ANOMALOUS RETINAL CORRESPONDENCE*
ITS ESSENCE AND ITS SIGNIFICANCE IN DIAGNOSIS AND TREATMENT

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INTRODUCTION

The attempt is made in the following pages to give a succinct survey of normal binocular vision in so far as it is of importance for the understanding of the visual act in strabismus and especially of anomalous retinal correspondence. This is followed by a discussion of the essence of anomalous correspondence and of its importance in diagnosis and treatment.

This presentation is largely didactic in purpose. It is therefore somewhat dogmatic in form, and opinions of other authors are not reviewed critically. The literature is not quoted because of the character of this article. It is readily available in other publications.

NORMAL CORRESPONDENCE AND THE BINOCULAR VISUAL ACT

1. THE SUBJECTIVE VISUAL DIRECTIONS

Each retinal element conveys when stimulated not only a sensation of brightness and color, but also a sensation of direction—that is, every visual sensation is localized in a definite direction. This direction is determined by the "local sign" pertaining to the stimulated retinal element; we speak of a spatial value inherent in every retinal element.

The visual directions determined by the spatial values of the retinal elements are not absolutely fixed in space; they change with the position of the eyes and are only fixed relative to the visual direction of the fovea which is termed the principal visual direction.

The visual directions, therefore, inform us only of the position of visual objects relative to each other and to the fixation point and that only in the horizontal and vertical extent of the field of vision. They do not inform us about the relative position of the visual objects in the third dimension (depth) or about the absolute (or egocentric) position of visual objects—that is, their position relative to our body (to the right or the left of us, above or below the level of our eyes, near or far from us).

Properly speaking, therefore, the spatial values of the retinal elements transmit a relative subjective visual direction.

2. CORRESPONDING AND DISPARATE RETINAL ELEMENTS

The visual apparatus of man is so organized that within the region of binocular vision there are pairs of retinal elements in the two eyes which have the same relative subjective visual direction. These pairs of retinal elements are termed corresponding retinal elements (fig. 1). Since corresponding retinal elements have a visual direction in common, they are also defined as retinal elements which have a common visual direction. Such corresponding retinal elements are, for example, the two foveas, but every other retinal element within the area of binocular vision also has a corresponding partner in the other eye.

Vertical and horizontal rows of corresponding retinal elements are corresponding retinal meridians; the horizontal and vertical meridians which intersect at the fovea are the principal horizontal and the principal vertical corresponding retinal meridians.

Retinal elements in the two eyes which have different visual directions are termed noncorresponding or disparate retinal elements. In analogy to the corresponding
retinal meridians, one speaks of noncorresponding or disparate retinal meridians.

Grossly, one may say that retinal elements in the two eyes which have the same relative position to the fovea (that is, which are for example equally far to the right and below each fovea) are corresponding points. Actually, however, the distribution of the corresponding retinal elements is neither regularly progressive from the fovea toward the periphery nor symmetrical. The actual distribution of the corresponding retinal elements can, therefore, only be determined by subjective methods.

This is a task for the laboratory, not for clinical investigation, and it suffices here to say that the best method for the determination of the distribution of corresponding retinal elements consists in the determination of the horopter. The horopter is defined as the locus of the object points in space which produce the stimulation of corresponding retinal elements in the two eyes. Knowing an individual’s horopter, we know, therefore, how his corresponding retinal elements are distributed.

3. Normal Correspondence

Normal retinal correspondence is said to exist in a person when retinal elements in the two eyes (for example, the two foveas), which should have a common visual direction, actually prove to possess it.

Normal retinal correspondence is the most fundamental fact in binocular vision. It is apparent from the foregoing discussion that it must be considered to be innate, not experiential. In other words, normal retinal correspondence is based on the anatomic and physiologic organization of the organ of vision; it is phylogenetically acquired and not acquired in the course of individual development.

4. Sensory Fusion and Panum’s Areas

Since the foveas are corresponding points, the fixation point is localized in the common visual direction of the two foveas and the fixation point is, therefore, seen singly. Likewise, any other object point which stimulates corresponding retinal elements is seen singly. The sensory unification of two retinal images impinging on corresponding retinal elements, based on the fact that corresponding retinal elements have a common visual direction, is termed sensory fusion.

Contrariwise, an object point which is imaged on disparate elements in the two retinas (if it is, for instance, nearer or farther than the fixation point) is localized in two different visual directions and is, therefore, seen double. However, within certain narrow limits the simultaneous stimulation of disparate retinal elements may produce a single visual impression.

Every corresponding retinal element forms the center of a more or less sharply defined area of disparate retinal elements. These areas are equal in the two eyes.

Sensory fusion occurs when elements
within the equivalent areas in the two retinas are simultaneously stimulated. The resulting fused visual impression is localized in the common visual direction of the retinal elements which form the center of the two areas.

These areas are known as Panum's areas of single vision. Thus, for instance, if we fixate an object point and then move a second object point in the midline toward us or away from us, starting at the fixation point, the second object will be seen singly up to a certain distance from the fixation point. Beyond this distance it will be seen double.

The distance within which the moving object point is seen singly is a measure for the horizontal extent on the retina of the area of Panum which has the fovea as its center (fig. 2).

