Central and peripheral retinal photoreceptor orientation in amblyopic eyes as assessed by the psychophysical Stiles-Crawford function

Harold E. Bedell

Retinal photoreceptor orientational tendencies were assessed within both eyes of samples of control and selected functional amblyopic observers, with the psychophysical Stiles-Crawford (S-C) function used as an indicator. S-C function determinations were made at testing locations spanning 30° of the horizontal meridian of the visual field and including the foveal region. Normal-appearing S-C functions with peak locations which clustered within a subregion of the pupil were found for all but one of the eyes tested. The single exception was a non-amblyopic eye of one of the amblyopic observers. Thus, within this sample of amblyopic eyes, visual acuity deficits are apparently not related to retinal photoreceptor alignment anomalies.

Key words: strabismic amblyopia, anisometropic amblyopia, squint, amblyopia, Stiles-Crawford effect, photoreceptor orientation, photoreceptor alignment, retinal directionality, peripheral vision, central vision

Functional amblyopia is characterized by a diminished visual acuity, usually in one eye only, which is not resolved by optimal refractive correction. Gross indications of pathological conditions are either absent or are of insufficient magnitude to account for the acuity loss.*

The nature of the anatomical and physiological changes which occur in functional amblyopia are as yet incompletely understood. The search for such changes is hampered by the high probability that amblyopia is not a unitary syndrome with a single underlying pathological defect. On the contrary, anomalies at any of a number of sites within the visual system might give rise to a decreased acuity.1-7

*For the purposes of this argument, any ocular or systemic condition which impairs vision and is localizable in its effect is deemed to be pathological. Thus, for example, opacification of the lens, which may simply be related to the aging process, andavitaminoses which impair photopigment production, transport, and/or regeneration, are here considered to be pathological conditions.
**Table I. Clinical data for amblyopic and control observers**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Rx</th>
<th>Acuity</th>
<th>Heterotropia</th>
<th>Fixation</th>
<th>Corr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. E. M.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>$-1.25 = +0.25 \times 180$</td>
<td>20/12%</td>
<td>6A LET, 1A RHT</td>
<td>OD: Central</td>
<td>ARC</td>
</tr>
<tr>
<td>OS</td>
<td>$-0.25$ sph.</td>
<td>20/200</td>
<td>Far and near</td>
<td>OS: $5.75-7^\circ @ 345^\circ$</td>
<td></td>
</tr>
<tr>
<td>L. B. P.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>$-2.25 = +0.25 \times 15$</td>
<td>20/15</td>
<td>4A LXT far</td>
<td>Central OU</td>
<td>ARC</td>
</tr>
<tr>
<td>OS</td>
<td>$-9.00 = +0.75 \times 90$</td>
<td>20/30</td>
<td>12A LXT near</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. M. C.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>$+2.25 = +0.75 \times 90$</td>
<td>20/35</td>
<td>3A E far</td>
<td>Central OU</td>
<td>NRC</td>
</tr>
<tr>
<td>OS</td>
<td>$-2.75$ sph.</td>
<td>20/12%</td>
<td>Ortho near</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. S. M.</td>
<td>Plano</td>
<td>20/125</td>
<td>8A RET far</td>
<td>OD: 1.2-1.8° @ 180°</td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>$+0.50 = +0.50 \times 90$</td>
<td>20/17%</td>
<td>16A RET near</td>
<td>OS: 0.4-0.7° @ 0°</td>
<td>ARC</td>
</tr>
<tr>
<td>B. A. J.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>$+1.25$ sph.</td>
<td>20/17%</td>
<td>4A LET far</td>
<td>Central OU</td>
<td>ARC</td>
</tr>
<tr>
<td>OS</td>
<td>$+1.00 = +0.25 \times 175$</td>
<td>20/25</td>
<td>8A LET near</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. L. C.</td>
<td>Plano</td>
<td>20/17%</td>
<td>6A LRT far and</td>
<td>OD: Central</td>
<td>ARC</td>
</tr>
<tr>
<td>OD</td>
<td>$+0.50$ sph.</td>
<td>20/175</td>
<td>near</td>
<td>OS: 0.5-0.6° @ 10°</td>
<td></td>
</tr>
<tr>
<td>OS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. S. D.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>$-1.50 = +0.50 \times 90$</td>
<td>20/30</td>
<td>4A LET, alt</td>
<td>OD: 0.4-1.4° var</td>
<td>ARC*</td>
</tr>
<tr>
<td>OS</td>
<td>$+1.00 = +0.25 \times 90$</td>
<td>20/60</td>
<td>HT</td>
<td>OS: 0.7-0.9° @ 320°</td>
<td></td>
</tr>
<tr>
<td>M. A. P.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>$-1.00$ sph.</td>
<td>20/17%</td>
<td>4A E far</td>
<td>Central OU</td>
<td>NRC</td>
</tr>
<tr>
<td>OS</td>
<td>$-0.75$ sph.</td>
<td>20/15</td>
<td>Ortho near</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. B. S.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD</td>
<td>$+0.50 = +0.50 \times 104$</td>
<td>20/17%</td>
<td>1A E far</td>
<td>Central OU†</td>
<td>NRC</td>
</tr>
<tr>
<td>OS</td>
<td>$+0.25 = +0.25 \times 80$</td>
<td>20/17%</td>
<td>2A X near</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*ARC indicated by Bagolini striated lens test; NRC indicated by afterimage test.
† Entoptic foveal projection decentered 0.6-0.9° with respect to functionally specialized fovea. See ref. 20.

