

Suprathreshold vision in acute optic neuritis

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SUMMARY The perception of contrast was measured in patients with acute unilateral optic neuritis by a technique of subjective suprathreshold contrast matching, and was compared with contrast sensitivity as defined by threshold measurements. The suprathreshold apparent contrast and threshold contrast sensitivity was repeatedly assessed during the recovery phase. Generally, an attenuation of suprathreshold apparent contrast was found for high and intermediate spatial frequencies in the eye with optic neuritis. At a low spatial frequency, however, the suprathreshold contrast vision was spared. The threshold contrast sensitivity was not however, spared at low spatial frequencies. During recovery this frequency-specific loss in suprathreshold apparent contrast diminished and finally a "normal" suprathreshold contrast vision was observed in all affected eyes reaching a visual acuity of 1·0 or better. In these cases also subjectively normal vision was reported in spite of a persisting abnormality in threshold contrast sensitivity.

Over the past two decades the use of spatially periodic stimuli has increased our understanding of visual processes in the normal human visual system.^{1,2} During the last decade visual stimuli in the form of sinusoidal gratings have been increasingly used as a test of the contrast processing of the normal and diseased visual system.³ In ophthalmological diseases affecting the ocular media or the retina, the contrast threshold for sinusoidal gratings of different spatial frequencies has been found to be abnormal.⁴⁻⁷ Contrast sensitivity, defined as reciprocal of threshold contrast also has been shown to be impaired in diseases of the retrobulbar optic pathway.⁸⁻¹²

In a previous study of acute optic neuritis a generalised impairment of the contrast sensitivity for all spatial frequencies was found.⁹ This finding would imply that the detectability expressed as the minimum contrast necessary to detect the presence of a stimulus pattern of all angular sizes is impaired. However, patients with optic neuritis often complain that objects in the visual scenery with high contrast are also dimmer and lose contrast. This perception abnormality experienced by patients with optic neuritis indicates a disturbance in suprathreshold vision. Investigations of the suprathreshold contrast vision of normal subjects have demonstrated that

characteristics of the threshold contrast sensitivity cannot be extrapolated to suprathreshold levels.^{13,14} Suprathreshold matching experiments in normal observers show that contrast sensation becomes independent of spatial frequency at higher contrasts unlike the case at threshold contrast. Our knowledge, however, of the contrast vision above threshold in disease is extremely limited.^{13,15}

In daily life mainly suprathreshold contrast vision is used for pattern recognition and the aim of the present study was therefore to study suprathreshold apparent contrast during the acute phase and recovery of optic neuritis, a disease that produces a profound and longlasting impairment of threshold contrast sensitivity.^{9,12} In the acute phase of optic neuritis the contrast sensitivity is depressed for all spatial frequencies but during resolution of the disease the sensitivity partially recovers.⁹ This study was designed to investigate the changes of contrast perception above threshold during the recovery phase in patients with acute unilateral optic neuritis. During the acute phase the suprathreshold contrast matching was abnormal but during resolution a normalisation occurred owing to some suprathreshold compensation of persisting threshold contrast sensitivity deficits.

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Patients and methods

Patients Eight normal controls (age 25-47 years) and five patients with acute optic neuritis (age 22-66 years) took part in this study (table). Every patient was sub-

jected to a careful neuro-ophthalmological examination. Three patients had isolated unilateral, retrobulbar optic neuritis of presumably demyelinating nature; the diagnosis was based on the criteria defined by Gould *et al.*¹⁶ Two cases had multifocal symptoms and signs of neurological dysfunction indicating the diagnosis of multiple sclerosis. In all cases acute symptoms of blurred vision occurred in only one eye. At each visit the subjects were examined ophthalmologically and the visual acuity was determined. Monocular visual acuity was determined with best correction at a test distance of 5 m using the natural pupil. An officially approved acuity chart (KIFA: Monoyer-Granström) illuminated with approximately 700 cd/m² in a LIC universal light box was used. Visual acuity of the eyes with optic neuritis ranged from 0.1 to 1.0 and the acuity in the contralateral eyes were 1.0 or better.