5. Stereopsis

The object point which is moved away from the fixation point is seen singly as long as it is imaged within Panum's area, but it also appears nearer or farther than the fixation point. A new quality is added to the visual impression, the quality of depth or stereopsis.

Stereopsis, the relative subjective localization of object points in the third dimension, is brought about by the simultaneous stimulation of horizontally disparate retinal elements located within Panum's areas. Vertical disparity does not produce stereopsis.

Within limits the depth effect bears a quantitative relation to the disparity of the retinal images; the greater the horizontal disparity, the greater is the depth effect. Below a certain minimum of disparity there is no stereopsis, above a certain maximum there is diplopia.

For our consideration, the most important characteristic of stereopsis is the assimilation of the visual directions of the retinal elements which takes place in stereopsis; the fused stereoscopic mental image of the disparate retinal images is seen in the visual direction of the corresponding retinal elements which form the frame of reference.

To make this a little clearer. A simple stereoscopic picture consists of two sets of vertically arranged dots, one set seen by each eye (fig. 3—A).

The images of the upper and lower dots, seen by the right and the left eye (1, 1'; 3, 3') fall when fused on corresponding retinal areas (fig. 3—B). They lie on corresponding meridians and are, therefore, seen in a vertical plane parallel to the forehead of the observer; that is, they appear equidistant (fig. 3—C).

The middle dots are shifted to the left in the right half of the stereogram, to the right in the left half of the stereogram. This means that they are imaged in crossed (temporal) disparity and that their fused image must appear in front of the dots 1, 1' and 3, 3'.

Fig. 2 (Burian). Panum's areas of single binocular vision. Any point lying on the line AB, including the fixation point F, is seen singly since it stimulates retinal elements within the areas of Panum (b_La_L and a_Rb_R) which have the foveas f_L, f_R for their center. Any point nearer than B (such as P) or farther than A is seen double (physiologic diplopia).
The middle dot is, however, seen neither to the right nor to the left of the dots 1, 1' and 3, 3' but in line with them (fig. 3—A, B, C). It is seen, in other words, in the visual direction of the corresponding meridian on which the upper and lower dots are imaged; the fused image of 2 and 2' has assimilated the visual direction of the corresponding retinal elements which form the center of the Panum’s areas to which the stimulated disparate points belong (in our example, the foveas).

According to the foregoing, stereopsis is more than, and essentially different from, the simple unification of corresponding retinal images. A new factor, the assimilation of the visual directions, makes its appearance and this new factor is responsible for the sensation of stereopsis.

**Essence of Anomalous Retinal Correspondence**

6. **Adaptability of the Organ of Vision**

While normal correspondence is innate and fixed, this does not imply that it is so rigid that no change may occur if abnormal conditions warrant a change.

Actually, one of the most striking features of the organ of vision is its adaptability. There is no visual function which is absolutely rigid. Accommodation, dark adaptation, the existence of Panum’s areas, and of fusional movements are a few of the most obvious examples.

When there is an extreme disturbance of the motor conditions in a patient—as in a case of concomitant strabismus—a profound upset in the visual act occurs which finds its expression in the sensory symptoms of strabismus.

But it must be kept in mind that none of these symptoms adds anything new to the visual act; they are all only pathologic exaggerations of physiologic phenomena. Suppression and amblyopia are closely related to suppression and retinal rivalry as they normally occur; anomalous correspondence is an extension, as it were, of the assimilation of the visual directions within Panum’s areas which normally takes place in sensory fusion.

7. **Essence of Anomalous Correspondence**

The last sentence has already indicated the essence of anomalous correspondence. It consists of a rearrangement of the common visual directions of the retinal elements of
the two eyes. Corresponding retinal elements lose their common visual direction; disparate retinal elements acquire a common visual direction.

A patient with a manifest strabismus may develop anomalous correspondence. From the foregoing, this condition can be defined in two ways.

One can say that in anomalous correspondence the two foveas which are normally corresponding points lose their common visual directions and acquire two different visual directions. Or one can say that an extramacular element of the deviated eye adopts the visual direction of a disparate point, namely that of the fovea of the fixating eye.

The shift of the visual directions which occurs in anomalous correspondence may become a little clearer by using the following simile (fig. 4). One can think of the fingers of the two hands as of the retinal elements and their spatial values. If the hands are joined as in the act of prayer (fig. 4—A) this can be taken as representing the cyclopean eye; the corresponding superimposed fingers are then the common visual directions. We shall call the middle fingers the “foveas.”

When one hand is now shifted relative to the other (fig. 4—B), this gives a picture of anomalous correspondence. The two “foveas” have no longer a common visual direction; the middle finger of the right hand (the “fovea of the deviated eye”) is superimposed on the index finger of the left hand (the “extramacular element of the fixating eye”) and the two have now a “common direction.”

![Fig. 4 (Burian). Symbolic presentation of normal and anomalous correspondence. (A) The two middle fingers (the foveas) have a common direction $\varphi$. (B) The two middle fingers have different directions ($\varphi_L$ and $\varphi_R$).](image-url)

This crude simile must not be taken too literally else it may lead to misunderstanding. But it demonstrates another feature of anomalous correspondence. When one hand is shifted relative to the other, the fingers, which are now superimposed, do not fit each other. This may be thought of as denoting the marked difference in visual acuity between the retinal elements which have a common visual direction in anomalous correspondence.

