

an oculist two things: one that Smith's operation, or one that completely removes lens and capsule, is preferable to the operation that does not: and the other that it is necessary sharply to scrutinize the eye before operating as to the condition of the ciliary processes, and to be able to estimate their departure from the normal standard. If this be done, then if confident that disease is present, there are two ways to act,—one to do Smith's or a similar operation—and the other, if the usual operation be preferred, to prepare the eye by previous treatment with Hyd. and iodid, or still more effectually by the use of the "Combined Treatment."

These conclusions seem to me to be rational and to enable reliable preventiva-

tive measures to be used. It is especially so, when nonsuccess has already occurred in one eye, and the operator does not wish to practice Smith's or a similar operation, but again to perform the same one in the remaining eye.

An additional preventative measure would be to do a preliminary iridectomy, tho it is so scathingly denounced by some oculists, but I beg to say, unjustifiably: for those cases in which a preliminary iridectomy has been followed by an inflammation, have been so affected on account of the inherently diseased condition of the ciliary processes, and not on account of any increased liability arising out of the preliminary operation, as this latter has a contrary, deterrent effect.

THE IMPORTANCE OF HETEROPHORIA TESTS IN ROUTINE REFRACTION.

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The mutual relations of heterophoria with errors of accommodation are discussed. A distinction is made between accommodative convergence and fusional convergence. The significance of various forms and manifestations of heterophoria are considered. Presented in the Section on Ophthalmology of the American Medical Association, at the St. Louis Meeting, May, 1922.

Homer failed to state why "Odysseus bored out the eye of Polyphemus," but we can safely infer that it was not a surgical measure for the relief of asthenopia, for with but one eye the Cyclops must have been free from the exacting demands of coordination necessary to binocular single vision. Rather, he was fortunate in the possession of a monocular system requiring only an incoordinated fixation and accommodation, and incidentally the ordeal of a single instead of a double operation. It is only in man in the highest, and in a few of the anthropoids in a lesser degree, that the most extraordinary function of binocular single vision has, in the process of evolution, been attained. It is, moreover, chronologically considered, one of the more recently acquired coordinating functions and, therefore, less stable than, more easily influenced by, and subservient to, the older fundamental functions. Heterophoria is, therefore,

essentially a problem of evolution in physiology. Among the lower vertebrates, in the hare, for example, the orbits are on opposite sides of the head, and the visual axes directed so nearly opposite that the two visual fields probably nowhere overlap. Further up, in the dog, much of the two fields is in common, and fair binocular vision is probable. Yet there is no evidence of a perfected binocular vision. In monkeys, the visual axes may approach parallelism and some may have acquired slight convergence, and most probably a moderate degree of binocular single vision. In man, it is a function of such mechanical precision as is nowhere else exhibited in our physiology, and subject to an error of less than a fourth of a minute of an arc.

The subject of heterophoria is most difficult because the function of muscle balance involves the coordinating action of two or more of the twelve extrinsic muscles, acting as a duet, quar-

tet or sextet, in association with the function of the intrinsic muscles, and under a myriad of circumstances involving varying distance and direction; yet, to meet the demands of binocular single vision, this balance must be of sufficient accuracy to satisfy the requirements of a mathematically exact horopter. Furthermore, no two cases of heterophoria are exactly alike, each having its own peculiar individuality, ever changing with the nervous status of the patient.

It is unfortunate that heterophoria has received such a small share of the study it deserves, and that its teachings are so little used in the practice of ophthalmology. I am convinced that there are many students well grounded in the principles of ophthalmology, having a good working knowledge of muscle balance, who, except in very apparent cases of asthenopia of muscular origin, seldom utilize the tests for heterophoria. Some ignore heterophoria as the cause of asthenopic symptoms, while the opposite extremists attribute many of man's ills to a few degrees of imbalance. Fortunately, however, the subject of heterophoria has had the earnest consideration of many of our most untiring scientific investigators, who have left us the golden fruits of their labors.

The excuse for occupying the reader's time with this much discussed subject is the fact that from one-quarter to one-third of all cases of asthenopia are due to anomalies of muscle balance, which cannot be cured by the correction of refractive errors alone. Reber¹ says: "A review of 1,000 refractive and muscular cases in the writer's private practice indicates that about 70 per cent of them were relieved of their symptoms by the use of their correction alone. The remaining 30 per cent required some manner of attention to their oculomuscular status to bring about more or less complete relief."