Information processing within the human visual system is primarily centripetal, in at least its early stages. It is apparent that psychophysically or neurophysiologically demonstrated abnormalities, sampled at proximal sites within human amblyopic or experimentally induced amblyopic visual systems, might reflect either anomalies at that level of processing, anomalous input from more distal sites, or both. It therefore seems reasonable to approach amblyopic pathophysiology in a distal-to-proximal direction, i.e., to ascertain the status of the information passed along to subsequent stations from each "processing" center in amblyopic visual systems.

Advances have already been made in this line of attack. In post hoc analyses of limited numbers of cases, the optical transfer properties (imaging capability) of the media of amblyopic eyes were found not to be impaired relative to that of nonamblyopic eyes.8-10 These results indicate that acuity deficits in sampled amblyopic eyes were not directly attributable to existing optical defects within these amblyopic eye media. It is clear that this statement must be qualified in cases of amblyopia with anisometropia.

The next most proximal elements in the visual processing chain are the retinal photoreceptors. The photoreceptors have optical properties of their own, which are in part contingent upon their orientation with respect to one another and to the eye pupil.11 In vitro studies of the optical properties of animal and human receptors indicate that poorly oriented receptors are less efficient light col-
Photoreceptor orientation in amblyopic eyes

<table>
<thead>
<tr>
<th>Media and fundus</th>
<th>History and remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal OU</td>
<td>Underactive LSO, apparently congenital</td>
</tr>
<tr>
<td>Normal OD</td>
<td>Childhood onset LET, postsurgical residual LXT</td>
</tr>
<tr>
<td>Myopic crescent OS</td>
<td>Anisometropia, amblyopia not diagnosed until 11 years old</td>
</tr>
<tr>
<td>Normal OU</td>
<td>Family history of strabismus; monocular diplopia OD</td>
</tr>
<tr>
<td>Reduced pigment 10° inf. to macula OS</td>
<td>Family history of strabismus and amblyopia</td>
</tr>
<tr>
<td>Normal OU</td>
<td>RET with onset 1-2 years</td>
</tr>
<tr>
<td>Normal OU</td>
<td>Congenital RET with family history; underactive LIO, LIR</td>
</tr>
<tr>
<td>Nevis at macula OD</td>
<td>Control observer</td>
</tr>
<tr>
<td>Normal OS</td>
<td>Control observer</td>
</tr>
</tbody>
</table>

Collectors and have poorer optical transfer properties than do well-oriented groups of receptors. Enoch has outlined the theoretical bases for reduced retinal resolution capability as the result of disturbed photoreceptor orientation.