Contrast sensitivity Vertical, stationary, sinusoidal gratings were generated on a black and white television display as previously described.^{5,7} The contrast sensitivity at threshold was determined monocularly by raising contrast from a subthreshold setting at a selected spatial frequency until a grating pattern was faintly seen. The television monitor was masked to subtend 6×6 degrees of angle at the eye, when viewed at a distance of 2.5 m and sixteen frequencies were explored twice in random order. The contrast was adjusted by the experimenter in steps of 2 dB within the contrast range 0.001 to 0.9.

Suprathreshold apparent contrast was measured by presenting two vertical, sinusoidal gratings side by side. For one eye television-generated grating with variable contrast (see above) and for the other a non-variable, photographically produced grating was shown. Both gratings had identical spatial frequencies, space-average luminance about 80 cd/m² and subtended 6×6 degrees at the eye. The non-variable photographic gratings were produced by photographing the television-generated gratings at different contrast levels and spatial frequencies. The modulation characteristics of the colour diapositives were checked by microdensitometry and they had a horizontally oriented sine-square light profile. The photographic gratings were projected by transillumination and the space-average luminance of the projected grating was matched to that of the television-generated one by neutral density filters.

Procedure The observer's head was fixed by means of a chin support 1.25 m in front of the gratings. The photographic grating was presented for the eye with optic neuritis and the grating with variable contrast was presented to the contralateral eye. The visual field for the two eyes were divided sagittally by placing a cardboard screen between the eyes perpendicular to the frontal plane. Centres of the gratings were separated by an angle of 20° subtended at the eye. By this arrangement the observer was forced to look at the grating with one eye at a time when rapid eye changes during the matching procedure and smaller adaptation effects were anticipated.

The task of the patient was to adjust with a continuous attenuator the contrast of the variable grating until it matched the photographic, non-variable one in apparent contrast. Fifteen different photographic gratings were presented twice during the test at the spatial frequencies (0.7, 2.7, 6.2 cycles/degree) and at five contrast levels (0.85, 0.60, 0.40, 0.25, 0.15) for each frequency (fig 1). Owing to small variations in the photographic procedure small differences in contrast levels of the photographic gratings occurred at different frequencies. The actual contrast values were 0.85, 0.57, 0.42, 0.31, 0.18 and 0.85, 0.64, 0.42, 0.27, 0.17 and 0.85, 0.62, 0.35, 0.23, 0.13 at 0.7, 2.7 and 6.2 cycles/degree respectively. To control for effects of possible side differences the normal subjects adjusted the contrast with the variable gratings positioned first to the left and thereafter to the right side at each session. Contrast matching started at the

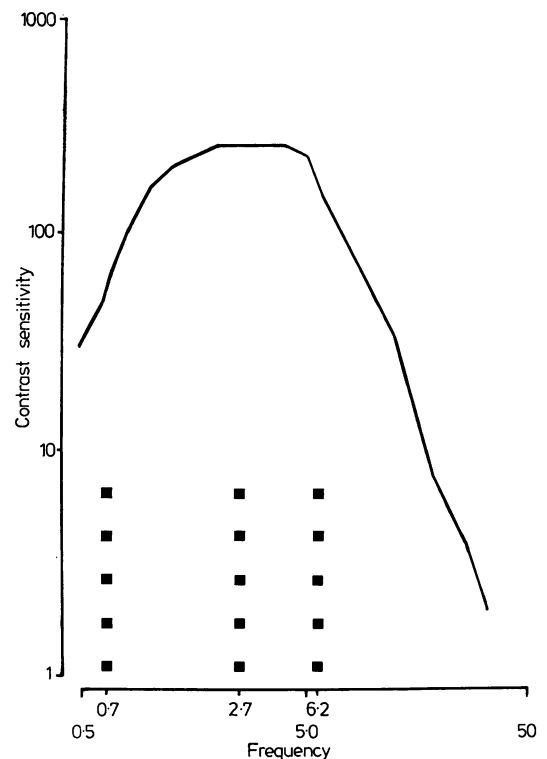


Fig 1 Contrast sensitivity versus spatial frequency (CSF) for a normal observer. Field size: 6×6 degrees of angle at the eye. ■ indicate all the points in the contrast-frequency diagram used for the suprathreshold measurements. The suprathreshold stimuli range from a maximum of 85% contrast in approximately 0.2 log unit (2 dB) intervals to 15% contrast. One stimulus was selected at 2.7 cycles/degree (at the peak of CSF) and the two other stimulus in the lower (0.7 cycles/degree) and higher (6.2 cycles/degree) spatial frequency part of the CSF.