What are we doing for this unfortunate class of patients? It is for the purpose of calling attention to this very important subject in every day practice of ophthalmology, especially in refraction, and in the consideration

of the causes of asthenopia, and with the hope that some of the phases of the subject may be elucidated, rather than to present any new findings, that this paper is presented.

In order to be able to recognize anomalies in muscle balance, we should familiarize ourselves with the normal functions of convergence and accommodation and their relations to each other, and to achieve this knowledge, the student should adopt rules for observing the necessary data; for it is only by careful observation of the normal that we are able to detect the abnormal, and it is especially necessary to form the habit of methodically recording the data thus found, for the sake of thoroughness, for your own information, for the patient's sake and for the advancement of scientific knowledge.

I venture, therefore, to enumerate below certain data to be sought during the routine examination for refraction. Certain essential tests should be made in every case, and most, if not all, should be utilized in asthenopic cases, especially those in which the patients have not definitely improved after wearing the refractive correction. Except when it is otherwise stated, the tests should be made with the proper ametropic correction worn.

ACCOMMODATION.

The determination of the accommodative power of each eye should be a routine in refraction, regardless of the patient's age. Many of our failures in refraction work have been due in part to a lack of this important datum. The punctum proximum (P.P.) is the nearest point at which, with maximum effort of the ciliary muscle, distinct vision is possible. A suitable test object, amply illuminated, and corresponding in size to that of Jaeger 0.5 diopter or larger, if necessary, depending on the visual acuity, and a 50 centimeter rule are ample equipment. The fine short line $1/3$ by 3 mm. in India ink on white cardboard, as devised by Duane, is especially adapted. I myself have found different sizes of black horsehair stretched across white cardboard quite as satisfactory. The test object is ad-

vanced toward the eye, the other eye being covered, until the image begins to blur. This locates the punctum proximum and its distance from the anterior focus of the eye (from 13 mm. in front of the cornea) or from the plane of the trial frame is the linear measure of the maximum accommodation of the eye. Since 100 cm. is the unit focal length, 100 divided by this distance (100/P.P.) equals the diopters of accommodation represented. Each eye should be thus tested and the results recorded as part of the necessary data in the consideration of the relation of accommodation to convergence. If mathematic accuracy is desired, the measurement should be made from the nodal point rather than from the anterior focus, but the latter is more convenient. The punctum remotum (P.R.) is the point at which the eye is focused when in a state of complete repose. In emmetropia, it is at infinity; in myopia, within infinity or at a finite distance; and in hyperopia, it is beyond infinity or virtual and its distance negative. Since the refractive power (R.) is the inverse of the focal distance (P.R.) measured in meters, $R. = 1/P.R.$, giving in diopters the plus value of P.R. in myopia and the negative value in hyperopia. These two distances (P.P. and P.R.) may be expressed in diopters, and their difference represents the amplitude of accommodation. Donders, Duane, Jackson and others have recorded abundant data on normal accommodation at various ages, the graphic curves of which are familiar to all. Duane's² show a gradual retrogression of the punctum proximum from the age of 8 or 10 to that of 51, after which the retrogression is very slow, changing only 0.5 diopter in ten years.

Among anomalies of accommodation may be mentioned³ insufficiency of accommodation, the punctum proximum being constantly farther away than normal for the particular age; excessive accommodation; inequality of accommodation of the two eyes, and a sluggish or ill sustained accommodation. As causes may be mentioned toxemia, nasal reflexes, vascular hyper-

tension, neurasthenia, and excessive use of eyes and undue and unequal rigidity of the lens.

RELATIVE ACCOMMODATION.

Relative accommodation is the amplitude of accommodation for a given amount of convergence. The greatest amount of accommodation for a given convergence is measured with the strongest minus sphere with which the object can be seen distinctly, and is known as the positive relative range of accommodation. The negative range of relative accommodation is measured by the strongest plus sphere possible without blurring the image. At 6 meters, the emmetropic eye free from presbyopia will accept a minus 3 D. sphere or more and maintain distinct vision; but for obvious reasons will not accept any plus sphere. Consequently, for distance there is about 3 diopters of positive and no negative relative range of accommodation. Similarly, at one-third meter, the positive and negative ranges are found; but from the positive must be deducted and to the negative added plus 3 diopters, which represents the normal convergence at one-third meter. In ametropia, a disturbed relationship exists between accommodation and convergence, which relationship rather than the ametropia per se is the principal cause of asthenopia. In hyperopia and hyperopic astigmatism, there is anatomically excessive negative and reduced positive relative accommodation, and in myopia and myopic astigmatism the reverse is true—an excess positive and a less negative relative accommodation. A person with hyperopia of 3 diopters may have 3 or more diopters of positive and 3 of negative relative accommodation for distance and a similar disproportion for near. A person with myopia of 3 diopters has no negative relative accommodation for either 6 meters or one-third meter, and a proportionately large positive range of accommodation.