An extensive body of evidence indicates that the psychophysical Stiles-Crawford (S-C) function reflects the orientational properties of retinal photoreceptor groups. In particular, the location of the peak of the S-C function appears to be a valid indicator of the overall alignment tendency of a group of receptors with respect to the pupil. The S-C functions of normal observers, when measured up to 35° in the peripheral visual field, have peaks which cluster near the center of the pupil, indicative of a receptor alignment tendency toward the pupil for at least this range of retinal locations. In eyes in which anomalous S-C functions have been measured at the fovea in conjunction with observable retinal pathology, other visual functions, including visual acuity, have also shown adverse changes. In cases in which the S-C function has been found to recover, visual acuity has also shown improvement. It is unclear, however, what portion of the visual acuity changes in these cases represents aspects of the observable pathological processes in addition to the inferred changes in receptor orientation.

S-C function measurements in a limited number of amblyopic eyes have indicated the existence of receptor alignment anomalies within some of these eyes. The anomalies have been in the form of (1) a significant displacement of the S-C function peak from the pupil center, presumably reflecting a modest "tilt" of the receptors, or (2) a disruption of the normal S-C function shape, so that the measured function is flattened, asymmetrical, or without a clear peak. The latter result is hypothesized to indicate a "general malorientation" of the receptors, in which there is presumably a disturbance of alignment not only with respect to the pupil center but also between neighboring receptors.

Anomalous photoreceptor alignment, which has been inferred within some amblyopic eyes, represents the first level in these amblyopic visual systems at which discrete pathological conditions can be identified. For this reason, the contribution of these anomalies to the status of visual functioning and to subsequent visual processing in affected amblyopic eyes warrants investigation. Since S-C function peaks have occasionally been reported to be displaced within the entrance pupil of presumably normal observers, the extent to which such anomalies occur in amblyopic eyes, as well as in nonamblyopic and apparently normal eyes, also requires clarification.

To date, the assessment of receptor orientation in amblyopic eyes has been confined to the fixation area or to a small region...
around it.\textsuperscript{31} Since the visual functioning of amblyopic eyes has been reported to approach that of nonamblyopic eyes in the amblyopic eye's peripheral visual field,\textsuperscript{35-37} it is of considerable interest whether, in amblyopic eyes in which receptor orientation anomalies are demonstrable, such anomalies are confined to a central retinal region. Alternatively, receptor orientation abnormalities might be found both centrally and peripherally in affected amblyopic retinas. These two alternatives carry differing implications not only for the extent of pathological processes within affected amblyopic eyes but also for the nature of the disturbance of presumed receptor alignment mechanisms within these eyes.

**Apparatus and procedure**

This research utilized the psychophysical S-C function to characterize the nature of possible receptor orientation anomalies within the eyes of functional amblyopic observers at several locations spanning the central and near peripheral retina. The two-channel Maxwellian view instrument used to determine S-C functions has previously been described.\textsuperscript{20-21}

Observers' eyes were dilated with 10\% phenylephrine hydrochloride (Neo-Synephrine) or with 1\% tropicamide (Mydriacyl) after ocular pathology and potential contraindications to drug use had been ruled out.\textsuperscript{*} Photopic S-C functions were determined by an increment threshold procedure, the test beam being fixed at the pupil center and the background beam displaced in successive steps across the pupillary aperture. The observer viewed a 0.5° test field flashed for 250 ms once each second and superimposed upon the center of a 4° 24' background field. Changes in the position of the retinal image of the background field, resulting from ocular aberrations affecting the beam at noncentral pupil entry positions, were compensated by shifting the aperture which defined the background field. The test and surround fields were thereby maintained in concentric alignment for all pupil entry positions of the background beam.

