The ERG's (Fig. 2), in contrast to the VER's show significant changes in structure depending on the direction of the period-jumps. In the left-hand column, two major peaks occur with latencies of 20 msec. (positive peaks) and 28 msec. (negative peaks), and as previously mentioned, the amplitudes of all these peaks are linearly related to size and sign of the period-jumps. In the right-hand column, where the period-jumps are in the opposite direction, the peaks occurring at 20 msec. become negative. However, the peaks occurring at 28 msec. remain negative as can be most easily seen in the top waveform. As the size of the period-jumps becomes small, the amplitudes of these negative peaks are reduced to near the level of signal noise making them more difficult to see. Whereas the VER data demonstrate almost complete linear rectification of waveform, the ERG data demonstrate a degree of waveform rectification as well as a degree of waveform linearity with respect to sign change of the period-jumps. Again a detailed analysis of these data show the ERG signals to be about 70 per cent linear and approximately 30 per cent rectified.

Substantial signal rectification in VER responses is not entirely unexpected considering the "on-off" neuronal subsystems of vision which are encountered at the ganglion cell layer of the retina and in other higher neuronal levels of the visual pathway. It is surprising, however, to see rectification in VER responses since these are considered to arise from retinal layers below that of the ganglion cells. Intracellular recordings from Necturus retina suggest that the amacrine cell is the only intraretinal neuron which rectifies. It is plausible, therefore, to conjecture that period-jump-elicited ERG responses might reflect amacrine cell activity.

If further investigations verify this suprafusion ERG-amacrine cell relationship, analysis of retinal activity by electrophysiological techniques would be enhanced. Since the period-jump phenomenon is probably coupled to cone activity, this technique as a diagnostic aid might be specific to macular dysfunction. Certainly there would be no difficulty in using the technique clinically since, except for the light source, only conventional ERG equipment is required.

From the Applied Physics Laboratory and the Wilmer Ophthalmological Institute of the Johns Hopkins University, Silver Spring, Md. This investigation was supported by United States Public Health Service Research Grants NS-07226 from the National Institute of Neurological Diseases and Stroke. Submitted for publication July 19, 1974. Reprint requests: Dr. R. W. Flower, The Johns Hopkins University, Applied Physics Laboratory, 8621 Georgia Ave., Silver Spring, Md. 20910.

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Contrast sensitivity in meridional amблиopria, R. D. Freeman.

Contrast (modulation) sensitivities for gratings of various spatial frequencies and orientations have been determined for meridional amblyopes. The entire contrast sensitivity function is reduced for gratings oriented in the amblyopic meridian. Therefore, neural elements that process a broad range of spatial frequencies are affected by meridional amblyopia.

In uncorrected astigmatism, one focal line may be considerably defocused for most or all observation tasks. If this occurs during important phases of visual system development, ambliopia ex anopsia might be expected, but it would only be manifest for spatial detail of particular orientations. This condition, meridional amblyopia, has been known clinically for a very long time. Recently, however, meridional amblyopia has been explored in detail partly as a result of laboratory experiments with cats who have undergone meridional visual deprivation. It has been established that the meridional differences in visual acuity, found in an as yet undetermined number of astigmas, are not optically induced, and they are associated with orientational differences in accommodation. Since the meridional effect can also be demonstrated using visual evoked potentials, it presumably must originate in pathways prior to or within the visual cortex.

In order to develop a rational basis for the treatment of amblyopia, it should be useful to first elucidate underlying physiologic mechanisms by studying various visual functions. The original experiments with meridional amblyopes were per-
Fig. 1. Contrast sensitivity (threshold contrast) is shown as a function of spatial frequency for a subject with insignificant astigmatism. Measurements have been made using vertical (open circles), horizontal (closed circles), and oblique (45°; open triangles) gratings. Each point represents the mean of five or more settings and bars depict ± 1 standard error. Curves have been drawn by eye through the data.

