that there is no consistent evidence for a greater sensitivity loss in one type of opponent-colour system; overall both red/green and blue/yellow stimuli revealed the same sensitivity losses, although individual patients may show greater losses for either red/green or blue/yellow.

The differences between the results of Fallowfield and Krauskopf (1984), Foster (1986) and our own may depend on the different spatial and temporal configurations of stimuli used. One question which may be asked is whether our results could be explained by a *selective* loss of the optic nerve fibres which carry colour information. This question cannot be answered on the basis of the results obtained so far, since differences in colour and luminance sensitivities may depend on the spatial frequency or temporal frequency of the stimulus, as well as on the area of visual field tested. Thus no firm conclusions can presently be drawn about the selectiveness of the colour vision deficit since under other conditions it might be found to be equal to or less than the deficit in luminance vision. The situation is further complicated since neurophysiological data have suggested that optic nerve fibres responding to colour may also carry some information about luminance contrast (Wiesel and Hubel, 1966; Ingling and Martinez, 1983) in which case some losses in luminance contrast sensitivity may be expected to occur in association with losses in colour contrast sensitivity. Thus further experiments are needed to analyse the spatial and temporal characteristics of the colour and luminance vision deficits before it can be decided whether any particular type of psychophysical channel has been selectively affected by demyelination.

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