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THE MEASUREMENT OF HETEROPHORIA

BY

NIGEL CRIDLAND, D.M., D.O.

PART II

Section I

The diversity of the available methods is only equalled by the diversion which some of them engender. The fantastic elaborations of the instrument-maker have introduced further complexity, so that the patient, when faced by an imposing mass of machinery, may be easily forgiven for his failure to relax, and the element of voluntary effort becomes a thunder-cloud obscuring the entire heterophoric horizon. The wonder is that the results of measurements by different tests are not even more contradictory than they are. Perhaps no pit-head winding gear can wholly prevent truth from emerging from her well.

Various groupings of the methods of revealing a latent deviation have been chosen by different writers on the subject, and all have ignored the primary dichotomy introduced by the position of rest which is to be attempted. True, only two methods fall into the group which essays the physiological position of rest, but that is no reason for denying them their distinction. All the remaining

tests aim at determining the fusion-free position, and they fall conveniently into four groups. There is first the group in which dissociation is effected by limiting the field of vision of one or both eyes. The second group contains the tests in which one image is displaced from the macula in such manner as to make fusion impossible. In the third group are the tests in which the stimulus to fusion is reduced or abolished by differentiation of the images seen by the two eyes, whether this be effected by change of colour or of form or of some other characteristic of the incident light, or of more than one of these. In the fourth group are the methods which do not attempt to suspend fusion, but the heterophoria is obtained by inference from measurement of some other quantity.

GROUP I

The feature common to all methods in this group is that the field of vision of one or both eyes is limited in such a way that every object seen by one eye is either not seen by the other or is so far from the visual axes as to be, at least in theory, incapable of stimulating fusion. The forerunner of all the tests in this group is the cover (or screen) test, and it, of all tests, most nearly reproduces the natural and "every-day" incidents in which binocular vision is temporarily lost.

The cover test is incomparably simple, and is also the most useful test. It creates the least disturbance, and is amenable to all conditions of distance and direction of fixation, and of type of heterophoria. No dissentient voice is heard among the pæans of approbation, and it is mentioned in most works on squint and on heterophoria. Some writers recommend it before every other test (Berens, Losey, and Hardy 1927, White 1936 *a, b*, Harman (see Perceval 1922), Duane 1914). It has one disadvantage, but one that is shared by nearly every other test, for its subjective form requires some mental acuity in the patient, while its objective form is somewhat handicapped by the wearing of glasses. The fixation point is anything from a star (Stilling, 1885) to a spot on the patient's own nose; the latter is not seen directly, but by reflection in a mirror on the examiner's forehead (Straub, 1892). The removal of the cover must of course be rapid, and the deviation is measured by the prism which, held before either eye, results in no movement being observed on uncovering. Maddox (1920) thought that the cover test gave more esophoric results than the Maddox rod, but later he expressed the opposite view (Maddox, 1921).

Its younger and more delicate brother, the parallax test, demands a power of observation in the patient of sufficient sensitivity to appreciate diplopia, and to declare its direction. Most

patients can attain this. Duane (1895) claimed that this test was able to determine a lateral heterophoria to $\frac{1}{2}^\circ$ and a hyperphoria to $\frac{1}{8}^\circ$. It involves either the transference of a cover from one eye to the other, alternating at a frequency of about once per second (Weymouth, 1916), or the momentary removal of the cover and its immediate replacement (Dolman, 1919, Thorne, 1930). Fischer (1922) used various periods from $\frac{1}{50}$ second to 1 second or longer. The actual measurement is made by finding the prism which gives "no diplopia" at the moment of uncovering. The prisms may be single, or in a battery (Pyle, 1903), or a rotating prism may be used, and Hazen (1900) has given the general rule that, in using prisms, one should work from low values upwards and not vice versa. Gaudenzi (1896) also suggested the use of two dots as objects, of which each eye saw one, and by varying the distance between them the point was found at which "no diplopia" occurred. This test was designed for near but is of course applicable to any distance. Most writers group the cover and parallax tests together, and Duane, in particular, favoured the combination (Duane, 1889, 1905, 1919). Weymouth's subjects found that the co-existence of a hyperphoria materially helped their judgment in the parallax test (Weymouth, 1916).

Cooke (1901) suggested that the patient's own eyelid was an adequate screen, and considered that he could determine heterophoria by the method of closing and opening the eyes, but Broughton (1902) quite rightly pointed out that part of the deviation was caused by the pressure of the lid muscles.

The use of the cover test for near was examined by Randall (1890) who emphasised the need for a small fixation-point, and also described by Clements (1924), who in 1926 made the additional point that the speed of recovery "is a fair estimate of the mental *desire* for binocular single vision." A variation of the cover test was Javal's use of a ground glass which obscured the patient's vision but left the eye visible to an observer: the method is quoted by Tscherning (1920, p. 399).

The use of a cover over one eye led naturally to other methods in which the fields of vision of the two eyes were prevented from overlapping, as they normally do, by screens variously disposed. A screen, stretching away from the patient and placed diagonally, *i.e.*, in a plane between the horizontal and sagittal planes of the body, was used by Holden (1887*b*). One eye saw a single vertical line on the wall, the other saw many, and the relation between the one and the many gave the measure of the heterophoria. Panni (1903) used a somewhat similar method, and Martin's method is much the same, though in this the scale seen by one eye is movable (Martin 1904). The use of two screens, each partly covering an eye, so that one sees only above and the other only below, the

horizontal plane, was suggested by Maddox (1912a). This method, but with one screen replaced by a mirror held almost horizontal over one eye, was given by Holden (1887b). It had the same effect, but the mirror projected the lower field so that it overlay the upper, and perhaps thus made the patient's task easier.

The most ambitious use of mirrors was made by Verhoeff, who devised a reflecting phorometer in which fusion was suspended by a cover, and the adjustment of the mirrors (two to each eye) enabled any apparent movement of the fixation object to be eliminated. The measurement of lateral and vertical heterophoria was thus made at once. The original description of this instrument was given in 1899, and a re-print of Verhoeff's paper appeared in 1926 (Verhoeff 1899, 1926). It followed the classical tradition of all good instruments in that its integrity originally depended upon string.

The "divided-field" principle reached its perfection, for near vision heterophoria, in Maddox's wing test, the universal enjoyment of which excuses any description. Its début was made in 1913. There are other "divided-field" instruments, of which some are still in use. The diploscope, devised by Remy, has spread itself over the literature in such a way that it is scarcely to be avoided. In its original form it was not a measuring instrument, nor was it properly an instrument for detecting heterophoria, but rather for demonstrating the presence of binocular vision. Crudely, it consists of two apertures through each of which each eye sees a letter, and if these four letters are all seen in their proper order and position binocular vision is present without any major degree of squint, latent or manifest. Many descriptions of it are given and a variety of models of it have been designed or made (Bjerke 1909, Hughes 1907, Remy 1906, 1908, Evans 1908, Bichelonne 1923, 1926, Beyne 1932). Bjerke (1910) has also converted it into a measuring instrument. Campos (1911) has discussed the objections to it, and says of it "Projection des images des lettres et des trous vers la plan qui contient le point de convergence des lignes visuelles et vision stéréoscopique; voilà la véritable théorie du diploscope," and Harman (1909a) has also pointed out some of its difficulties.