8. ANOMALOUS CORRESPONDENCE AND BINOCULAR VISION

The fact that in anomalous correspondence the fovea of the fixating eye and an extramacular element of the deviated eye have a
common visual direction implies single vision with these two, originally disparate retinal elements. It is apparent, therefore, that the acquisition of an anomalous correspondence represents an adaptation of the sensory apparatus of the eyes to the abnormal position of the eyes. Anomalous correspondence is an attempt of the organism to restore some semblance of binocular vision.

Whereas, such a teleologic interpretation of anomalous correspondence is forced upon us by all the observed facts, one must not assume that anomalous retinal correspondence fully replaces normal correspondence in the visual act of the squinting individual. This has been repeatedly pointed out and the very term anomalous "correspondence" has been criticized on that basis.

It has been emphasized that anomalous correspondence connects retinal elements of markedly different visual acuity, that in addition suppression prevents these elements from cooperating, and that there is no stereopsis in anomalous correspondence—that is, no response to disparate stimulation. It is indeed not quite correct to say, as is sometimes done, that in anomalous correspondence the patient uses the fovea of one eye with an extramacular area of the deviated eye. On the other hand, at least some patients with anomalous correspondence do make use of both eyes in the binocular act in a way approaching normal binocular vision.

The fact of suppression may actually serve to equalize the acuity of the retinal elements which have anomalous common visual directions. And when the central areas are not used together, vertical fusional movements can be elicited in anomalous correspondence by peripheral disparate stimulation indicating a rather high degree of binocular cooperation, although stereopsis is always absent.

9. ANOMALOUS CORRESPONDENCE AND SUPPRESSION

It has long been established that patients with concomitant strabismus have areas of selective suppression in the deviated eye. One such area is in the macular region, the other in the extramacular area upon which impinges the image of the fixation point.

The co-existence of suppression and anomalous correspondence has always intrigued the investigators interested in this subject. On the one hand, it was considered that suppression was necessary to loosen the normal correspondence. Suppression would, therefore, be a necessary step in the establishment of anomalous correspondence.

On the other hand, some investigators questioned the correctness of the whole concept of anomalous correspondence because of the presence of suppression. They reasoned that in the presence of suppression anomalous correspondence could not establish itself and that common visual directions between a suppressed area in one eye and a nonsuppressed area in the other eye could not be of any conceivable use to the organism.

These objections are not justified. First of all, they are not based on fact. In virtually every patient it is possible to demonstrate the existence of common visual directions, normal or anomalous, between the retinas of the two eyes. Often it is not possible to do this with a major amblyoscope because of suppression and, if an investigator relies exclusively on the synoptophore test, he may be led to the erroneous conclusion that there is no "functional correspondence" between the two eyes. But if other tests are also employed, normal correspondence or some type of anomalous correspondence is always evident.

Secondly, the objections rest upon false premises. Anomalous correspondence is a physiologic not a psychologic process. It is brought about by the abnormal stimulus situation which exists when the fixation point impinges upon the fovea of the fixating eye and an extramacular area of the deviated eye.

This abnormal stimulus situation results in some way in the loosening of normal correspondence and the creation of a new rela-
tionship between the retinal elements of the two eyes.

Suppression in the deviated eye does not interfere with this process. Even though the patient is not aware of visual impressions coming from certain regions of the retina of the deviated eye, the sensitivity of the retinal elements and the function at least of the lower neurons is not impaired. There is no reason why the stimulation of the retinal elements in the suppressed areas should not result in more or less normal excitations and exert a physiologic effect. That it actually does is shown just by the co-existence of suppression and anomalous correspondence.

10. Neurophysiology of Anomalous Correspondence

How does the abnormal stimulus situation produce the loosening of normal correspondence and the establishment of anomalous correspondence?

Nothing is known about the neurophysiologic processes which are the correlative of what appears subjectively as anomalous correspondence. But a conjecture may be permissible.

One must first ask oneself what makes normal correspondence possible. The tremendous arborization, both protoplasmic and axonal, within the nervous structures subserving vision allows anatomically a potential contact of almost every retinal element with almost every cell in the visual cortex of the brain.

The physiologic point-to-point relationship which we know to exist must result from the fact that the impulses generated in the retinal elements are normally conducted along physiologically predetermined pathways. The predetermining physiologic factor is likely to be, as Lorente de Nó assumed, the threshold of excitation at the various synapses.

Under ordinary conditions of binocular vision, a certain leeway exists which permits the assimilation of visual directions within Panum's areas.

Under abnormal stimulus conditions, as in concomitant strabismus, we may assume that a change occurs in the threshold at the synapses, facilitating the transmission of the impulses at some points, impeding it at others, thus redirecting the flow of the impulses.

11. Conditions for Establishment of Anomalous Correspondence

This conjecture may serve to emphasize the physiologic nature of anomalous correspondence and to allow us to form a picture as to how the shift in visual directions comes about. The hypothesis may be incorrect in detail; for clinical purposes this is of no concern, since we are thoroughly familiar with the conditions for the establishment of anomalous retinal correspondence and with its clinical manifestations.

