juvant in this group. Our results indicate that ocular involvement in sarcoidosis may be more common than generally recognized.

In conclusion, we believe the association of an elevated serum ACE with a chronic granulomatous uveitis suggests the diagnosis of ocular sarcoidosis. Serum ACE is a useful ancillary test for diagnosing ocular sarcoidosis and other granulomatous disorders. From the Department of Ophthalmology and the Francis I. Proctor Foundation for Research in Ophthalmology, University of California School of Medicine, San Francisco. Supported in part by a Sammy Davis Jr Award from Fight for Sight, Inc., N.Y.C. to Dr. Weinreb, a Basil O'Connor Starter research grant to Dr. O'Donnell from the National Foundation-March of Dimes, and National Eye Institute grants EY-01786, EY-01759, EY-02072, and EY-01441. Dr. Char is the recipient of a NIH Research Career Development Award (KO4 EY-00117). Submitted for publication April 30, 1979. Reprint requests: Dr. Robert N. Weinreb, Department of Ophthalmology, Room U-490, University of California, San Francisco, Calif. 94143.

Key words: sarcoidosis, uveitis, granulomatous uveitis, angiotensin converting enzyme (ACE), sarcoid uveitis

Peripheral stimulation and human cyclofusional response. MARK J. SULLIVAN AND ANDREW E. KERTESZ.

Cyclofusional responses consisting of both motor and nonmotor components were measured during stimulation in the peripheral visual field. A 5.75° torsional disparity presented in 10°, 30°, and 50° diameter visual stimulus fields induced binocular, torsional eye movements averaging 2.8° to 3.4°. When torsional disparity was excluded from regions up to 30° diameter in the center of the visual field, binocular torsional eye movements of 3.5° to 4.4° were observed. A presentation of simultaneous, conflicting torsional disparities in center and annular surround regions of the stimulus field also induced torsional eye movements which reduced the disparity in only one of the two regions while increasing it in the other. The directions of eye movement changed when the surround stimulus area was enlarged at the expense of the area of the conflicting central stimulus. Based on an objective method of monitoring eye position, the findings in this report suggest that peripheral stimulation exercises a strong influence on the cyclofusional motor response component and that under suitable conditions such stimulation may have a greater influence on the cyclofusional motor response than central stimulation.

The response to fusional stimulation within the central visual field (foveal and near foveal regions within 10° diameter) has received considerable study, especially in the case of horizontal disparity stimulation and the associated response mecha-
Fig. 1. Examples of the types of randomly segmented line stimuli used. A, Full-field stimulus containing a positive torsional disparity. Full-field stimuli were 10°, 27°, or 50° in diameter. In the first experiment each eye's stimulus was rotated 2.375°. B, Annular stimulus containing a negative torsional disparity. Annuli were 13° to 50°, 30° to 50°, or 13° to 27° in diameter. C, Example of the type of randomly segmented line stimuli used in the second experiment. The center region was 10° or 27°, and the corresponding surround region was 13° to 50° or 30° to 50°, respectively. Opposite torsional disparities were presented in each of the regions. In this example the center contains a negative disparity; the surround, a positive disparity. The different center-surround disparity combinations are specified in Table II. The rotations of the stimuli depicted in the figures have been exaggerated from the actual stimulus rotations in order to show the directions of right and left eye stimulus rotations clearly. The fused percept of the disparate stimuli consisted of single, straight, horizontal segmented lines.

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lines were used. The stimulus luminance level of 34 cd/m² falls within the mesopic range.

The time course of the torsional disparity stimulus was essentially as shown in Fig. 2. The steeply sloped changes in the disparity were actually not smooth but consisted of small, incremental changes in the disparity at the rate of 0.125° per each 64 msec interval. The subject maintained fixation during the entire 45 or 50 sec run, and the torsional positions of both eyes were recorded.

One emmetropic subject (A. E. K.) provided most of the results. Difficulties were encountered with the contact lens method used to record eye movements, so that only the movements of the left eye of the second subject (M. J. S.) could be reliably recorded. The contact lens method severely limits the number of experimental subjects; however, with this method it was possible to record ±5° of eye torsion with a resolution of 2 min arc. Extorsional eye movements are given a positive sign, and intorsional eye movements are given a negative sign in the eye position traces and the tables.

Results. The initial six stimuli, including the two examples shown in Fig. 1, A and B, were used to present an easily fused −5.75° torsional disparity. However, when disparity was presented in the 30° to 50° peripheral annulus, the fusion criteria of singleness, straightness, and horizontality of the stimulus could not be judged while the subject maintained fixation.

Table I presents the average torsional eye movements that were obtained from both subjects. Fig. 2 shows typical plots of the averaged torsional eye movement records of Subject A. E. K. in response to disparity in the 30° to 50° peripheral annulus. Such plots provided the data given in Table I.

Substantial intorsional eye movements were obtained in response to disparities presented with each stimulus configuration, including the annular patterns which stimulated only peripheral portions of the visual field. It is noteworthy that despite uncertainty about the occurrence of fusion, the 30° to 50° peripheral stimulus induced torsional eye movements. Across all stimuli tested, Subject A. E. K. compensated for 49% to 80% of the −5.75° disparity by intorsional movements of the eyes; the remainder of the torsional disparity was compensated through a nonmotor mechanism.