The various forms of the "trou dans la main" method have also been extensively described (Cantonnet 1917, 1918a, b), and a scale was added in order to obtain measurements (Cantonnet 1919, Bichelonne 1926) while Baldino (1920) altered it so that it used two tubes and thus became a distant relative of Stevens' clinoscope. Cantonnet (1918a, b) has left a pleasing apophthegm "*L'expérience du 'trou dans la main' permet donc de faire du diploscope sans diploscope*": at least it serves as "a pneumatic (sic) tip to remember . . ." (ibid.).

The view is still current that the "Bishop Harman diaphragm test," which was described by him in 1909, is an instrument for measuring heterophoria, but a little consideration shows that this is not so. Its true functions are two, the detection of heterophoria, and the measurement of a character from which it is possible to infer the stability of the fusion reflex, namely, the "central, cerebral, desire for fusion." It measures, by progressively decreasing it until fusion fails, the size of the overlap of the fields of vision which is necessary to maintain the correct orientation of the two fields in relation to each other. It is used to some extent in this country for flying fitness tests. Theoretically, it is admirable, but its practical utility falls materially short of this estimate; for it is extremely rare to find a patient who fails in the test, unless he has a manifest squint, to which cases the test is, *ex hypothesi*, inapplicable. The theory and the mathematical basis of the instrument were explained by Harman (1910).

Merlin's and Stock's tests should perhaps be included in this group (Merlin, 1938, Stock, 1922).

Critical examination of these tests leads inevitably to the conclusion that most of them transgress one or other of the standards which emerged in the early discussion. The cover test alone is exempt, but it is, of necessity, a relatively crude test, as all objective tests of this very delicate function must be. Its subjective counterpart, the parallax test, requires careful attention to detail, for, if the alteration of the cover be rapid, no time is given for the deviation to develop, while, if the alternation be slow, there is an instinctive ocular readjustment made, on the basis of memory, in order to minimise the movement of re-fixation. Brief uncovering of one eye, followed by immediate replacement of the cover, gives clear results provided a prism be in use. Thorne (1930) hands over control of the prism, a variable one, to the patient. The reputed delicacy of the test is materially hampered by the speed of observation which is required of the patient. It is, in both senses, a delicate test. The other tests are either clumsy, or crude, or frightening by their complexity. The tests of the "trou dans la main" type require the patient to fix a distant object and focus a near scale, with the exception of Baldino's method. To this last no theoretical objection can be raised, but of its practical value little information is available. The diploscope and all its derivatives do not exclude fusion tendencies since they leave many objects in view to both eyes. Moreover, though this is a criticism of the instruments rather than the method, the distance of fixation is intermediate, being generally 1.20 metres.

Of the near vision tests, the Maddox wing test is outstanding, for it falsifies none of the principles enunciated, and it remains simple. The other tests require no further comment than has already been made.

GROUP II

All the tests in this group are based on von Graefe's original prism-diplopia test, and all are open to the objections that have already been discussed. These are, briefly, stimulation of the fixation reflex which may also result in the production, during the attempted vergence, of latent deviations in the plane of the measurement, and the stimulation of the mental desire for symmetry. A third source of error in the estimate was pointed out by Maddox (1915), for he showed how the co-existence of a cyclophoria and a lateral heterophoria would result in the appearance of a false hyperphoria, if the attempt to measure it was made with any prism-diplopia method. Loring (1868) has set out some of the objections to the prism-diplopia method, and Krukoff (1871) raised the point that "*. . . lorsqu' on fait usage du prisme à l'angle dirigé en haut ou en bas, la divergence relative est différente, selon la côté vers lequel est dirigé l'angle du prisme; elle est moindre, quand l'angle du prisme est dirigé en haut. Cette différence n'est pas fixe . . .*" This is the opposite result to that which might be expected, for Jaesche has shown that with both eyes looking up a latent divergence is more readily obtained than when looking down (quoted by Hansen Grut 1890).

Despite the objections that effectively exclude this group, the method has been extensively used, and also modified in a multitude of instruments, of which each numbers its devoted supporters. The partisanship displayed by some writers makes their views suspect, and it is, perhaps, fairer not to identify the author of the following: "with these instruments rudely approximate results only may be reached . . . it is safer to trust to the . . .," although his name is great in the world of workers in this subject. It is not possible lightly to dismiss the accumulated practical experience of clinicians, among whom can be found many that prefer this type of method. Of the comparisons between this and other means of measuring heterophoria there can be found several, which will be considered with all such comparisons later. Their evidence is nicely imbalanced for and against prism-diplopia methods. There is no question of the weight of criticism that can be brought against this group of methods and their use should be tempered with a full realisation of the inherent dangers.

There are some five or six phorometers which differ mainly in the details of their manufacture, and in the size of the prism used for producing diplopia. The best known is undoubtedly that of Stevens, the priority of whose instrument is generally accepted too, though this is questionable. His original description was given in 1888, whereas Holden (1887*a*) had described a "refraction apparatus cum phorometer" a year earlier.

In some instruments the amount of separation of the images in the axis at right angles to the deviation to be measured varies, because the prisms that produce the diplopia are also rotated for measuring, while in others these two functions are independent. The variety of prisms used is considerable. Stevens' phorometer totals 12° , Berlin 16° , Wilson and Schiotz each 10° and Savage 6° : Magnani and Lavagna used a rotating combination of three prisms, two of 7° and one of 14° giving a range of 0° to 28° (Stevens 1887, Wells 1926, Pasetti 1911, Schiotz 1899, Magnani and Lavagna 1899, Berlin 1871). Some of the methods use rotating prisms for measurement, while in others the deviation is measured on a scale. Bielschowsky (1911) and Ferri (1884) have each used a scale in their instruments for near vision and the former uses colour differentiation in addition.

There remains the double prism of Maddox and the quadruple prism of Folinea. The former was said by Maddox (1890*a*) to be the forerunner of the rod which bears his name. The latter was described by Folinea in 1922. The disadvantages of these methods have been examined, but the double prism is of use in testing for cyclophoria.

This is the most convenient point to discuss the means of measuring a deviation, whatever the method employed for rendering it manifest. The tangent scale was apparently first used by Ferri (1884) and descriptions of scales for use in the distance were given by Maddox (1890*b*), Herbert (1893), and Bailey (1904). The difficulty has already been discussed of the fallacy introduced if the image of the part of the scale which is to be read does not fall on the macula. Alternatively, some form of prism may be used to restore the displaced image to the position it would occupy in orthophoria. The single rotating prism has the property of displacing the image in two directions, which is sometimes a disadvantage, but in the compound rotating prism the component in one of these directions is neutralised. This latter is associated with the name of Crétès; Prince (1893, 1894, 1898), Lewis (1897), Stevens (1890), and others have all used the type in various combinations. Without doubt, the rotating prism is the most convenient method of realising the principle of displacing neither image from the macula.