In contrast to normal correspondence, anomalous retinal correspondence is acquired by usage. The position of the patient's eyes, the constancy of the angle of squint, the use a patient makes of his eyes are, therefore, of paramount importance in the establishment of anomalous retinal correspondence.

Also, normal correspondence is not at once supplanted by anomalous correspondence. This is a process requiring time and the length of time necessary, as well as the success in the establishment of anomalous correspondence, depend on the individual adaptability.

The number of patients is considerable in whom normal, as well as anomalous, correspondence can be elicited in one way or another. How easy it is to elicit normal correspondence depends on how deeply the anomalous retinal correspondence is rooted.

If the angle of squint is unstable, as in the accommodative type of strabismus, if it is markedly different for distance and near vision, the likelihood is much less that an anomalous correspondence will be established. The same holds true for the intermittent type of strabismus in which the eyes of a patient are straight a good deal of the
In all these patients the anomalous correspondence, if it is at all present, is unstable and in many tests these patients can be made to localize either according to normal or anomalous correspondence.

In general, one can say that the more time which has elapsed since the onset of the strabismus or since a change in the condition has occurred spontaneously or under the influence of therapeutic measures and the more stable the deviation is, the more one is likely to find a stable anomalous correspondence.

12. CLINICAL MANIFESTATIONS OF ANOMALOUS CORRESPONDENCE

In testing for anomalous correspondence, one may find a normal sensory relationship of the two retinas or an anomalous correspondence, or both.

If there is anomalous correspondence the anomalous angle between the visual directions of the two foveas (the angle of anomaly) may be equal to the deviation. For instance, if there is a concomitant esotropia of 15 degrees, the angle of anomaly (found in the after-image test) may also be 15 degrees. If this is the case, the anomalous correspondence is termed harmonious (fig. 5—A), since the sensory condition is fully adapted to the deviation. Often it is, however, found that the angle of anomaly is smaller than the angle of squint. Sensory and motor conditions are then not in accord and this type of anomalous correspondence is termed unharmonious or subharmonious.

A harmonious anomalous retinal correspondence can only develop under especially favorable conditions. Frequent changes in the angle of squint make a development of a harmonious anomalous correspondence impossible and the best the organism can do
under the circumstances is to choose an average common visual direction and form an unharmonious anomalous correspondence.

In some patients one may find that the retinal relationship is harmonious for certain conditions (for example, when the patient is tested with his glasses on), but unharmonious for other conditions (for example, when the patient is tested without his glasses).

A special type of unharmonious anomalous correspondence is the so-called paradoxical diplopia (fig. 5-B). A patient who has been recently operated upon (or whose angle of squint is corrected by glasses or prisms) may present this type of diplopia. If the patient was previously esotropic, he will now present crossed diplopia; if he was exotropic he will show uncrossed diplopia. This is explained by the persistence of the anomalous retinal relationship which has as yet not had time to catch up with the changed motor conditions.

Since patients in all stages of development or regression of anomalous correspondence present themselves for examination, there is a wide variety of its clinical manifestations. There are patients whose anomalous correspondence is so deeply rooted that normal correspondence can only be elicited with the greatest difficulty if at all. At the other end of the scale are the patients whose anomalous retinal correspondence is so superficially established that it may be only fleetingly present and only in tests which simulate in so far as possible the conditions to which the patients are adapted. Between these extremes there are many shades and gradations.

As a rule, if the anomalous retinal correspondence is unstable, normal and anomalous localization appear successively in the same or different tests. There are, however, rare cases in which a normal and anomalous response is elicited at the same time.

These patients localize simultaneously in two visual directions with the deviated eye and are said to have monocular diplopia or binocular triplopia (fig. 5-C).

This phenomenon occurs only in patients with relatively labile anomalous correspondence in whom there is a rivalry between the normal and anomalous mode of localization. It is most frequently seen as a transitory stage after operations when the normal retinal relationship is beginning to get the upper hand. Presumably it is also present as a stage in the development of anomalous correspondence. We have now learned from the work of Frances Walraven that it can be artificially produced by macular stimulation on the synoptophore in many more cases than was thought possible before.

Binocular triplopia may thus acquire increasing practical significance for the orthoptists. Also, its understanding leads to a full appreciation of the essence of anomalous correspondence. It is therefore important to make quite clear to oneself what binocular triplopia represents.

This may best be grasped if one thinks first of paradoxical diplopia. In paradoxical diplopia the anomalous correspondence continues to exist after the angle of squint has been changed and the patient localizes therefore according to anomalous correspondence. If, at the same time, normal correspondence is present the patient has two subjective angles on the synoptophore and triplopia in the double image test; one of the secondary images is seen in paradoxical diplopia, the other is localized normally.

Essentially this means that the fovea and all other retinal elements in the deviated (or formerly deviated) eye have actually and simultaneously two spatial values; that eye possesses two systems of retinal correspondence, one normal and one anomalous (fig. 5-C).

One must get away from the idea that the extramacular area in the deviated eye on which the fixation point was originally imaged plays a role in this phenomenon. Using the neurophysiologic explanation of anomalous correspondence already given one can assume that, in monocular diplopia, im-
pulses reaching the retina are conducted simultaneously along two channels.