Gratings with a sinusoidal luminance profile were produced on an oscilloscope using conventional electronics. The patterns could be rotated to vary orientation. Average screen luminance was 22 cd. per square meter. Subjects viewed the gratings from 172 cm. and a circular mask provided a field of 2.3°. Appropriate ophthalmic lenses were used and refractive error was checked while the subjects observed the patterns. For the cut-off frequency determinations, spatial frequency was increased until the subject indicated the point of pattern disappearance. Subjects set contrast thresholds with switches that provided logarithmic steps of contrast. A bracketing procedure was used, whereby contrast was reduced until the grating disappeared and then it was increased until reappearance of the target. Before each measurement, the gain control for the Z-axis was changed so that switch position could not be used as a clue by the subject. For each variable, five or more measurements were made.

The contrast sensitivity function for a control subject who has negligible astigmatism is shown in Fig. 1. Data have been taken for vertical, horizontal, and oblique gratings. The overall sensitivity functions show typical high- and low-frequency attenuation. There is also an approxi-
Fig. 4. A meridional amblyope with oblique axis astigmatism has matching maximum and minimum contrast sensitivity functions. Symbols are as in previous figures.

...mutely linear relation between log contrast sensitivity and spatial frequency for frequencies greater than 5 cycles per degree, as observed previously. As expected, cut-off frequencies are essentially equal for vertical and horizontal gratings while the oblique target (axis 45°) yields a lower value. This oblique reduction is well known and has been found for various targets. Contrast sensitivities for other spatial frequencies follow a similar pattern with horizontal and vertical about equal and oblique slightly reduced. These findings only apply to frequencies greater than about 5 cycles per degree and, for lower frequencies, no orientation differences are present.

Fig. 2 contains data for a meridional amblyope, BB, who is marginally hyperopic in one meridian and severely myopic orthogonally (+0.25 - 5.00). Therefore, for all fixation distances further than around 20 cm., only vertical lines are in focus when ophthalmic lens correction is not used. Tests with optimal lenses show that the spatial frequency cut-off value is substantially higher for vertical than for horizontal or oblique gratings. Moreover, this difference extends over the entire spatial frequency range including a low frequency of 1 cycle per degree. The overall contrast sensitivity function is markedly reduced for horizontal and oblique gratings and the usual maximum at around 5 cycles per degree is absent.

Results showing orientation differences reverse to the previous subject are given in Fig. 3. This subject, MS, is a compound myopic astigmat, with an axis unusually oblique (-3.00 -3.50 • 155°). In accordance with the idea that visual acuity development can be selectively retarded, a remarkable correspondence is shown between maximum and minimum cut-off frequencies (65° and 155°, respectively) and the astigmatisms: meridians. As in the other cases, the orientation differences apply to contrast sensitivities for various spatial frequencies.

Although the measurements were made using carefully determined correcting lenses, relatively little defocusing can, in theory, reduce contrast sensitivity substantially. Therefore, modulation sensitivities for laser-created interference fringes which bypass the eye’s optics were determined for some meridional amblyopes. In addition, tests were made using several artificial pupil diameters. In all cases, the same orientation differences in sensitivity remained with both techniques.

These results show that meridional amblyopia involves more than a simple reduction in high-frequency cut off. The involvement of middle and low frequencies suggests that the defect affects a number of neural groups or channels that are sensitive to specific spatial frequencies and orientations. To probe possible physiologic...
mechanisms, the Fourier transform can be used to relate frequency and spatial domains. The resulting spatial weighting functions enable a description of plausible receptive field organization in meridional amblyopia.  

From the School of Optometry, University of California, Berkeley, Calif. This work was supported by a grant from the National Eye Institute, National Institutes of Health (EY 01175). Submitted for publication Sept. 3, 1974. Reprint requests: Dr. R. D. Freeman, School of Optometry, University of California, Berkeley, Calif. 94720.

Key words: meridional amblyopia, contrast sensitivity, modulation sensitivity.

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