GROUP III

The feature common to all tests in this group is the presentation to the two eyes of images differing in some way. Colour differentiation is the most obvious method, and the first suggestion was the ruby glass, followed later by the cobalt glass. As with most tests in this group the fixation object is a spotlight. Neither of these is particularly efficient at suspending fusion.

Various red-green tests are in use; in each the patient sees, through a red glass over one eye and a green glass over the other, red and green objects of such character that each is completely unseen by the eye wearing the opposite colour. The first of such tests to be described was that of Williams (1907), which is quoted by Stirling and Maddox (1913). Wells (1926) speaks of the Prentice red-green test and his own modification of it. Brailey described his test of this type in 1919. Hess' method for plotting the diplopia in squint was produced in 1908.

All these tests would in theory be excellent, if it were not for the fact that both images cannot fall on the respective maculae unless the objects are on corresponding retinal meridians. If they are on such meridians, and the test is done in darkness as recommended by Livingston (1939*b*), "colour fusion" occurs; Livingston (*ibid.*) says this occurs in about 10 per cent. of cases. Of eleven or twelve persons who, at the author's request, determined the tendency to colour fusion in themselves, five found that the residual stimulus to fusion was so great that an artificial hyperphoria of $\frac{3}{4}$ to 1 prism-dioptre was reflexly produced, in order to obtain coincidence of the images. Neame used the red-green test with a prism as a check in occasional cases (see Maddox 1929), but the introduction of the prism immediately transfers the test to Group II, and opens it to the objections raised there. Its use in flying tests has been mentioned. Clements' series of 277 cases measured by this test gave 39.3 per cent. orthophoric, while the author's series of 582 cases measured in daylight gave 52.1 per cent. orthophoric and of 462 cases measured in partial darkness 49.8 per cent. in the same category. These figures are probably too high (see Fig. II) by comparison with the accepted opinions, even when allowance has been made for the differences between the populations tested, and support the view that the red-green test is inefficient in practice. When, further, fatigue needs to be invoked to give the true result in such exophoric cases as show esophoria at first "owing to over-compensation" (Clements 1924), it is reasonable to regard the test with marked suspicion. Further evidence on the practical value of the test will be discussed later.

Maddox (1912*b*) devised a test with patterns perforated in red and green celluloid films which were to be seen against a light. The patient wore red and green glasses and moved the films till he obtained coincidence of the patterns. The films were then clipped together and subsequently measured to obtain the heterophoria for near. There appear to be no theoretical objections to this test, but the lack of general use suggests its practical value.

Burian (1939), in his work on the effect of peripheral stimuli, used light polarised in two planes at right angles, and appropriately-placed films of polarising material then ensured that each

eye saw only the light polarised in one plane. This method appears to be simple and free from theoretical objection, but of its practical value more evidence is required.

A variety of methods involving distortion of one image has appeared. The stenopaic lens (Stevens 1892*a*, *b*, also given by Hansell and Reber 1912, *et al.*), and Roger's cone (quoted by Maddox 1912*a*) both stimulate the mental desire for symmetry, and the more so immediately any attempt at measurement is made. The remaining tests are all based on the effect of a cylindrical lens in converting the image of a point object into a linear image. Maddox (1890*a*) gave his original description of the instrument which bears his name just fifty years ago, and Berry (1890) introduced it to the French in the same year. Bumstead (1892) describes a similar method which he attributes to Ridgeway. Ostwalt's method (Ostwalt 1893) and Jackson's plan of using a 12-dioptre cylinder with a dot as object for near-vision heterophoria (Jackson 1893*b*), are other versions of the same principle. Herbert (1894) suggested the addition of a stenopaic slit to the Maddox rod and he also stipulated that the rod should be a half-rod, *i.e.*, plano-convex in cross-section, and should be red. Norton (1894) produced an ingenious device of two grooves at right angles cut into a frosted glass which gave the appearance of a white cross, while the other eye saw the spot of light through a red glass. The cross was then rotated till the spot of light lay on one arm of the cross, after which the use of a prism set at the angle thus determined measured both the lateral and vertical heterophoria at once. Ballantyne (1914) devised a method giving a somewhat similar effect, for he left a $\frac{1}{8}$ mm. chink between the rods in a multiple Maddox rod, which thus showed a bright red spot in the centre of the duller red streak. The rod is turned till the white spot lies on the streak, and prisms then used at that angle till coincidence of the red and white spots indicates the correction of the deviation. Apparently the chink does not upset the dissociation, for he says, "I find that the measurements obtained are identical with those obtained by the instrument in its original form" (*ibid.*). Maddox, however, specifically said that dissociation would be incomplete if space were left between the rods (Maddox 1929). Both these methods are defective, since the effect of cyclophoria will be concealed and if present will vitiate the measurement, for, as Maddox (1915) has pointed out, his criticism of prism-diplopia tests also applies to the use of the Maddox rod if the rod is not kept truly horizontal or vertical, irrespective of the appearance of the streak. Riley (1902) has suggested that the Maddox rod may, in ambulatory practice, be replaced by a cylindrical bottle filled with water; the water is presumably coloured to taste. Aiken (1894) apparently first described the use of several rods to form the multiple Maddox

rod. Finally, the Maddox rod is used in near-vision tests devised by Bartels (1908) and by Schanz (1912); in each case the deviation is read on a scale. It will be noted that many of these methods employ colour-differentiation in addition to distortion of one image as further aid in the hard battle against fusion.

There has been divergence of opinion about the character of the spot of light to be used as fixation-object when the Maddox rod (which remains the standard method to-day) is employed. Thus Elliott (1915) recommends a lamp giving an area of even brightness, and using also a glass of a "deep neutral-tint" before the fixing eye. Howe (1906) advises a light of fixed size and position. Dolman (1919) says that a bright light increases the fusion tendency, while Clarke (see Maddox 1929) declares that the point of light should be very bright. There is a similar diversity about the general lighting during the test. Howe (1906) recommends a "long, darkened, room," Maddox (1907) advises a partial darkening of the room, while Hanna (1895) used a tapering tube of rectangular cross-section, suspended from cords and 19 feet 7 inches long, to act as a totally dark room. Dolman supports Maddox, in that he says that the exclusion of extraneous retinal images increases the fusion tendency, and he also points out, as did Stevens, the need for a blank surround to the test-object, with the suppression particularly of horizontal and vertical lines (Dolman 1919, Stevens 1906).