When anomalous correspondence was first investigated clinically, the term pseudomacula or pseudofovea was coined to designate the area in the deviated eye which acquires a common visual direction with the fovea of the fixating eye.

It was soon found that this is a misnomer, since the extramacular area of the deviated eye on which the fixation point is imaged in no way acquires macular properties, except that it exhibits, in binocular vision, a common visual direction with the fovea of the fixating eye.

One must, therefore, not expect, as some beginners do, that the cover test will be influenced by the type of the patient's retinal correspondence. The deviated eye will always assume fixation, if it can at all fixate, when the fixating eye is covered, irrespective of the state of the retinal correspondence.

Eccentric fixation which is a monocular phenomenon must not be confused with anomalous correspondence which is a binocular phenomenon. And it is more than unlikely that anomalous correspondence will adversely affect the cosmetic result of operations by forcing the eyes back into a deviated position.

**Diagnosis of Anomalous Retinal Correspondence**

13. Importance in Orthoptic Diagnosis

Well-established anomalous retinal correspondence is a serious obstacle to the recovery of normal binocular vision. Herein lies its significance for the orthoptic diagnosis.

It is, however, not enough simply to state that a patient has anomalous correspondence. The value of any diagnostic procedure is determined by the amount of help it lends in establishing the prognosis and in directing the course of treatment.

It is essential, therefore, that it be investigated whether a patient has harmonious or unharmonious anomalous correspondence, whether his anomalous retinal correspondence is stable or labile, whether and under what conditions normal correspondence can be elicited, and so forth. All this cannot be achieved with any one test, routinely applied.

It is one of the purposes of this presentation to put in a plea to the orthoptists not to restrict themselves to one single test, but to avail themselves of all possible tests. The application of various tests will not only make the work more interesting; the practical advantages gained will make the additional effort put into the examination well worthwhile.

14. Basis of Tests

Owing to the shift in visual directions, a patient with anomalous retinal correspondence sees double with retinal elements with which he should see single (for instance the two foveas) and single with retinal elements with which he should see double (for instance the fovea of the fixating eye and an extramacular area of the deviated eye). This behavior is utilized in the tests for anomalous correspondence.

Both criteria—double vision and single vision—can be made use of and the methods of clinical testing may be divided into two groups.

In the first group, the deviation (the position of the eyes) is compared to the subjective localization or biretinal stimuli, or to the angle at which the patient superimposes or fuses the visual impressions reaching the retina.

In the second group, the visual direction or directions of the two foveas are directly determined.

In the first group belong the synoptophore and red glass (diplopia) tests and their modifications. In the second group belong the after-image test and the observation of apparent movement (phi phenomenon).

15. Synoptophore Test

In the test using major amblyoscopes the deviation (the objective angle) is first deter-
mined in the usual manner and is then compared with the subjective localization (subjective angle). This can be done in two ways.

One may place the synoptophore targets at the previously determined objective angle. If the patient superimposes the targets in this position, he has normal correspondence. If he sees them separated, he has anomalous correspondence.

Or, if one wishes to determine the amount of the subjective angle, one may ask the patient to adjust the targets until they appear to be superimposed. One then compares the angle at which the patient does so with the objective angle. If the two angles are the same, the patient has normal correspondence. If they differ, there is anomalous correspondence: superimposition at zero indicates harmonious anomalous correspondence; superimposition anywhere between the objective angle and zero indicates unharmonious anomalous correspondence.

When the targets of the major amblyoscope are in the position of the objective angle, the task assigned to the patient is to superimpose stimuli which reach simultaneously the two foveas. This is not always easy for the patient; simultaneous macular stimulation is the thing which squinting patients try above all to avoid.

Also, bimacular stimulation is an unusual condition and, in patients with labile anomalous correspondence, one may under those circumstances find a different subjective localization than when the fovea of the fixating eye and an extramacular area of the deviated eye are simultaneously stimulated.

The latter situation obtains when it is attempted to determine the subjective angle on a major amblyoscope. In using this method one finds, however, in a considerable percentage of patients that they are unable to superimpose the targets in any position, owing to suppression.

16. Diplopia Test

This suppression of the extramacular area of the deviated eye is often more easily overcome in the diplopia test than on the major amblyoscope.

In the diplopia test, the patient is asked to fixate a small light source. After the objective angle has been determined by the prism and cover test or any other objective test, a red glass is placed in front of one of the patient's eyes. He will as a rule readily see two lights, one red one and one white one.

In normal correspondence the direction and amount of separation of the two lights correspond to the direction and amount of the deviation. In anomalous correspondence the separation of the two images is smaller than one would expect from the angle of squint; it may be zero (fig. 5—A), in which case the sensory anomaly is harmonious, or even opposite in direction (paradoxic diplopia, fig. 5—B).

The diplopia test is easily performed, even in small children, but one must guard against certain errors and know how to avoid difficulties which may arise.

The red filter must be sufficiently dark to eliminate from the field of view everything except the fixation light which appears as a dark-red spot. The red filter should always be placed first in front of the eye which the patient habitually uses for fixation. By dimming first the dominant eye it is easier to make the patient aware of diplopia, since the brighter white fixation light is less likely to be suppressed than the darker red light.