TONICITY.

The natural anatomic position of a pair of eyes during sleep, drunkenness, anesthesia or death is that of diverg-

ence, and according to LeConte⁴ and Prentice ranges up to 20 degrees or more. This tendency to divergence is overcome by innervation (Prentice) or tonic convergence (Maddox). There is diversity of opinion as to the importance of the tonicity test, owing in part, no doubt, to the various methods employed by different observers. This test is made in a darkened room at 6 meters, first without and afterward with the patient's correction. It is generally conceded that, in order to obviate the tendency to fusion, the false image should be such and in such position that it will fall outside the fusion area, which, according to Savage,⁵ extends vertically 3 degrees upward and downward, 8 degrees nasalward, and 25 degrees temporally. The displaced images with the double prisms, bases horizontal, show a greater amount of divergence of the visual axes (more exophoria or less esophoria) at 6 meters than does the distorted image of the Maddox rod, whose image extending across the fusion area stimulates fusion convergence. In order that the vertical and oblique muscles may be as nearly at rest as possible, the light or test object should rest on the extended horizontal plane. Each eye should be tested separately, the image of the other eye being undisturbed. Under these conditions, an exophoria of from 0 to 1 degree, in my opinion, is within the normal. This "physiologic exophoria" is less if the test object, a star, for instance, at infinity, is used instead of the light at 6 meters, where there may be, in the latter case, as much as 0.16 diopter of associated accommodation inducing slight convergence. The nearer the test object is approached, the greater the amount of this exophoria which fusion convergence compensates for under ordinary demands of binocular single vision.

The vertical tests for the vertical muscles should show the images in perfect alignment when the double prisms are turned bases vertically. In order to obviate the tendency to fusion of the lights in these positions, a prism *base in*, sufficient in strength to place the image of the eye examined beyond the

fusion area, may be in some cases better suited for the vertical muscle test than is the double prism.

The tonicity test at 6 meters taken alone is of little value except when correlated with that of duction, convergence and accommodation, and especially with the refractive error.

COVER TEST.

This test, while not accurate in amount, is most responsive, the most convenient, and the quickest test for heterophoria of considerable degree, and is both an objective and a subjective test. The covered eye wanders in the direction and to the position of rest, and when uncovered, the redress toward the point of fixation is easily noted by the observer, and the seemingly reverse motion of the object by the patient. This test is especially serviceable in roughly determining the existence of conjugate muscle imbalance, especially convergence insufficiency and excess for near.

CONVERGENCE.

Convergence is the angular relationship of the visual axes. The distance of the intersection of the visual axes from the base line connecting the centers of rotation divided in to a hundred, measures in meter angles the amount of convergence of each eye, and this multiplied by 7 measures approximately in degrees the amount of convergence. To be more accurate, one-half the interpupillary distance divided by the distance of the object equals the sine of the angle.

The punctum proximum of convergence is the point of intersection of the visual axes during maximum convergence. Duane finds this to be normally about 7.5 cm. from the base line connecting the centers of rotation, representing about 13.3 meter angles of convergence. The punctum remotum of convergence is the intersection of the visual axes when at the least convergence (or greatest divergence). The difference between the maximum and minimum convergence represents the amplitude of convergence and is measured in meter angles, prism diopters, or degrees.

ACCOMMODATIVE CONVERGENCE AND FUSIONAL CONVERGENCE.

In order to satisfy the requirements of binocular single vision, the visual axes must converge to the point observed with an astonishing accuracy. But the stimulus of accommodation alone does not normally accomplish all of this divergence, since the cover test at the reading distance shows that the covered eye deviates outward. This outward deviation is the measure of reflex, or fusional, convergence, and should bear a relationship of about 1 to 3 to the total necessary for the point observed. Maddox allowed three quarters of a meter angle of associated convergence for each diopter of accommodation, leaving 0.25 meter angle to be cared for reflexly. The amount of this reflex increases as the fixation point approaches from a distance, except that when it approaches near enough to the eye to tax the accommodation, then accommodative convergence is coordinately stimulated excessively, and thereby furnishes a proportionally greater percentage of the demanded convergence than does fusion.