Of the instrument itself and its personal defects several discussions are extant. Jackson (1894) showed that discontinuity of the streak was due to total internal reflection. The bias towards esophoria is noted by many writers (Pyle (see Hubbell 1899), Duane 1901, 1905). Duane and Conway express opposite views on dissociation, for the former (Duane 1895) says: "the impulse towards bringing two dissimilar images into line is almost as strong as when the images are alike" and applies this particularly to the Maddox rod, while Conway (see Dobson, 1937) thought the dissociation of the images with this instrument was artificial and inclined to increase any imbalance, as also did Schenk (1917). Dolman (1920*b*) has made a careful study in which he found only six, out of twenty rods examined, free from the defects of indistinctness of the line of light and prism unintentionally incorporated. The former defect results in a false projection of the line, and is avoided by making the patient fix the spot of light. Dolman's further work showed that the fusion tendency was increased not only by exclusion of extraneous retinal images (Dolman, 1919), but also by horizontal and vertical lines in the background (which Jackson (1893) said was unimportant), by other sources of light, and by a too bright light as fixation object. The addition of a cover over the eye behind the rod apparently removes all these

difficulties (Maddox 1920, 1929, Dolman 1919, Thorne 1930, *et al.*) but this of course immediately transfers the method to Group I.

The supporters of the Maddox rod are nearly as vociferous. Hubbell (1899) approved it "because there is introduced absolutely no extraneous impulse to muscular contraction" and said that it was a "more precise and trustworthy guide" than the phorometer. Pasetti's careful examination led him to conclude that it was the best test from the points of view of accuracy and ease of application (Pasetti 1911). Bissell (1892) decided that it was better than the phorometer for a variety of reasons, and Field (1911) agreed with this view.

A prism was intentionally added to the Maddox rod by various investigators. Prince (1893, 1894, 1898) has traced this development through the variable prism, and its addition to the single rod, to its combination with the multiple Maddox rod. Jackson (1893*a*, *c*) had one prism of the pair ground on the rod itself. Berens (1935) adds a prism of 0.75 prism-dioptre to the rod, purely for quick elimination of the cases with less than this amount of deviation. Only one prism rotating is needed in practice when combined with the multiple rod, because the deviation produced by it resolves itself into two components, of which that in the direction of the luminous streak can be disregarded. This makes for a very neat and simple instrument.

The attempt to sum up is necessarily difficult, in view of the variety of external factors which may affect the results with tests of the group, but certain conclusions may be drawn. The Maddox rod and the polarised light methods have the least theoretical objections against them, and the former celebrated fifty years of extensive clinical trial last year, which is ample proof of its practical utility. The estimate of low degrees of heterophoria is extremely difficult, and the rod is probably the most efficient method for these degrees, although the cover test is better, whether with or without the rod. The red-green tests are theoretically objectionable, and inadequate in practice, for colour differentiation alone is apparently not enough.

GROUP IV

This group contains a medley of methods whose only characteristic in common is that, with one exception, they do not measure a heterophoria directly.

The tropometer of Stevens measures the excursions of the eye in various versions. It gives a measure of the degree of shortening of the muscles but not of the force of their contraction which, incidentally, has been directly determined by Fischer (1926). Shaw (1906) says of the tropometer "... it is the only instrument we

have for measuring . . . the pull of the extrinsic ocular muscles," but the truer description would be that it measures the degree to which that pull can affect the position of the eyeball. It cannot determine the demands which are made on the ocular muscles by fusion.

Passing mention may be made of some instruments for measuring the punctum proximum, or the maximal angle, of convergence. Livingston (1935), and Schurr (1939), have each described such instruments, and Martin's is the "gadgeteer's dream" (Martin, 1938).

Stevens' clinometer measures cyclophoria directly, and its utility is beyond question. The Maddox rod is also used for this purpose (Baxter, 1898, Wray, 1912).

The next method has been much used, and variously modified. In it fusion is not suspended, and the quantity measured is the degree of strain to which the fusion reflex can be subjected. To each eye is presented a similar image, and the fusion reflex immediately strives to secure their incidence on corresponding retinal points; by changing the angle of presentation of one or both images, the eyes can be forced into a variety of abnormal positions. It is essential to realise that this gives an estimate of two factors together, the strain to which the fusion reflex can be subjected, and the power of the ocular muscles. Woods (1920) regards this method as determining the degree of strain which the accommodation-convergence reflex can stand. It is a dynamic, not a static, measure, and it is obtained by perverting the physiological co-ordination of the binocular apparatus. There is no justification for the view, quoted by Le Fever (1903), "It is assumed that there is a definite relation between the statics and the dynamics in any given case," and he goes on to show how only half of the 14 cases (out of 100 consecutively chosen for testing) which showed "hypovergence" had any corresponding static imbalance. The interpretation of the results of this method requires the greatest caution, and particularly when inferences as to a position of rest are to be drawn from data obtained in perverted activity.

Abraham (1931*b*) gives some of the ways of employing this method of ductions, and describes the use of extra prisms to obtain diplopia or monocular doubling of the image. The correlation between the results of duction tests and the Maddox rod has been examined by Risley (1912), and Field's work leads him to prefer either of these before the phorometer (Field, 1911). Haessler's excellent paper on 1,000 substantially consecutive cases compelled the conclusion ". . . that the degree of exophoria or esophoria was *not* determined by a balance between divergence and convergence . . ." (Haessler, 1938). The earliest reference to the method of ductions is by Stevens (1887). This will-o'-the-wisp has

thus had a long innings and has only recently been pushed off its perch by the relentless scythe of time.

Hyperphoria is well known to be more easy to reveal than lateral heterophoria, and it is surprising that Appleman (1931) should have found his method of calculation necessary. He uses the difference between two readings for distance, taken with and without the full correction found for near vision hyperphoria. Chenoweth (1933) considers this to represent "the latent error which was compensated for because of muscular contraction called forth by the natural desire for single, superimposed images."

The obscurantism of the last method introduces easily the method of "prolonged occlusion," devised by Marlow and of which a fair "statement of claim" was given by himself in 1930. It has evoked a voluminous outpouring of unscientific hyperbole and almost hysterical vituperation. "A complete and accurate diagnosis of heterophoria . . . can only be made by the aid of prolonged monocular occlusion" says O'Connor (1924). He continues "as absolute proof of this statement . . ." and offers the fact that, of 23 patients orthophoric before their temporary disablement, 17 had hyperphoria afterwards. Proof was defined by Chavasse as "evidence which is incompatible with any alternative assertion," while no definition of "absolute proof" has yet been dared. O'Connor (1929) proclaims, "The test behind the patch is the true one," and describes it as "exactly like" refraction under a cycloplegic.