highest spatial frequency and proceeded in order to the lowest one. At each spatial frequency all contrast steps were presented in randomised order. Generally, a mean value for the two matches of the contrast for each pair

of gratings was calculated. However, if the difference between the two measurements was more than 10% a third contrast match was carried out. In all these cases the third matching was in between the preceding ones and a

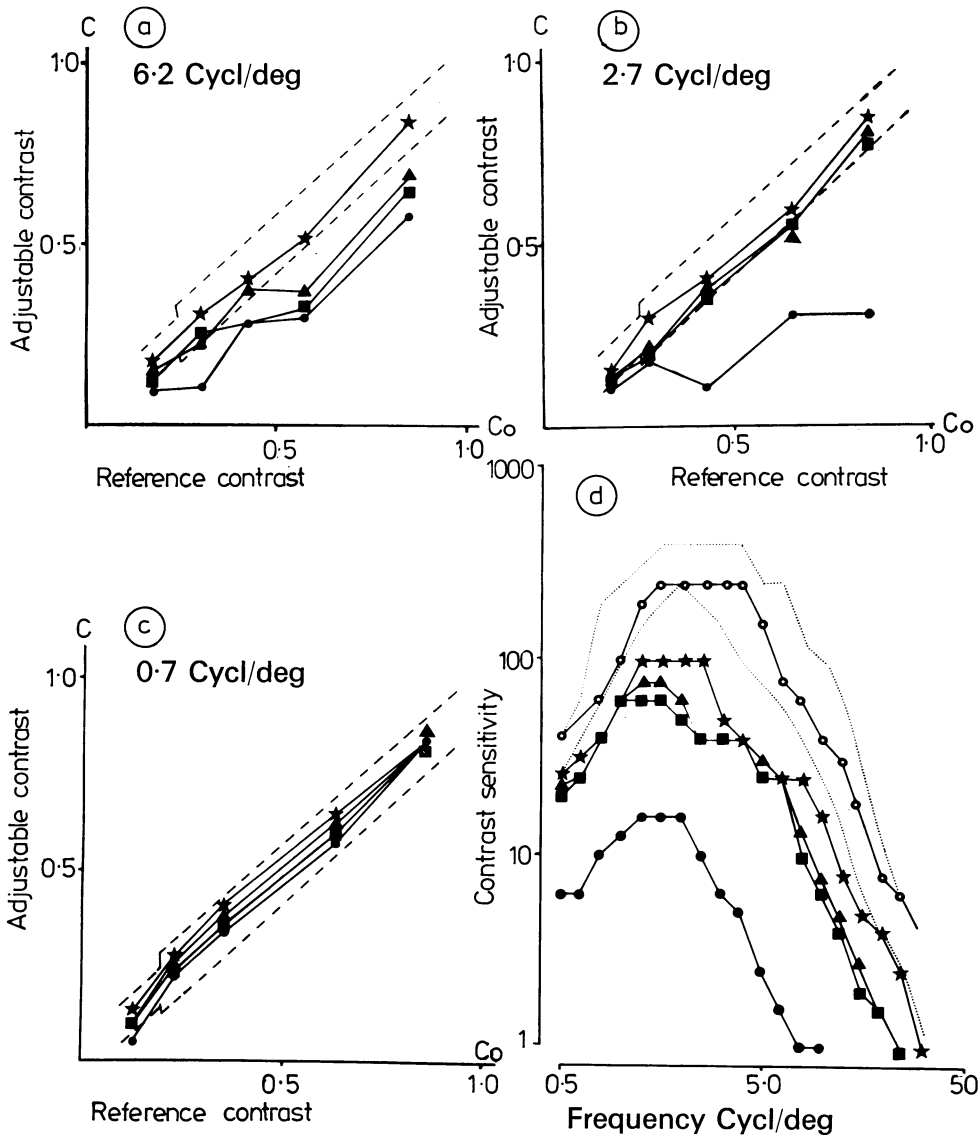


Fig 2 a-c Suprathreshold determinations in case EH plotted as the adjusted contrast (C) of the television generated grating versus level of suprathreshold contrast (C_0) of the non-variable photographic grating. Range of matching in normal controls is indicated by the interrupted lines. Solid lines indicate the suprathreshold matching at different time intervals and visual acuity levels during the recovery from unilateral optic neuritis, ● VA 0.1, ■ VA 0.6, ▲ VA 0.7, and ★ VA 1.5. d. CSF of the eye with optic neuritis at the same time intervals as used for suprathreshold determinations (same symbols as above). * indicates the CSF of the contralateral eye. Dotted lines indicate the normal range of CSF in 10 normal observers. The normal observers are at approximately the same age as EH.