Discounting the S-C function itself, background field luminance was 3.04 log photopic trolands. Both test and background fields were orange (Kodak Wratten No. 23A filter). Increment thresholds with both test and background beams at the pupil center were determined over a 4 log unit range at each visual field test location for each observer. The increment threshold data indicated that all S-C tests were conducted on the linear, Weber portion of the increment threshold curve.\textsuperscript{31, 32}

The observer was held in position by means of a dental impression and forehead rest, both attached to a mill frame adjustable in the x, y, and z directions. The experimenter positioned the observer with these controls while observing the image of his entrance pupil upon a scaled reticle viewed in an infrared image converter. Pupil position was monitored continuously and adjusted during experiments to maintain proper alignment with respect to the test and surround field beams and the exit plane of the instrument.

The test and background fields were placed in optimal focus by supplemental lenses determined by retinoscopic examination both foveally and peripherally. For data recorded other than at fixation, the observer's gaze was directed to a dim red collimated fixation source. At the locus of fixation, the centered test array itself served as a fixation target. Thresholds were determined by the method of adjustment, with the stipulation that the observer always approached the end point from the same direction, i.e., either ascending or descending.

S-C functions were measured at a number of visual field locations spanning central and near peripheral retinal positions. The test locations chosen were (1) 10° temporal visual field (TVF), (2) 5° TVF, (3) the locus of fixation, (4) 5° nasal visual field (NVF), (5) 10° NVF, (6) 20° NVF, and (7) the fovea if different from location 3. All visual field testing locations were not examined for all observers.

In order to determine whether testing at the fixation locus also included the fovea, the Purkinje retinal vessel pattern was generated within the S-C testing apparatus. In this way, the entoptically viewed avascular zone of the vessel pattern could be located with respect to the test field under the actual testing conditions. A 2 diopter prism, placed in the background channel and rotated by a variable speed motor, caused the background field beam to rotate through a circle of approximately 2 mm radius in the observer's entrance pupil. Observers who could appreciate the pattern* saw a slightly wobbling retinal vessel pattern within the surround field and noted, when fixating the test field, whether the avascular zone of the vessel pattern was concentric about the test field. If not, the

\*For this purpose, intraocular pressures of all observers were determined by applanation tonometry and found to be within the normal range.
observer located a variable-position fixation target at the visual field position which brought the avascular area of the vessel pattern to surround the test field. "Foveal" S-C functions were determined with the observer fixing this fixation target.*

Observers. Amblyopic and nonamblyopic control observers were recruited from campus student and Health Center populations. None of the observers of this study was referred directly from clinical sources, and therefore this sample may not be typical of clinical amblyopic populations. One of the control observers (S. B. S.) had participated in a previous S-C function study. All other observers were naive to visual psychophysical measurements.

Evaluation. Both the amblyopic and nonamblyopic control observers were evaluated with the same program of clinical tests. These included (1) a history, (2) monocular visual acuities for 8-position, double-break Landolt C targets, (3) refraction, (4) motility and strabismus examinations, (5) monocular fixation positions, assessed by one or more of three entoptic tests20, 38 (Maxwell's spot, Haidinger's brush, and the Purkinje vessel pattern), and (6) biomicroscopy and fundus examinations.

Selection criteria. Amblyopic observers were expected to have a difference of at least one line in their best corrected, monocular visual acuities for Landolt C targets. The acuity deficits were expected to be of long-standing, i.e., dating to childhood, as revealed by the history. Furthermore, a contributory history of strabismus, anisometropia, or early abnormal visual experience was anticipated. Anterior chamber and fundus examinations were expected to reveal no abnormalities which might be responsible for the acuity findings. All the amblyopic observers met these criteria. The results of the clinical examinations of the amblyopic observers are summarized in Table I.