Marlow's first description was given in 1897 and papers from his pen on this subject have also appeared in 1915, 1918, 1920, 1921, 1927, 1934, and 1936. It is of course related to the method of Cooke (1901), and a development from the well-known difficulty that any deviation requires time to develop. Starr (1898) originally used a period of twelve hours' occlusion, but the periods used now range from three to fourteen days. Marlow (1921) has emphasised the need for continuity and completeness of occlusion. Duane (1927) speaks of the method as "half-way emancipation" from fusion control, and Dunnington (1931) quotes Maddox (who also discussed it in 1929) as saying "a derelict machine is not so informative as a functioning one although we can learn something from it." Young (1926b) is in favour of the test, but he admits that "many of the patients will not accept corrections clearly indicated by the occlusion test" and concludes that it "does not seem to be of much value" in cases of lateral heterophoria. Swab (1930) says "the writer is constrained to admit that on several occasions prisms that were prescribed after occlusion tests had to be removed later. This result was generally attributed to the brevity of the occlusion and also to spasm of muscles not directly affected by the prisms." It seems a pity to introduce spasm as

an explanation, for it would appear to conceal rather than clarify the position. Fink (1927), in a short series of cases, found that all but one (which was orthophoric before) developed a hyperphoria after occlusion, whereas three only had shown it before. Of the 15 cases which were esophoric before, 12 became exophoric afterwards, while the exophorics all remained so. He arrived at the cautious conclusion that "it suggests the possibility that many of the deviations uncovered should not be looked on as pathologic." In six cases in which Abraham (1931a) occluded each eye in turn, all developed a hyperphoria of the occluded eye. He says bluntly that it is "... a subjective test for demonstrating Bell's phenomenon, and it is not a test for latent heterophoria." Examination of Chenoweth's series of 56 cases shows that hyperphoria appeared on the occluded side in 41 (Chenoweth 1933). Beisbarth (1932) gives figures which work out thus: In 15 cases where the eye which was hyperphoric before was occluded, 12 showed an increase, 2 no change and 1 a decrease, in the hyperphoria. But of 5 cases where the eye which was not hyperphoric before was occluded, 3 showed a decrease, and in the others the hyperphoria changed to the occluded eye. And, in the 5 cases out of 8 tested which, orthophoric before, developed hyperphoria after, all showed it in the occluded eye. Taylor (1932) suggests that each eye has its own balance—Friedenwald (1936) and Bielschowsky (1936) deal with this more extensively—and that prolonged occlusion of each eye in turn gives two values of which the *algebraic* sum is the true error. Clark (1927), Talbott (1929), and O'Brien (1925) have all written in favour of the method. Hughes (1934) is cautious and thinks the test is not to be relied on in all cases but that in difficult cases it may be a signpost.

It is clear that the position of rest revealed by prolonged occlusion is close to the physiological position of rest, but can never attain it because the fixation reflex is in play. The hyperphoria thus revealed in nearly every case very strongly suggests a persistence of the protected position of the eye in sleep, the persistence of any abnormal position being well-established. It is a method which demands the greatest caution in its interpretation. Finally, it is but a preparation for a measurement; and this comment is not superfluous since any result attributed to this method must also contain any errors due to the actual method of measuring.

Reference may be made here to a few of the published descriptions of the routine of muscle-balance examinations. Duane has often described his routine (Duane 1901, 1904, 1914, 1919), Savage set out his in two papers (Savage 1891, 1901) and other expositions were given by Dean (1895), by Berens, Losey, and Hardy (1927), by Perceval *et al.* (1922), and by Reber (1914).

Section II

The earliest record of any direct comparisons between tests is that of Bissell (1892) who applied the phorometer and the Maddox rod to 70 unselected cases. In the 52 cases which showed any deviation the two tests gave the same result in 25, and the rod gave the higher reading in all but one case (which had an amblyopic eye) of the remaining 27. He gives various reasons for preferring the rod. Banister (1898) published a rather inconclusive examination based on a hundred fit cases. Duane (1905a) has expressed the view that the Maddox rod gives an excess of deviation, especially in esophoria, and puts the figure at about 1° . Pyle (see Hubbell, 1899) gave the excess as from 1° to 3° . Hubbell (1899) made a comparison over a series of measurements by the phorometer and the Maddox rod which gave the following results: the rod gave a lower reading in 8 cases, the same in 36, a higher in 71, and the opposite heterophoria in 10. This does not quite fit Duane's statement that the phorometer "... in many instances, particularly at near points, indicates an excess of deviation" (Duane 1901). Field's work has already been referred to: his comparison was made on 100 carefully selected cases. Weymouth (1916) took eleven cases, and compared the Maddox rod with the parallax method, using a frequency of one alternation per second, and with a prism-diplopia method. His subjects found the rod the easiest test. The result was that, on the average, the rod gave an esophoria of 0.4° , and the parallax an exophoria of 0.2° , when the prism-diplopia method showed orthophoria. He concluded that "all give consistent results which differ so little" that the method is immaterial. In the estimate of hyperphoria, Abraham (1931b) found that the Maddox rod reading was the same as that determined by the difference in sursum and sub-versions in 73.8 per cent. of 772 cases, and differed by 0.25° or less in 92.3 per cent.

Summing up it may be said that, of the tests which attempt the physiological position of rest, Fischer's is only of laboratory application at present and certainly requires much more investigation. Donders' method requires development and trial, and it too appears liable to be only of restricted clinical use. Both methods, moreover, have questionable value in the actual problem of treating heterophoria.

Of the remaining tests Group II and Group IV may be at once set aside. The parallax test is probably the best test available, closely followed by the Maddox rod, provided always that a prism be used in both to measure the deviation. Certain other precautions also require to be observed, which have been considered. All tests which rely on colour-differentiation alone are inadequate. The remaining divided-field tests are fairly satisfactory provided they

transgress none of the canons already laid down. Preparation for a test by the prolonged occlusion method is liable to lead to extremely deceptive results and should be employed with the greatest caution.

PART III

Introduction

It has recently become possible to make some comparison between the "red-green" test and the Maddox rod test as to their relative efficacy in revealing and measuring a heterophoria. The material for this investigation was a mixed batch of men presenting themselves for tests for fitness for flying: their ages were between 18 and about 55, the majority being in the 19-23 age period, while their experience ranged from nil to some 8,000 hours' flying time. The population from which the results were obtained is, therefore, fairly heavily selected, because tests of intelligence and educational attainments had already made considerable exclusions, while the known high standard of physical fitness debarred from presenting themselves all who did not feel at least optimistic about their prospect of success. Further selection was also essential, for five or six examiners had shared in the actual tests and of these only two had large enough series of cases to permit satisfactory calculation. The allocation of cases to examiners was entirely fortuitous. The following cases were also excluded from the series given here: all cases with manifest squint, all cases with visual acuity in either eye worse than 6/12, all cases that wore glasses constantly, and all cases in which the lateral heterophoria exceeded 3 prism-dioptres as measured by the red-green test. The last exclusion was made because the red-green instrument did not measure above 3 prism-dioptres. Of the number of cases excluded on each of the above grounds no exact record was kept, but the figures were roughly six, fifteen, ten, and fifteen respectively, out of the total candidates offering themselves during the period in which the series was collected. The cases were all tested at 20 feet without the correction of any refractive error and, except where otherwise specified, the results are given only of lateral heterophoria. It is to be noted that one effect of exclusion on the grounds of low visual acuity is the high proportion, in the cases analysed here, of hypermetropes, for the majority had hypermetropia of between 0.5 D. and 1.5 D. in each eye (both eyes finally tested together), but the proportion of cases with hypermetropia over 2 D. was about 2 per cent. Where the red-green tests gave difficulty because of "colour fusion" or suppression, the addition of a cover to the test enabled

a reading to be obtained. No figures are available as to the frequency of these difficulties, but the impression is that 5 per cent. is a liberal estimate of the maximum proportion of such cases.