mean value was calculated. Retesting within the same day according to the procedure described above in two of the cases demonstrated a range of approximately 10% between the means of the two measurements. Each setting of contrast rarely took more than 10 seconds to

make and each grating was inspected generally less than two to three seconds at a time before the eye position changed. The range of individual matches did not vary observably with the sequence of presentation of contrast levels. A minimum of two minutes were allowed for rest

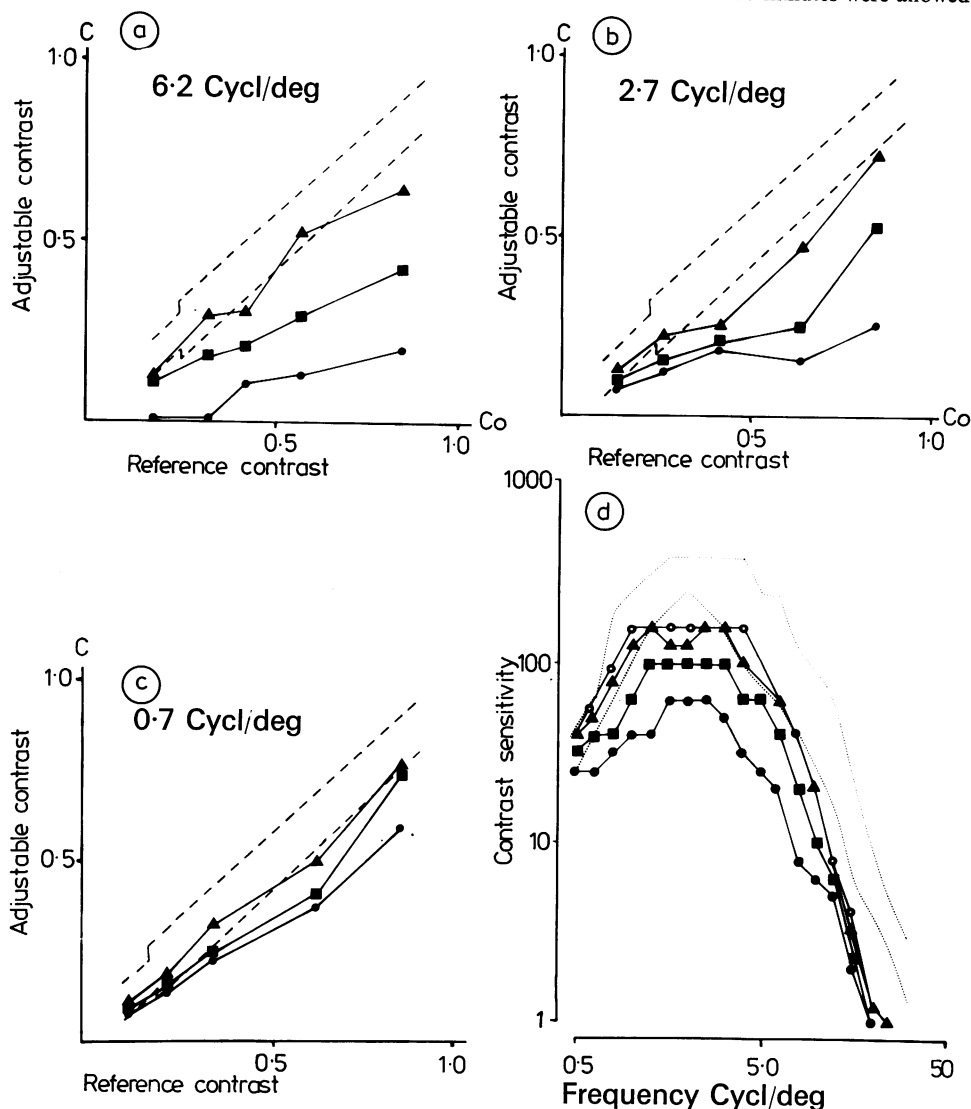


Fig 3 a-c Suprathreshold determination in case TP. Plotted as the adjusted contrast (C) of the television generated grating, versus level of suprathreshold contrast (C_0) of the nonvariable photographic grating. A-C shows the suprathreshold contrast matching for the three different frequencies 6.2, 2.7, and 0.7 cycles per degree respectively. Range of contrast matching in normal controls is indicated by the interrupted lines. Solid lines indicate the suprathreshold matching at different time intervals and visual acuity levels during the recovery from optic neuritis, ● VA 0.6, ■ VA 0.9, ▲ VA 1.0. d. CSF of the eye with optic neuritis at the same time intervals as used for suprathreshold determinations (same symbols as above). * indicates the CSF of the contralateral eye. Dotted lines indicate the normal range of CSF in 10 normal observers. The normal observers are at approximately the same age as TP.

between each spatial frequency tested.

Definitions The pattern contrast (C) is defined as

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

where L_{\max} and L_{\min} denote maximum and minimum luminances respectively. In figs 2 and 3 c denotes the pattern contrast of the television generated grating and c_0 that of the photographic grating.

Results

THRESHOLD CONTRAST

The contrast sensitivity function (CSF) at threshold, that is, the reciprocal of the contrast threshold versus spatial frequency (fig 2d, range indicated by dotted lines) was similar to that obtained for normal subjects in a previous study⁷ with a peak value at approximately three cycles/degree. The threshold contrast sensitivity of the eye contralateral to the diseased eye was within normal range in all cases with isolated optic neuritis (fig 2d, ●). However, in the two cases with multiple sclerosis the contrast sensitivity of the contralateral eye was subnormal (fig 3d) in agreement with findings of earlier studies.^{8,9}

The CSF of the eyes with acute, unilateral optic neuritis was depressed over the whole frequency spectrum (figs 2 and 3d, filled circles) as described previously.⁹ During recovery the extent of impairment of the CSF was correlated roughly to visual acuity. In four of the five cases investigated the visual acuity recovered to 1.0 or above (table). The CSF, however, was still below normal range (figs 2 and 3d).