If the patient does not at once notice diplopia, the test is facilitated by covering alternately first one eye of the patient, then the other, thus teaching him what he is supposed to see. If the patient nevertheless suppresses too strongly, one may place a prism base-up or base-down (5 to 10°) in front of one eye. This displaces the images above or below the region of elective suppression and this device never fails to produce immediate diplopia, except in extreme and very rare cases.

In general, however, I do not recommend the use of prisms with the diplopia test, except where the angle of squint is so large that
it must be reduced. But it should not be fully corrected by prisms, unless this is done with the special intention of studying the response to bifoveal stimulation. For, when the angle of squint is offset by prisms, the fixation light stimulates the foveas of both eyes and this may lead in cases of labile anomalous correspondence to a change in the sensory response. This has been pointed out already in the discussion of the synoptophore test.

While it is advisable to begin the diplopia test by placing the red filter in front of the habitually fixating eye, one should never fail to place the filter also in front of the habitually deviated eye. In so doing one may find that the response of the patient varies according to which eye is used for fixation.

What occurs is that these patients localize anomalously when fixating with the habitually fixating eye but localize normally when they fixate with the habitually deviated eye.

This is interpreted as meaning that the patients are not adapted to this condition and revert therefore to the innate normal correspondence when they are forced to fixate with the habitually deviated eye. It indicates that the anomalous retinal relationship is not deeply established and offers, therefore, a significant prognostic and therapeutic hint to the orthoptists.

The Lancaster red-green test and the congruence test of Tschermak are modifications of the diplopia tests which have been discussed elsewhere and need not be gone into in this paper.

17. After-image test

In all tests mentioned so far the two retinas are simultaneously stimulated (by one stimulus in the diplopia test, by two stimuli, one for each eye, in the red-green and synoptophore tests). The patient's response depends, therefore, on the relative position of his eyes, since this determines the relative position of the retinal images. For instance, if the patient has an esotropia with harmonious anomalous correspondence he will see single in the diplopia test, but if the deviation is reduced he will have crossed diplopia. The situation is analogous in the synoptophore test.

Not so in the after-image test. It is in the nature of this test, and one of its great advantages, that it is entirely independent of the position of the eyes, since the stimulation of the two retinas is successive. Each eye is fixating during the stimulation and the result of the test is solely determined by the visual directions of the two foveas.

The after-image test is performed in the following way: The eyes of the patient are successively exposed to a lamp with straight filament, one eye receiving a horizontal, the other a vertical stimulus. During the exposure of one eye the other eye is well protected from the light of the lamp. The central part of the lamp is concealed by a metal ring which bears a fixation mark. This is the essential part of the whole arrangement, without which the test is pointless.

By means of the ring, the foveas remain unexposed to the stimulus and the region of the foveas appears as a gap in the vertical and horizontal after-images which have been produced. The relative position of the gaps, as seen by the patient, indicates the condition of the retinal correspondence.

If the two foveas have the same visual direction, as in normal correspondence, one gap will be seen at the center of a cross formed by the after-images, no matter what the relative position of the eyes and regardless of changes in the relative position of the eyes during the observation of the after-images.

If the foveas have two different visual directions, as in anomalous correspondence, the vertical after-image with its gap will appear shifted to the right or left on the horizontal line.

Again this relation is not affected by a temporary change in the relative position of the eyes during the observation of the after-
images or by a permanent alteration of the position of the eyes. It is, for instance, the same prior to and after a successful operation for strabismus, provided the sensory retinal relationship has remained unchanged.

The angle of anomaly is determined with satisfactory accuracy by means of the after-image test. If the length of the filament of the lamp is known and if the patient is at a known distance from the lamp during the exposure, the angular size of the filament relative to the eye can be computed, and the distance between the gaps is a direct measure of the angle of anomaly.

One finds, as a rule, in the after-image test, during one test or a series of tests under varying conditions, only one mode of localization. But even in the after-image test, different types of response may be obtained. Some patients may, for instance, localize the positive after-images normally, the negative ones anomalously; or they may localize differently when their eyes are dissociated than when they are straight, and so forth.

This variability in localization in the after-image test is found in transitional periods in which an anomalous localization is well on the way to being established but has, as yet, not succeeded in replacing completely the normal retinal relationship.

18. Observation of Subjective Movement (Phi Phenomenon)

Another method of determining directly the visual directions of the two foveas, which so far has not been applied clinically to any extent, consists of the application of the so-called phi phenomenon.
If retinal elements having different visual directions are successively stimulated in monocular or binocular vision, the observer will perceive an apparent movement. If retinal elements having the same visual direction are stimulated successively, no apparent movement will be noted. "Moving" advertising signs are an example of this phenomenon and the so-called prism-and-parallax test is based on it.

Consequently, if the foveas of the two eyes are successively stimulated with a suitable arrangement, no movement should be perceived by the patient if he has normal correspondence (fig. 6—A), but if he has anomalous correspondence, an apparent movement should be noted (fig. 6—B).

Contrariwise, with stimulation at the subjective angle no movement should be perceived by a patient with anomalous correspondence.

It would seem that, at least from an academic point of view, this interesting situation should be well worth investigating and that the major amblyoscopes with their flashing devices might offer a good opportunity for its study.