With one exception, no exclusions were made on any other grounds than those set out. It will be appreciated that, though this is in no sense a "random sample," the population from which the results were obtained is a fair basis for comparative work on the tests and their circumstances.

The statistical methods used are set out in Yule & Kendall (1937). Without the personal guidance of Dr. Bradford Hill, the complexity of these methods would probably have brought the evidence to unhallowed conclusions, and I desire to record my gratitude for his unfailing patience and his explicit help.

Section I

The first series contains 267 cases: the examiner was C and the place of the examination A. The examination was conducted in a well-lighted room, usually in daylight, and no attempt was made to secure the absence of vertical and horizontal lines in the immediate background. The deviation elicited by the Maddox rod was measured by a single rotary prism combined with the rod, giving a maximum correction of 10 prism-dioptres. Deviations above this amount were measured by the addition of other prisms in front of the eye fixing the spotlight. The Maddox rod (in future this will be called the MR) was invariably placed before the left eye, which was the "non-master eye" in the majority of cases. The candidate was instructed to "look steadily at the spot of light," and subsequently adjured to the same effect if any doubt was felt about the concentration of his attention. When, after adjustment of the prism, the appearance of orthophoria was signified by the candidate, the question, "And the streak remains steadily through the light?" was asked after two or three seconds' pause; not until the affirmative answer was obtained was the instrument removed. In the occasional cases where the "streak" oscillated, an estimate was considered to be satisfactory when the oscillation was judged to be of equal size on each side of the spotlight, but these cases were uncommon. The minimum period of suspension of fusion was about 12 seconds, and the average period about 20 to 25 seconds, while occasionally the instrument had to be left before the eye for nearly a minute before a steady state was reached. The measurements were recorded to the nearest 0.5 prism-dioptre, up to 3 prism-dioptres. Above that figure the nearest integral value was recorded, the lower integer being chosen when the reading lay midway between two integers.

The routine has been described at length because some such

standard method was essential, and it was found very quickly that this method ensured the maximum reliability of the result, as judged by the steadiness of the reading and the assurance of the candidate's answers. It will be noted that no attempt was made to fix the head. The candidate was instructed to "look straight at the light" and any obvious deviation of the gaze from the primary position was corrected before fusion was suspended. He was also as free from "voluntary effort" as relaxation in a straight chair, during an examination to decide his future career, would permit.

The red-green test (in future called the RG) was similarly performed and the result was considered to be obtained when a steady state was reached. It was, in all series but one, done before the MR.

The distribution of cases is set out in Table I. In each compartment of the table is the number of cases which give the reading of the heterophoria shown by the column and row in which the compartment lies. The measurements are given in prism-dioptres. The compartments completely enclosed in heavy lines are those in which the heterophoria is the same by both tests. The emptiness of the left upper and right lower sections of the table shows in how few cases the tests give opposite heterophoria, and should be compared with that in succeeding distribution tables, in which the same plan is used.

The following methods of analysis were then used. The linear regression equation of each "characteristic" on the other was calculated by the method of least squares, and the coefficient of correlation determined. As a matter of interest the quadratic regression equation of MR on RG, for this series only, was also calculated by the same method, but it is little improvement on the linear, and its use would introduce many disadvantages for small corresponding gain. Throughout this work MR is invariably treated as the Y-co-ordinate, RG as the X-co-ordinate, and exophoria is considered as having a positive, esophoria a negative, sign.

A preliminary survey of the figures of series 1 shows that 42.3 per cent. of the cases gave the same value by each test, 46.8 per cent. a higher reading by the MR, and 10.1 per cent. a higher by the RG, while in 2 cases (0.8 per cent.) the heterophoria was in opposite directions by the two tests. It is particularly interesting to note the cases in which the difference between the readings was large. One of these cases was examined twice (his second examination only is included in the series) because at the time of the first examination he was extremely tired. On that occasion by both tests he had an exophoria of 13^Δ. 12^Δ was shown by the MR at the re-examination, but the RG would not uncover more

TABLE I
Distribution of Cases in Series 1

	Eso				RG				Exo				Total
	3	2	1'5	1	0'5	N	0'5	1	1'5	2'5			
Exo 12								1			1		
10									1		1		
4							1			1	2		
2'5						1	1	1			3		
2							3		3		6		
1'5							5	4			9		
1						1	12	7			20		
0'5						7	11				18		
MR N				1	8	81	14	4			108		
0'5					9	19	1				29		
1				3	14	7					24		
1'5				5	4	2					11		
2		2	2	7	5	2	1				19		
2'5			2		1						3		
3		1	1		1						3		
4				1		2					3		
5	1	1	1	1							4		
6		1									1		
Eso 7		1				1					2		
Total	1	6	6	18	42	123	49	17	4	1	267		

than 1^{Δ} of this amount, whichever eye saw the movable object, and a repetition of the test a few minutes later gave no different result. This was an admirable demonstration of the assistance which the RG derived from fatigue; the MR did not require such assistance, being adequate to suspend fusion without it.

Of the cases in which the RG gave the higher reading of the same type of heterophoria, none showed the RG exceeding the

TABLE II
Distribution of difference between MR and RG:
Series 1

Difference	No. of Cases	
	MR > RG	MR < RG
11'0	1	0
8'5	1	0
7'0	1	0
5'0	1	0
4'0	4	0
3'5	2	0
3'0	2	0
2'5	2	0
2'0	5	0
1'5	13	0
1'0	27	5
0'5	66	22

Differences in prism-dioptres, in this and similar tables

MR by more than 1^{Δ} , whereas the greatest disparity between the readings in those cases where the MR gave the higher result was 11^{Δ} . The distribution of differences between MR and RG is given in Table II. It is thus seen that the figure of 1^{Δ} , which is accepted as the expected excess of the MR reading over the RG, is not very useful, for the excess does not even average this figure. The average is actually 0.52^{Δ} , and Table II shows that the expected excess of 1^{Δ} of MR over RG would only occur in 27 out of 267 cases.

Reverting to Table I, the regression equation of MR on RG is found to be

$$MR = 1.85 RG - 0.17$$

This regression equation is of necessity a makeshift, for it represents a "best-fit" line, a line so drawn that the total of squared differences between calculated and observed results is a minimum, and it is therefore no more than the best linear expression of the relationship that can be obtained. But it is probably an improvement on the "constant excess" method of expressing the correspondence between the two tests. The extent of this correspondence is also described in the correlation coefficient which in this series is 0.710 (were correlation perfect the figure would be 1).