Control observers were expected to have at least 20/20 best-corrected monocular visual acuities for Landolt targets and minimal between-eye acuity differences. Anterior chamber and fundus examinations were expected to reveal no abnormalities. The control observers were also expected to be orthophoric or heterophoric. The two control observers met these criteria; the results of their clinical examinations are also presented in Table I.

Data analysis. Raw S-C data were computer-fit to a least-squares regression equation based upon the parabolic equation proposed by Stiles.39 The equation used was:

\[ y = b_2x^2 + b_1x + b_0 \]

where the log_{10} neutral density attenuating the test field beam at threshold is represented as \( y \) and the pupil entry position of the surround beam as \( x \). The best-fitting parabola was estimated from data within 3 mm of the function peak, since S-C func-
The S-C function peak location for a single pupillary meridian was estimated from the fitted regression equation as the ratio \(-b_1/2b_2\). The location of the peak of the two-dimensional S-C function within the pupil for each visual field test location was estimated by vectorially summing the estimated peak displacements from the pupil center along the horizontal and vertical test meridians. That is, considering the pupil as a Cartesian coordinate plane, the estimated S-C function peak locations within the pupil plane were determined as the coordinate locations corresponding to the estimated horizontal (temporal-nasal, x axis) and vertical (superior-inferior, y axis) peak displacements from the pupil center.

S-C function directionality (broadness) was estimated both with Stiles' rho value, represented as the parameter \(b_2\) of the fitted regression equation, and the half-sensitivity half width, computed from the fitted parabola. The half-sensitivity half width is defined as the separation in the entry data more than 3 mm from the peak are no longer well fit by a parabola. Pupil entry position data (x values) were adjusted for beam displacements resulting from the use of spectacle lenses within the S-C apparatus. Additionally, since the pupil appears foreshortened when viewed obliquely, corrections were made in the meridian of foreshortening when testing was 15° or more in the peripheral visual field. Thus, for example, when testing was at 20° in the NVF, a correction of \((\cos 20°)^{-1}\) was applied to horizontal surround beam entry positions. In this case, no correction is required for vertical displacements. At 10° obliquity and less, the cosine correction was considered insignificant.
trance pupil, in millimeters, between the peak of the S-C function and the entrance pupil location at which sensitivity equals one-half that at the S-C function peak.

Results

**Control observers.** The estimated S-C function peak locations for visual field test locations between 10° TVF and 20° NVF are shown for both eyes of the control observers, S. B. S. and M. A. P., in Fig. 1. The estimated S-C function peak location for a test area 35° in the TVF of observer S. B. S.'s left eye, replotted from Bedell and Enoch, is also shown in Fig. 1.

Inspection of Fig. 1 reveals that the estimated S-C function peak locations for both eyes of the two control observers and for test positions spanning 30° of the horizontal meridian of the visual field, in all cases clustered within a small area near the center of the pupil. When considering the figure, one should recall that 1 mm in the entrance pupil corresponds to approximately 2.5° at the retina. The results shown here were similar to those reported by Enoch and Hope for one eye of each of three observers tested over the same range of visual field locations and to the results of one eye of each of four additional observers tested over only a part of this range. Additionally, a comparison of the pattern of estimated S-C function peak locations within the two eyes of each control observer revealed very little difference in the clustering tendency between the eyes.

**Amblyopic observers.** Clearly anomalous S-C functions were not identified within any of the sample of amblyopic eyes studied at any of the visual field test locations. All amblyopic eye S-C functions had estimated peaks falling well within the dilated pupil. Moreover, all of these amblyopic eye S-C functions were well fit within 3 mm on either side of the estimated peak location by parabolas.

These results were not expected. In fact, the two amblyopic observers S. L. C. and S. S. D. were recruited for S-C function testing at and around the locus of fixation only after no examples of anomalous S-C functions had been found in the original sample of five amblyopic observers.