19. EVALUATION OF TESTS FOR ANOMALOUS CORRESPONDENCE

Two factors and their interaction determine the result which is obtained in the examination of a patient with anomalous correspondence. One is the condition of the patient, the other the nature of the test.

Every individual is born with normal correspondence; it has to be overcome to establish a new sensorial retinal relationship. Not every individual is equally well able to make this adjustment. Also, it is a slow process and at first this new relationship is not very deeply rooted. But as it takes deeper roots it will push the innate normal relationship more and more in the background.

Now, if the normal retinal correspondence is stable or an anomalous correspondence fully established, all tests will tend to give the same result and modifications of the tests will not influence it. If, on the other hand, the anomalous correspondence is more or less labile, different tests will yield different modes of localization and the patient's response can be modified by modifying the test conditions.

The type of response elicited depends then on the nature of the test. Anomalous correspondence is a result of adaptation of the organism. This adaptation occurs for the specific conditions of casual seeing under which the patient uses his eyes. Therefore, the more closely a test duplicates these conditions, the more likely is the patient to respond with an anomalous localization; the farther removed the test is from the conditions of casual seeing, the more frequently one will find that the patients revert to normal correspondence. Only if anomalous correspondence is very deeply rooted does the nature of the test remain without influence; the patients present then the same anomalous correspondence in all types of tests.

It seems to me that the synoptophore test is closest to the natural conditions of seeing, the diplopia test is much less so, and the after-image test is quite devoid of any connection with the normal use of one's eyes. Instead of detracting from it, different responses in the different tests add, on the contrary, significantly to their value as an aid in establishing the prognosis. The prospect of curing an anomalous correspondence is least certain when a patient habitually has anomalous correspondence in all tests; it is greatest when anomalous correspondence is found only in the synoptophore test. Between these two extremes many transitional types of response are met with.

ANOMALOUS RETINAL CORRESPONDENCE IN TREATMENT OF CONCOMITANT STRABISMUS

20. BASIS OF TREATMENT

The state of the sensorial retinal relationship is of small practical interest in patients in whom a satisfactory cosmetic result by surgery is the only goal. But to the orthoptist
whose task it is to restore to the patient normal and comfortable binocular vision in casual seeing, anomalous correspondence is a factor of major importance. Anomalous retinal correspondence is the greatest single obstacle in orthoptic treatment.

Whereas anomalous retinal correspondence may be considered to result from a purposeful adaptive process, it is not always easy to reverse this process. All the factors that are operative in the establishment of an anomalous sensorial relationship (usage, time, individual adaptability) are also operative in the reestablishment of normal correspondence.

If it is correct that anomalous retinal correspondence is the result of the abnormal stimulus situation which obtains when the two eyes have a faulty relative position, then the methods which might be expected to restore the normal retinal relationship must avoid the abnormal stimulus situation.

This may be done in a passive way by preventing one eye from taking part in the act of vision, or in an active way either by correcting the faulty position of the eyes (operations, prisms), or by offering to the eyes as frequently as possible an adequate stimulus situation (orthoptic treatment).

21. TREATMENT BY OCCLUSION

If one eye is excluded from the act of vision for a prolonged period of time, there is no binocular stimulation and this may lead to a loosening of the abnormal sensorial retinal relationship. Any such loosening implies, however, automatically a restoration of normal correspondence and it is understandable, therefore, that occlusion of the better eye (or alternate occlusion in alternating strabismus) has been generally recommended as an essential adjunct in the treatment of anomalous correspondence.

There are some rare cases in which occlusion alone appears to cure an anomalous correspondence, but I know of no case in which the cure is permanent. Sooner or later the eyes revert to anomalous correspondence.

To accomplish a permanent cure a more active treatment is necessary than is afforded by occlusion alone.

22. TREATMENT BY OPERATION

The ideal treatment would seem to be to place the eyes mechanically in such a position that they are straight, thus creating a normal stimulus situation. And, indeed, all writers seem to agree that the most favorable results are obtained by operations. It is, however, by no means true that operations invariably insure a return to normal correspondence.

First of all, even in the hands of the most experienced and skillful operator, the ideal result which would exactly duplicate the normal conditions can only be approximated. But even when they are as closely approximated as our coarse surgical procedures permit, normal correspondence is reestablished spontaneously only in a fraction of the cases. The reestablishment must be encouraged by other means.

23. TREATMENT BY PRISMS

In principle, one should expect that the normalization of the stimulus situation by the use of prisms should be very beneficial in the treatment of anomalous correspondence. It seems, however, that their usefulness is not as great as one would anticipate. One of the reasons for this is that patients with concomitant strabismus try to avoid simultaneous macular stimulation.

If the image of the fixation point is brought by prisms on the two fovea, it will not stay there; the patient will change his angle of squint until the image of the fixation point is again removed from the macular area. This, of course, defeats the purpose for which the prisms were given.

I believe, nevertheless, that prisms have not been sufficiently tried to permit a final judgement. I think that they are valuable, if only as an adjunct, particularly for the correction of small postoperative residues of deviations, and more especially for the cor-
rection of vertical deviations, and I should urge that the orthoptists insist that they be more frequently used.

24. TREATMENT BY ORTHOPTIC EXERCISES

The type of treatment which aims most directly at the re-awakening of normal correspondence is the treatment in which a major amblyoscope is employed to produce biretinal stimulation of selected areas.