The further conclusions to be drawn from this series will emerge in comparison with other series. It is to be regarded as the standard against which the others will be viewed.

In the next series (2) were 192 cases, seen by examiner H and at the same place A. The red-green test was carried out in the same way. In the Maddox rod test the candidate was asked to declare at what point on a marked (not numbered) scale the streak appeared to cross. The Maddox rod was held before either eye indifferently. The cases are distributed (Table III) in substantially the same way, to a casual examination, for the percentages with MR readings higher than (52.0 per cent.), equal to (40.2 per cent.), or lower than (6.8 per cent.), the RG readings are much the same. Comparison of the frequency-distributions by the χ^2 test gives a somewhat different picture as is shown in Table IV.

Throughout this work, where the χ^2 test is used, the value "n" is the number of degrees of freedom, that is, the product of one less than the number of columns and one less than the numbers of rows in the distribution-table. The frequencies are so grouped as to give the maximum number of "cells" consistent with maintaining 5 as the minimum "expected" frequency in any cell. Table IV shows that, in the two series, there is little divergence between the frequencies of the various degrees of heterophoria by the RG, whereas the divergence in the case of the MR is sufficiently marked for the chance of its occurrence to be only once in a hundred times. The result being thus unlikely to be due to pure chance, it is reasonable to ascribe it to the difference in methods.

For this series, the regression equation is

$$MR = 1.37 RG - 0.26$$

and the correlation coefficient is 0.779. The distribution of differences is given in Table V. The average excess of MR over RG is 0.41^A.

TABLE III

Distribution of Cases: Series 2

		Eso				RG				Exo			
		3	2	1'5	1	0'5	N	0'5	1	1'5	2	Total	
Exo	2						1	1	1	1	1	5	
	1'5							1	1	1		3	
	1						2	5	4	1		12	
	0'5						15	9	1			25	
	N					1	45	9				55	
MR	0'5					13	26	2				41	
	1				1	13	7					21	
	1'5			2		2	3					7	
	2	1	1	1	4	5	3					15	
	2'5			1	1							2	
	3			1	1							2	
Eso	4		1	1	2							4	
Total		1	2	6	9	34	102	27	7	3	1	192	

TABLE IV

Comparison of Series 1 & 2 by χ^2 Test

Values of

		n	χ^2	P
MR		5	4.44	approx. 0.50
		9	21.50	approx. 0.01

TABLE V

Distribution of differences between MR and RG :
Series 2

Difference	No. of Cases	
	MR > RG	MR < RG
3·0	2	0
2·5	1	0
2·0	6	0
1·5	11	0
1·0	18	1
0·5	62	12

A short series (SA) by examiner S at place A, was also available for comparison. S used the same methods exactly as H, but was a much less experienced examiner, and his series contained only 64 cases. This is too small for reliance to be placed on values calculated from it, and the figures are therefore given without comment. In 45·3 per cent. of the cases the MR exceeded the RG, in 50 per cent. it was the same, and in 4·7 per cent. the RG was the larger. There were no cases where the MR and RG gave opposite types of heterophoria. The average excess of MR over

TABLE VI

Comparisons, by χ^2 Test, of Series SA with Series 1 and 2
Values of

	n	χ^2	P
RG : Series 1	4	6·35	approx. 0·10
RG : Series 2	3	1·53	approx. 0·50
MR : Series 1	5	11·11	approx. 0·05
MR : Series 2	5	22·25	approx. 0·001

RG is 0.52^A, and Table VI gives the comparisons by the χ^2 test with Series 1 and 2. The regression equation of MR on RG is

$$\text{MR} = 1.91 \text{ RG} - 0.11$$

and the coefficient of correlation between the tests is 0.742. This series is omitted from subsequent consideration for the reasons given above.

Reviewing the results of these series, certain conclusions become apparent. The MR gives an equal or higher reading in 89.1 per cent., and 92.2 per cent., of cases in series 1 and 2 respectively. Very rarely do the two tests give heterophoria of opposite types, and in the four cases where this occurred the change was from exophoria by the RG to esophoria by the MR—no question, therefore, of fatigue supervening. The average excess of the MR over the RG is higher when both images fall on the maculae of the respective eyes, as in series 1, than when one image does not so fall (series 2). It is also to be noted that the first series contains 14 cases showing 2.5^A exophoria or 5^A esophoria or more, while the second has none such. In the same way, the regression equations show that the higher value by the MR is given by series 1, for almost any chosen value by the RG. It was shown earlier that the test giving the higher reading is the better test, provided it does not induce movements which would vitiate the measurement. Of these movements, exophoria and hyperphoria are not induced by the MR, while esophoria was seen to be due usually to avoidable causes—and in any case the tendency to false and excessive esophoria can be detected by the instability of the measurement, and the impression of an attitude of strain in the candidate. It follows that the MR, whether used with a tangent scale or with a prism, is more efficient at uncovering a latent deviation than the RG. Also, as might be expected from the foregoing, the correlation coefficient is higher in series 2 than in series 1.

Section II

That there are other reasons for preferring the MR to the RG was shown by two series designed to determine the consistency of results obtained when each test was repeated. For both these series, of 100 cases each, the examiner was C, the place of examination V, and the conditions of the test varied only in that, as both series were undertaken during the assessment of the effect of darkness, the room was partially darkened. It was a rather bare room, painted dead-black, and for these two series the whole of one long side was made of a black Hessian curtain which passed enough light to allow of reading a newspaper on bright days. The room was normally too dark to distinguish between the marks on the tangent scale twenty feet away.

The first series, G, consisted of the RG test, followed by the MR test, and then the RG test was repeated. The two readings by the RG test are set out in Table VII, in a manner similar to that of Tables I and III. This series is included in the cases which make up series 3, as it differs from them in none of the conditions. For the second series, M, the order of testing was the MR, followed

TABLE VII
Distribution of Cases: Series G

	First Reading									Total
	Eso 2'5	1'5	1	0'5	N	0'5	1	1'5	Exo 2	
Exo 2'5									1	1
1'5							1			1
1					1		1	2		4
0'5				1	5	2	4	1		13
Second Reading N			1	4	44	11	2	1		63
0'5		1	1	1	3	3				9
1		1	1		3					5
2'5	1									1
Eso 3	2	1								3
Total	3	3	3	6	56	16	8	4	1	100

by the RG, and then the MR was repeated: the two MR results are given in Table VIII. This series is not included in any other series used.