In all but one case, the nonamblyopic eyes of the amblyopic observers also revealed estimated S-C function peaks which clustered within a subregion of the dilated pupil. The left, nonamblyopic eye of observer P. M. C. (Fig. 2) was an obvious exception to this generalization. The results for this eye suggested that photoreceptors within this eye were aligned more closely toward the center of the eye than toward the exit pupil. These data will be more completely considered in a separate communication. The estimated S-C function peak locations for both eyes of five amblyopic observers tested at a range of visual field positions are shown in Fig. 2. Estimated S-C function peak locations for observers S. L. C. and S. S. D. at the fovea are presented in Table II.

In some cases, the measured amblyopic eye S-C function peaks did not cluster about the pupil center. For example, the S-C function peak locations of observer M. S. M.'s right amblyopic eye fell between 1.25 and 2 mm from the pupil center (Fig. 2). However, S-C function peak locations determined for the fellow, nonamblyopic eye of this observer were similarly displaced from the pupil center. A tendency for S-C function peaks to cluster around a region slightly displaced from the pupil center was also observed for one of the normal observers of Enoch and Hope. Displacements of this magnitude are not considered to be indicative of significantly disturbed receptor alignment.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Amblyopic eye</th>
<th>Nonamblyopic eye</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. L. C. OS</td>
<td>0.6 mm nasal</td>
<td>OD 0.6 mm nasal</td>
</tr>
<tr>
<td></td>
<td>0.6 mm inferior</td>
<td>0.4 inferior</td>
</tr>
<tr>
<td>S. S. D. OD</td>
<td>0.5 mm nasal</td>
<td>OS 1.1 mm nasal</td>
</tr>
<tr>
<td></td>
<td>0.8 mm inferior</td>
<td>0.3 mm inferior</td>
</tr>
</tbody>
</table>

S. S. D.

*Estimated S-C function peak locations for the individual horizontal and vertical pupillary traverses are tabulated, for both control and amblyopic observers, in Appendix C of Bedell.

A comparison of the estimated S-C func-
Fig. 3. S-C functions for horizontal traverses of amblyopic left eye pupil of observer L. B. P. at a range of visual field test locations. Log relative sensitivity is plotted on the ordinate (hash marks = 0.1 log units) and millimeters in the entrance pupil on the abscissa. The functions are arbitrarily displaced along the ordinate. Solid curves are fitted least squares parabolas (see text). Error bars are 1 S.E.M. Note the systematic shift of S-C function peaks from nasal to temporal of pupil center between testing locations at 10° TVF and 20° TVF.

S-C function directionality. The S-C functions determined at different visual field testing locations indicated a clear and orderly change in directionality. Considering the results of the four control eyes, a pattern was found to be relatively low (small rho value, large half-sensitivity half width) at the locus of fixation, to increase symmetrically at perifoveal testing locations on both sides of the fixation locus, and then to decline once again at more peripheral testing locations. These relationships are evident in Fig. 4, which presents the means of the directionality estimates of horizontal and vertical S-C functions for the four control eyes at each of the visual field testing locations between 10° TVF and 20° TVF.

The amblyopic and nonamblyopic eyes of the amblyopic observers tested in this study also showed an overall pattern of increased directionality for perifoveal testing locations and a fall-off at more peripheral and more central retinal locations. Since S-C functions...
were not determined at the same retinal locations in all the amblyopic eyes of this study, mean directionality values for the range of testing locations cannot meaningfully be presented. The interested reader is referred to Appendix D of Bedell20 for a complete tabulation of S-C function directionalities for both the control and amblyopic observers of this study.

Discussion

For all the control eyes and for all but one (nonamblyopic) eye of the amblyopic observers, retinal receptor orientation, as inferred from these S-C function determinations, tended to be directed toward a subregion of the exit pupil of the eye for all testing locations. The single exception to this generalization was the left, nonamblyopic eye of observer P. M. C., within which receptor orientation apparently conforms to a different law. The data for this observer will be treated in detail in a separate communication.