It is not my task to enter into the details of the techniques developed to this end and I am not qualified to do so. A few general remarks may, however, be permissible.

When an image is moved over the retina of the deviated eye in binocular vision, anomalous localization may be suddenly replaced by normal localization. This is utilized in orthoptic treatment either by “massaging” the macula of the deviated eye or by “kinetic bi-retinal stimulation” at or near the objective angle.

In these methods the normal correspondence is re-established, at least for the duration of the treatment, and the patient is made aware of the proper localization.

Another approach to the problem has been discovered by Frances Walraven. In her technique, alternating foveal fixation is practiced somewhere beyond the subjective angle and the deviating eye is trained to become the fixating eye during the test. When this is achieved, the arms of the synoptophore are moved until the subjective angle is reached and at this point many patients will, according to Miss Walraven, display monocular diplopia.

If they do, they are then taught to distinguish between the two images and to suppress the image which is localized anomalously. In the further course of the treatment, the arms of the instrument are moved ahead until they reach the objective angle and the treatment is continued at that angle.

At the present time I am unable to tell you how successful this treatment is in its practical application, but on theoretical grounds it would seem to me to be most promising and deserving of widest attention.

The monocular diplopia technique—and for that matter any other orthoptic technique —can be successful in re-establishing normal correspondence only if the anomalous relationship is not too firmly rooted. Unless there is a certain lability one cannot expect the normal correspondence to come readily to the surface by orthoptic means.

25. PLACE OF ORTHOPTICS IN TREATING ANOMALOUS RETINAL CORRESPONDENCE

The ophthalmologist has probably the most powerful tool in his hands for the permanent correction of anomalous retinal correspondence. This tool is the operative procedure. And yet this correction is not as often achieved as might be expected, for reasons inherent both in the operations and in the patients. The ophthalmologist needs the assistance of the orthoptist who will help prepare the ground by pre-operative training and establish the gains achieved in the operations by postoperative treatment.

On the other hand, I feel very strongly that the orthoptist needs the help of the ophthalmologist. The ophthalmologist must be willing to operate when the orthoptist has achieved all she can reasonably expect to achieve. Nowhere are proper timing and cooperation between doctor and orthoptist more important than here.

Also, the training with a major amblyoscope occupies only a small fraction of a week. During the rest of the time, the patient is on his own. I feel very strongly that weekly or biweekly visits are rather useless and I should like to insist that daily visits—even for a relatively short time—should be instituted wherever this is possible. And it should be possible.

Orthoptic treatment of anomalous correspondence is a luxury. Not every patient must be treated or should be treated. But when treatment is undertaken it should be carried out to best advantage, in fairness both to the patient and to the orthoptist.

It goes without saying that, during the
periods in which no treatment is given, the patient should wear an occluder over one eye. However, postoperatively or where the deviation is small the ophthalmologist, in cooperation with the orthoptist, should attempt the use of prisms in order to encourage the normal cooperation of the eyes rather than to discourage it.

The treatment of anomalous correspondence is a difficult and thorny problem. Yet, looking back over the past 15 years I can not help but feel optimistic. The progress made has been quite remarkable and the general interest which has been aroused bodes well for further and even more significant advances.

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TORSIONAL EYE MOVEMENTS
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Torsional eye movements have been the source of considerable confusion and controversy in the study of ocular motility. This paper has been prepared with the hope that it may assist in clarifying certain aspects of torsional eye movements. The results of a few simple experiments concerned with torsion will also be reported. It is felt that a definite understanding of the rules or laws that govern torsion may lead toward a more simplified concept of the mechanics and physiology of ocular movements in general.

For the sake of simplicity in terminology, and ease of visualization by the reader, only monocular motility will be considered in this paper, when this is possible. However, it will be necessary to make reference to binocular eye movements in order to clarify certain concepts.

REVIEW

Movements of the globe have often been described as occurring about a center of rotation. Although it is known that the center of rotation is not a definitely fixed point, the assumption of such a point being fixed does help in the visualization of ocular movements.

In 1854, Fick described three primary axes, all perpendicular to each other and all passing through the center of rotation. These were called the vertical (x), horizontal (y), and the anteroposterior (z) axes.

Movements of the globe may be thought of as being resolved into coordinates referable to these primary axes. Thus from the primary position a rotation occurring about the vertical axis results in a movement of pure abduction or adduction. A rotation of the globe occurring about the horizontal axis results in a movement of pure elevation or depression. It is well accepted that such movements can and do occur voluntarily.

A rotation of the globe occurring about the anteroposterior axis would result in a movement of pure intortion or extortion. The term cycloduction is used to denote such a movement.

Duke-Elder is quoted, "Cycloduction indicates a wheel motion, dextrocycloduction and laevocycloduction indicating a rotation of the upper pole of the cornea to the right and left respectively. . . . The term torsion, sometimes used in this sense, I am retaining for the physiologic wheel motion which occurs when the eye is moved in a tertiary position (for example, up and to the right)."

For descriptive purposes in this paper cycloduction will sometimes be referred to as a pure torsional movement. As for the occurrence of cycloduction, it is usually accepted that a pure torsional movement (intortion or extortion) is possible but that such