SUPRATHRESHOLD CONTRAST: NORMAL SUBJECTS

Contrast matching with subjective equalisation of *suprathreshold* contrast was carried out twice (see methods) on two separate occasions. The individual range of these four measurements of adjustable contrast was calculated for each spatial frequency and in no case this range was above 0.03. Measurements in all subjects at specific spatial frequencies and contrast levels showed a range in matching of ± 0.07 . At the lowest contrast level, however, the range was less, that is, ± 0.05 as a maximal contrast deviation from the preset level (indicated by interrupted lines in figs 2 and 3 (a-c)). The difference between the two eyes was 0.03.

OPTIC NEURITIS

Measurements of suprathreshold apparent contrast between the symptom-free and involved eyes of patients with acute optic neuritis demonstrated an abnormal contrast matching in all cases (table).

Figures 2 and 3 (a-c) shows the contrast values adjusted on the TV-screen (C) as a function of the reference contrast (C_0) of the photographic grating presented to the eye with optic neuritis. In these graphs a normal contrast matching, that is, similar contrast perceived by both eyes, fell between the interrupted lines. In cases with unilateral acute optic neuritis a loss of apparent suprathreshold contrast experienced by the affected eye occurred. The patient adjusted a contrast with his fellow eye below normal values. This loss of apparent contrast is illustrated in figs 2 and 3 (a-c) by solid lines falling below the normal range (interrupted line). Typically, an attenuation of suprathreshold apparent contrast was found for the involved eye for high (6.2 cycles/degree) and intermediate (2.7 cycles/degree) frequencies (figs 2, 3a and b). This relative contrast loss increased at higher contrast levels. During the acute phase the loss was dramatic with adjusted contrast levels up to seven times below that of the photographic grating. At a low spatial frequency (0.7 cycles/degree) the contrast matching showed smaller or no deviations from normal (figs 2c and 3c). In two cases, contrast matching at low spatial frequency was within normal limits (table, fig 2c), despite marked contrast loss at higher spatial frequencies. In two cases the apparent suprathreshold contrast was above that of the contralateral eye at a low spatial frequency although threshold contrast at low spatial frequencies was markedly impaired. During recovery of visual acuity the contrast matching improved gradually at high and intermediate spatial frequencies. When an acuity level of 1.0 or above was reached the majority of the matching values was within normal limits (table; fig 2 (a-c), indicated by asterisks) in spite of a persisting attenuation of the threshold contrast sensitivity (table, fig 2d).