The present results confirm earlier work by Enoch and Hope21-22 and Bedell and Enoch,23 who found evidence of a receptor alignment tendency toward the exit pupil of the eyes of normal observers, across a range of visual field testing locations, using the S-C function as an indicator. The present results also extend those of the earlier studies. In the present case, between-eye comparisons of estimated S-C function peak locations can be made for several observers. For the two control observers and for at least two amblyopic observers, the patterns of estimated S-C function peak locations within the two eyes appear to be highly similar (Figs. 1 and 2). For two other amblyopic observers, the data suggest a somewhat greater dispersion in the locations of the estimated S-C function peak locations within the amblyopic eyes for the visual field locations sampled (Figs. 2 and 3). The suggested differences between the eyes of these latter two observers are not qualitative in nature but rather seem to be differences in the degree of S-C function peak dispersion within the pupils of the two eyes.

S-C function directionality (rho value or half-sensitivity half width) was found to change in systematic fashion from central to peripheral retinal test locations (Fig. 4). Similar patterns of results were obtained for amblyopic, nonamblyopic, and control eyes. The increased directionality of S-C functions at perifoveal as compared with foveal testing locations was described by Westheimer44 and also by Enoch and Hope.22 The latter study indicated that perifoveal directionality values are attained at or before 2° from the fovea. The subsequent fall-off at more peripheral testing locations is suggested in the data of Enoch and Hope22 and is more clearly evident in the results of Bedell and Enoch.23 Because rod saturation was probably not achieved in the present study, a rod contribution to the broader directionality of peripherally measured S-C functions, although unlikely,23 cannot be ruled out.

The visual field testing locations at which S-C functions were determined in amblyopic eyes were selected to include both central and near peripheral retinal regions. Every effort was made to measure S-C functions within the foveal region of these amblyopic eyes. A priori considerations indicated that retinal receptor orientation disturbances within the fovea were most likely to contribute to decreased visual acuity shown by amblyopic eyes. The amount of visual acuity loss which might reasonably be accounted for by receptor alignment anomalies is modest.17 Thus it was not deemed likely that receptor mal-orientation at extrafoveal locations, at which visual acuity presumably is limited by retinal receptive field sizes rather than receptor
mosaic grain, would meaningfully degrade visual acuity by a mechanism other than by a possible brightness or contrast decrement of the acuity target.

Entoptic projections of the foveal region were employed in order to direct S-C function determinations to the foveal region. The S-C functions determined at the presumed foveal region in the amblyopic eyes of this study are not qualitatively different from those obtained at other visual field testing locations.* That is, there is no hint in the data that a selective disruption of receptor orientation occurs at the foveal region of any of the amblyopic eyes of this sample.

Since none of the amblyopic eyes of this study showed evidence of the anticipated receptor orientation anomalies, such as had been found by previous investigators within some amblyopic eyes,¹⁴-¹⁶ ²⁸-³¹ an assessment of the retinal extent of receptor orientation anomalies was not possible for any of the present sample of amblyopic observers. As noted above, the present sample may or may not be representative of clinical populations of functional amblyopic observers. Thus the possibility of a modest receptor misalignment contribution to decreased visual acuity within other samples of amblyopic eyes must continue to be considered. Differences between the results of this and of previous studies may reflect, in part, vicissitudes inherent in sampling small groups from a nonhomogeneous population.

It is concluded that for the amblyopic observers of this study, retinal receptor orientation at a range of visual field testing locations across the horizontal meridian of the visual field and including the foveal region is essentially undisturbed. Thus, for this sample of amblyopes, anomalous retinal receptor orientation apparently does not contribute to decreased amblyopic eye visual acuities. Within these amblyopic eyes, one must apparently look to a more proximal site or sites within the visual system for the seat of the amblyopic visual loss.

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