A second experiment was designed to probe the relative importance of central and peripheral stimulation. In this experiment, only Subject A. E. K. participated. Examples of the stimuli used in this experiment are shown in Fig. 1, C. A 50° stimulus field was divided into two independent regions: a center and a surround. In the first of two cases considered, the center region was 27° diameter, the surround was 30° to 50° diameter, and 0° or ±4° torsional disparities were presented in all possible combinations with the two stimulus regions. In the second case, torsional disparities were presented in the same combinations as above, but the center region was reduced to 10° diameter, the surround was changed to 13° to 50° diameter, and the disparity size was fixed at 2°. The 4° and 2° torsional disparity sizes represented the largest disparities that the subject could fuse during the presentation of disparities having opposite sign in the center and surround stimulus regions. In all cases, the subject used the same criteria for fusion as in the first experiment.
The data indicate two different response trends from each center-surround disparity combination. Associated with the large central (27°) stimulus was a torsional eye movement that generally reduced the retinal image disparity in the central region. When the central region was smaller (10°), the motor response compensated for the retinal image disparity in the surround (13° to 50°). When the central region was smaller (10°), the motor response compensated for the retinal image disparity in the surround (13° to 50°).

### Discussion

**Cyclofusional stimulation in only the visual periphery evoked a cyclofusional response which consisted, in part, of the disjunctive torsional eye movements which we measured accurately with a sensitive, continuous monitoring of eye position.** In the response to central or peripheral stimulation, the resultant torsions took 10 or more seconds for completion. Stimuli located out as far as 30° from the center of the visual field induced a motor response. However, we cannot provide any precise functional relationship between stimulus position and cyclofusional motor response because we have results from only two experimental subjects. We can say that cyclofusional stimulation in the visual periphery is a significant factor in both nonmotor and motor components of the cyclofusional response.

The second experiment further illustrated the effects of peripheral stimulation during simultaneous stimulation in both central and peripheral retinal regions. By measuring the motor response component when central and peripheral disparity information conflicted, we obtained clear evidence that the fusional mechanism can exhibit a motor response which reduces retinal image disparity in a 13° to 50° region of the visual periphery while increasing the retinal image disparity in the 10° center of the field. The central 10° stimulus alone could have provoked a compensatory motor response as was shown earlier.

These eye movements were surprising and could not be predicted. Their occurrence raises a number of questions about the relationship of motor and nonmotor components of cyclofusional response. One would expect coordination between the two response components in order that single vision be facilitated primarily in the center of the visual field. There may, however, be instances of increased need for single vision in the visual periphery, such as in cases of impaired central vision. Our results imply that the relative contributions of motor and nonmotor components are not solely determined on the basis of minimizing torsional retinal image disparity uniformly across the visual field or in central retinal regions only.

One further item should be mentioned along with the results already covered. Several years ago Kertesz found himself and other subjects not to have a cyclofusional motor response to 10° diameter stimuli in the central visual field. We have obtained data which suggest that experience with wide-angle cyclofusional stimulation aided in the development and maintenance of A. E. K.'s cyclofusional motor response. When wide-angle cyclofusional stimulation was deliberately not given to Subject A. E. K. for 1 month, his cyclofusional motor response was diminished on retesting. After a few minutes of wide angle stimulation, however, the motor response increased. This bit of evidence plus A. E. K.’s initial development of a motor response after exposure to wide-angle cyclofusional stimulation implies that the cyclofusional motor response is partly dependent on the history of exposure to wide-angle cyclofusional stimulation.

From the Department of Electrical Engineering and Computer Science, Northwestern University, Evanston. This research was supported in part by National Institutes of Health grants EY1055, GM574, and RCDA EY70887 to A. E. K. Submitted for publication Nov. 27, 1978. Reprint requests: Mark J. Sullivan, Ph.D., Bell Laboratories, Holmdel, N.J. 07733.

**Key words:** cyclofusion, peripheral vision, eye movements, binocular disparity

### REFERENCES


### Table II.

Average torsional eye movement (in degrees) in response to conflicting torsional disparities in center and surround regions (A. E. K.)

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Torsional disparity</th>
<th>Average eye torsion*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Center</td>
<td>Surround</td>
</tr>
<tr>
<td>Center:27°; surround: 30°-50°</td>
<td>+4°</td>
<td>-4°</td>
</tr>
<tr>
<td>+4°</td>
<td>0°</td>
<td>-2°</td>
</tr>
<tr>
<td>-4°</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>Center:10°; surround: 13°-50°</td>
<td>+2°</td>
<td>-2°</td>
</tr>
<tr>
<td>-2°</td>
<td>0°</td>
<td>+0°</td>
</tr>
<tr>
<td>-2°</td>
<td>0°</td>
<td>+0°</td>
</tr>
</tbody>
</table>

*— = Intorsion, + = extorsion.
Each entry represents an average of three to five responses.