Discussion

The main finding of this study is that during the acute phase of optic neuritis the apparent suprathreshold contrast is reduced in the affected eye compared to that of the unaffected eye. This relative loss of apparent contrast experienced by the affected eye was mainly restricted to high and medium spatial frequencies. The loss was most marked at the higher contrast levels. However, the contrast matching of suprathreshold grating of low spatial frequency was near normal unlike the marked loss in contrast sensitivity for the same grating at threshold.

Our study thus demonstrates that frequency-specific losses occur in contrast sensation in acute optic neuritis. In normal suprathreshold vision the gain

Table Patient data, visual acuity and suprathreshold apparent contrast during the acute phase and recovery of unilateral optic neuritis

Patient	Age (yr) sex	VA of the affected eye at different phases of recovery	VA of the fellow eye	Impairment of the apparent suprathreshold contrast of the affected eye at different spatial frequencies and contrast levels								
				0.67 cycl/deg			2.67 cycl/deg			6.2 cycl/deg		
				>0.35*	0.35	<0.35†	>0.42	0.42	<0.42	>0.42	0.42	<0.42
EH	30/F	0.1	1.5	0‡	0	0	++	‡‡	0	+	+	‡‡
		0.6		0	0	0	0	0	+	+	0	
		0.7		0	0	0	0	0	+	0	+	
		1.5		0	0	0	0	0	0	0	0	
TP	22/F	0.6	1.0	+	+	+	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡
		0.9		+	+	0	‡‡	‡‡	‡‡	‡‡	‡‡	
		1.0		+	0	0	+	+	0	+	+	0
L-OE	34/M	0.4	1.0	0	0	0	+	+	‡‡	‡‡	‡‡	‡‡
		0.5		0	-	-	+	+	‡‡	‡‡	‡‡	‡‡
		0.6		-	-	-	+	0	+	‡‡	‡‡	‡‡
		1.0		0	-	0	0	0	0	0	0	0
GJ-R	32/F	0.4	1.0	0	0	0	‡‡	‡‡	‡‡	+	‡‡	‡‡
		0.5		0	0	0	‡‡	+	+	‡‡	+	
		0.7		0	-	0	0	-	0	+	+	0
		1.0		0	0	0	0	0	0	0	0	0
IB	66/F	0.1	1.0	+	+	0	‡‡	‡‡	‡‡	‡‡	‡‡	‡‡
		0.8		‡‡	0	0	+	0	+	‡‡	‡‡	+

* > 0.35 or >0.42 denote the average at the two suprathreshold contrast levels above 0.35 or 0.42.

† < 0.35 or < 0.42 denote the average at the two suprathreshold contrast levels below 0.35 or 0.42.

‡ 0 indicates contrast matching within normal range.

+ indicates $C \geq 50\%$ of C_0 , ++ $C < 50\%$ of C_0 , - $C > C_0$.

that is the average slope of the linear relationship between stimulus contrast and apparent contrast, is relatively constant over the spatial frequency and suprathreshold range used in this study.¹⁷ The frequency-related losses are interesting in the light of the observation that the mechanisms involved in apparent contrast sensation of normal observers are as frequency specific as those involved in detection.^{18,19} The findings in our study imply that the blurred vision in optic neuritis due to loss of apparent contrast in suprathreshold vision of a medium or high frequency grating might be cancelled by magnifying the grating.⁸

To our knowledge suprathreshold vision has not been evaluated in optic nerve disease previously. In amblyopia abnormalities of suprathreshold vision have been reported.^{15,20-22} Hess and coworkers²² described spatial distortions of grating patterns at suprathreshold levels in amblyopia even though threshold contrast sensitivity could be normal. Georgeson and Sullivan¹³ reported that some astigmatic observers showed considerable suprathreshold compensation for their orientation-specific neural deficit in threshold contrast sensitivity. They found that the attenuation observed at threshold (with optimal optical correction) for gratings oriented along the poor meridian was not reflected in suprathreshold apparent contrast for some of the astig-

matic observers. Therefore, it is not valid to go from threshold results to suprathreshold predictions if the visual loss has a neural basis as shown by their and our study. In the case of neural loss, allowing for a recovery period, threshold may be affected without any significant suprathreshold impairment due to a changed gain-setting mechanism as demonstrated in our study. However, when the visual loss has a pure optical basis, for example cataract, the threshold impairment may be extrapolated to suprathreshold levels.⁴