To measure accommodative convergence, the conditions of dissociated images outside the fusion center, one image being undisturbed as in the tonicity test, must be fulfilled, the eyes must be accommodating and any presbyopia corrected. To this end, the test object should be small in proportion to the visual acuity, to assure the precise accommodation. The small type, 10 or 12 point horizontal line with a short, broad vertical line drawn across its center, but not long enough to be refracted into the fusion area, helps to induce the proper accommodation, and its size and direction assist the patient in determining when their images are properly aligned. The strength of the prism necessary for this alinement measures the reflex component of convergence, and the total convergence for the point (3 prism diopters for one-third meter) less the amount of this reflex measures the accommodative convergence. This convergence for one-third meter dis-

tance is 3 meter angles, or about 19 prism diopters for each eye. Of this, accommodative convergence supplies normally about 13, and fusion convergence the remaining 6 prism diopters. The asthenopia incident to presbyopia is more often due to disturbed accommodative convergence than to insufficient accommodation. Maddox⁶ implies this when he says, "The most important minute of a refractive consultation is that in which we deliberate what reading lens to order."

AMPLITUDE OF CONVERGENCE.

If, while fixing at the near point of accommodation, the double rotating prism, base out, is increased in strength to the point of diplopia, maximum convergence is induced. This, added to the prism divergence for distance, measures the amplitude of convergence, which is normally about 14 meter angles.

DUCTION.

Duction tests taken alone are of little value, but, considered in connection with the other tests, are often invaluable. For example, when the duction tests are found normal in connection with abnormal tonicity, innervational rather than anatomic muscle deficiency may be suspected. The monocular phorometer, with prism base *in*, gradually increased in strength to the point of diplopia, measures adduction; similarly, with base *out*, it measures abduction; with base *up* and *down*, it measures superduction and subduction, respectively. Each test should be repeated until uniform answers assure accuracy. Normally, the external rectus overcomes a prism of 6 or 7 degrees, the internal rectus 12 to 30 degrees, depending on practice, the superior and inferior recti 2 degrees each. The tonicity should be considered in determining the amount of abduction and adduction. The amount of esophoria should be added to abduction and deducted from adduction, and the amount of exophoria deducted from abduction and added to adduction.

FUSIONAL CONVERGENCE.

Fusional convergence should be determined at one-third meter or, rather,

at the ordinary working distance. A vertically placed line of letter of the alphabet holds the patient's attention and helps to induce accommodation. With each eye fixating this object at the working distance, the rotary prism over one eye, base *in*, increasing in strength to the point of diplopia, measures the negative, and the same, base *out*, the positive fusion reserve. The amount of positive fusion reserve is important in cases of excess tonic exophoria and physiologic exophoria, and that of negative reserve in esophoria and convergence excess. According to Landolt, for comfortable vision no more than from one quarter to one third of the amplitude of convergence should be in constant demand.

VERSION.

Version may be determined by the perimeter or tropometer, and, according to the painstaking observation of Duane, the average readings are 53 degrees inward, 43 upward, 51 outward and 63 downward.

CYCLOPHORIA.

Cyclophoria has been given considerable importance in the writings of Savage,⁵ who considers it a frequent cause of asthenopia. Impaired action of any one of the ocular muscles may, when the eyes are turned in certain positions, cause cyclophoria—even the lateral muscles; but it is the obliques which, when impaired, cause the greatest tilting of the vertical axes. These axes normally diverge upward, the degree of divergence increasing as the eyes are directed downward, more when directed upward and outward and upward and inward. The divergence in the primary position is about

3 degrees, and increases on convergence of the visual axes. The simplest way to measure the degree of divergence of the vertical axes is with the double prism base horizontal, and a straight horizontal line, the two vertical images tilting downward nasalward indicating a normal tilting of the vertical axes of the eyes outward.

The cyclophoria test is one of the most important heterophoria tests, especially in dealing with the functions of the obliques.

The duction tests in this connection may be applied both at 6 meters and at one-third meter by the use of a Maddox rod with vertical axis over each eye, tilting each rod outward and inward until diplopia is imminent.

FIELD OF FIXATION.

Even slight variations in the field of fixation may have an important significance in determining the pathologic condition present.

While all tests should be made with the eyes in the primary position, it is necessary also to repeat them in the cardinal and oblique positions, where the limitation of motion is most exaggerated, indicating the muscle or group of muscles or the innervation at fault.

The subject of heterophoria was chosen with the hope that the essay may elicit a free discussion and criticism of its contents; that the members of the section may become more concerned with the importance of the rôle of muscle imbalance as the cause of asthenopia, and that the section may be induced to devise some plan for standardizing muscle imbalance tests and adopt a nomenclature of the special terms used in dealing with this vast problem.

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