During recovery following the acute phase of optic neuritis a normalisation of suprathreshold vision occurred. In spite of a persisting abnormality in threshold contrast sensitivity as demonstrated in this and other studies^{9,10,12} the suprathreshold vision recovered in all patients in this study. This finding may imply that some compensatory mechanism is active in suprathreshold vision. An alternative possibility is that suprathreshold vision is mediated by a different mechanism. At the same time our observations demonstrate that threshold contrast sensitivity tests are more appropriate for discovering axonal degeneration or demyelination in diseases of the visual system.^{8,9} Changes in suprathreshold matching not consistent with contrast sensitivity data has been reported also for an amblyopia by Ginsburg.¹⁵ By monocular suprathreshold matching technique

Ginsburg found evidence for complex gain systems in an amblyope with over-compensation or under-compensation in different frequency channels at suprathreshold contrast levels. Our finding of two cases with apparent contrast above that of the contralateral eye at low spatial frequencies in spite of marked threshold loss may be interpreted as an overcompensation, that is, the eye with neuritis required less contrast for matching. These data indicate that much more complex gain systems for different frequency channels might be present in disease than those found in normal observers.¹³

In this study few near-threshold contrast levels were studied and our results only demonstrate losses at contrast levels above 0.15, that is, at high suprathreshold levels. At contrast levels above 0.3 Georgeson and Sullivan¹³ have found in normal observers a contrast constancy, that is, the suprathreshold apparent contrast is to a large extent independent of the contrast sensitivity function and the gratings are seen in normal eyes as having an apparent contrast corresponding to its physical contrast. Testing of suprathreshold contrast levels near the threshold might have given different results, since Kulikowski²³ has observed that for normal eyes suprathreshold apparent contrasts are equal only when their suprathreshold contrast is defined as the actual grating contrast minus its threshold contrast. This means, however, contrast constancy of patterns of higher contrast since at those levels the differences in contrast thresholds are negligible. Even though the lowest suprathreshold contrast in our study was 15 to 35 times the threshold contrast in normal observers this contrast level was near threshold in a few affected eyes with severely depressed contrast sensitivity functions. For these near-threshold values some frequency dependence of the suprathreshold contrast sensation might be anticipated in analogy with the finding of Georgeson and Sullivan¹³ for normal observers.

One major criticism of our method of contrast matching is that effects from adaptation could occur from free inspection of high contrast gratings.¹⁸ To minimise the risk of adaptation the two gratings were separated by an angle of 20° subtended at the eye which forced the patient to look with one eye generally less than two to three seconds at a time. Furthermore, each setting of contrast rarely took more than 10 seconds to make—a period of time much shorter than that used for adaptation studies.¹⁸ Interestingly enough, Raymond *et al*²⁴ have found abnormally small adaptation effects in patients with multiple sclerosis besides the finding of a reduced contrast sensitivity function. On the other hand, Enoch *et al*²⁵ have demonstrated visual fatigue in a patient with retrobulbar optic neuritis and probable

multiple sclerosis when exposed to high luminance levels. Another complicating factor in suprathreshold matching experiments is also that the affected eye has to be compared to the fellow, symptom-free eye, which may be subclinically affected, as demonstrated in threshold contrast studies of patients with multiple sclerosis.^{8,9} In such cases an equalisation of suprathreshold matching between the two eyes do not imply normalisation. Studies are in progress in our laboratory to evaluate this by using a monocular matching technique.¹⁵ In conclusion, dramatic relative losses of suprathreshold contrast sensitivity may occur during the acute phase of optic neuritis. Thus, for the diseased eye a high contrast grating may look identical to that of a low contrast presented to the fellow eye. This might explain why patients with acute optic neuritis often complain that objects in the visual scenery of high contrast are dimmer and lose contrast.

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