A preliminary survey shows that while the RG test gave a different second reading in 50 of the 100 cases, the first and second readings by the MR differed in only 20 of its 100 cases. The correlation coefficients between the two readings are 0.957 for the MR and 0.778 for the RG. It is interesting to note that, in series G, where the RG had, as it were, two attempts at "scoring" the

exact value given by the MR, it succeeded in 46 cases, of which 19 were cases showing no deviation at any time. In the remaining 27 cases, on no occasion did the RG produce the same reading twice. For series M, in 31 cases one MR result agreed with the RG—15 of these being cases showing no deviation at any time—and both MR results agreed in 12 out of the remaining 16 which

TABLE VIII
Distribution of Cases: Series M

		First Reading														Total	
		Eso	6	5	4	3	2.5	2	1.5	1	0.5	N	0.5	1	1.5	2	Exo
Exo	2														1	2	3
	1.5												1		2		3
	1											1		8			9
	0.5											1	11		1		13
	N									1	1	16	1				19
Second	0.5										11						11
Reading	1								3	15							18
	1.5								6		1						7
	2						1	2		1							4
	2.5							1									1
	3	1				3											4
	4		1	1		2											4
	5		2														2
Eso	6	1	1														2
Total		2	4	1	3	3	3	9	17	13	18	13	8	4	2		100

showed any deviation. The MR and RG correlation coefficients are strikingly different, and the application of the "Z-Transformation" of Fisher (see Yule & Kendall 1937) shows that this RG result differs from the MR by 8.5 times the standard error of the latter, which difference is significant in the statisticians' sense of the word. The conclusion is inevitable that the MR is very much more consistent with itself than the RG. The latter, in fact, may fairly be described as "temperamental."

Section III

The next series (3) comprises all those cases examined by C, at the place of examination V, under conditions of partial darkness, as described above. The distribution of cases is shown in Table IX. Again there are no cases showing esophoria by the RG and exophoria by the MR, but the number showing the reverse has

TABLE IX

Distribution of Cases: Series 3

		Eso					RG				Exo			Total
		3	2.5	2	1.5	1	0.5	N	0.5	1	1.5	2		
Exo	7									1			1	
	4							1					1	
	2.5							2			1		3	
	2							3	1	1		1	6	
	1.5							1	3	3	3	1	11	
	1							5	8	3	2		18	
	0.5							11	15	2	1		29	
MR	N						1	44	7	3			55	
	0.5						3	12	3				18	
	1				1	2	3	18	4				28	
	1.5			1	1	1	4	2					9	
	2				2		4	4					10	
	2.5					2							2	
	3		2		1	1		1					5	
	4		3					1					4	
	Eso	5	1			1							2	
	Total		1	5	1	6	6	15	105	41	13	7	2	202

increased to 7 (3.47 per cent.). 19 cases show lower readings by the MR than the RG. The regression equation is

$$MR = 1.35 RG - 0.24$$

and the correlation coefficient is 0.706. The distribution of differences between MR and RG is given in Table X, and the comparison by the χ^2 test between series 1 and 3 in Table XI.

TABLE X
Distribution of differences between MR and RG :
Series 3

Difference	No. of Cases	
	MR > RG	MR < RG
6.0	1	0
4.0	2	0
3.5	1	0
3.0	1	0
2.5	2	0
2.0	9	0
1.5	14	0
1.0	32	4
0.5	42	15

TABLE XI
Comparison by χ^2 Test of Series 1, 3 and 4

		n	χ^2	P
Series 1 and 3	RG	7	13.91	approx. 0.05
	MR	11	20.96	approx. 0.02
Series 1 and 4	RG	6	16.66	approx. 0.01
	MR	9	25.75	approx. 0.005
Series 3 and 4	RG	6	10.70	approx. 0.10
	MR	9	6.43	approx. 0.75

TABLE XII
Distribution of Cases: Series 4

		RG										Exo		Total
		3	2.5	2	1.5	1	0.5	N	0.5	1	1.5	2	2.5	
Exo	11							1						1
	7								1					1
	3									1	1			2
	2.5											1	1	2
	2								1		1	1	1	4
	1.5							1	2	2	2	1		8
	1					1		3	7	2	2	1		16
	0.5						1	8	6	2	2			19
MR	N					1	4	22	4	3	2			36
	0.5						2	11	2	2				17
	1				1	3	5	14	2					25
	1.5				5	1	4	3	1	1				15
	2			2			1	2						5
	2.5		1											1
	3	1				2		1						4
	5					1								1
	6							1						1
Eso	22						1							1
Total		1	1	2	6	9	18	67	26	13	10	4	2	159

Note.—One case has been omitted, see text.

The average excess of MR over RG is 0.52^{Δ} .

Series 4 of cases was examined by C in the same room, now with a wall instead of the curtain, and with all windows between the eye and the fixation objects completely blacked. The darkness was not absolute, but such that the card for visual acuity tests could not be distinguished from its surroundings. Here the correlation coefficient fell to 0.320, the regression equation being

$$MR = 0.96 RG - 0.26$$

There were two outstanding cases. The first gave esophoria of 0.5^{Δ} by the RG and 22^{Δ} by the MR, while the second showed esophoria of 1^{Δ} by the RG and exophoria 13^{Δ} by the MR. The first case was also subjected to the cover test, which confirmed the MR estimate. The second was a strident example of "over-compensation"—which, it should be noted, did not affect the MR reading—and the exophoria was confirmed by the cover test. In view of this, the second case was ruled out from all further consideration. No such objection excluded the first case. The regression equation now is

$$MR = 1.09 RG - 0.36$$

and the correlation coefficient is 0.392. The distribution is set out in Table XII. Ten cases in all show opposite heterophoria by the

TABLE XIII

Distribution of differences between MR and RG :

Series 4

Difference	No. of Cases	
	MR > RG	MR < RG
21.5	1	0
11.0	1	0
6.5	1	0
6.0	1	0
4.0	1	0
3.0	1	0
2.0	5	0
1.5	7	2
1.0	23	7
0.0	36	15

MR and the RG, and they account, in part, for the low coefficient of correlation.

14.5 per cent. of the cases show lower readings by the MR, whereas the MR exceeded the RG in 48.4 per cent. of the total cases, and was equal in 30.2 per cent. The distribution of differences between MR and RG readings is given in Table XIII, and

FIG. 3.—See text for description.

the comparison by the χ^2 test of this series with series 1 and 3 in Table XI.

In attempting to picture the effect of darkness on the two tests the following method was devised. The average excess of the MR over the RG, for each of the seven RG readings between 1.5⁺ on either side of orthophoria, was determined, and a "best-fit" line for each series calculated, by the usual method, relating the average excesses to the RG readings. The result is given in Fig. 3. It will be seen that the lines decrease progressively in steepness as

darkness increases, so that the effect of darkness is to decrease the difference between the tests. The percentages of orthophoria and each type of lateral heterophoria appearing in the three series, and as measured by each test, are set out in Table XIV.

TABLE XIV
Percentages of types of heterophoria: Series 1, 3 and 4

		Series		
		1	3	4
by RG	Exophoria	26'6	31'2	34'6
	Orthophoria	46'1	52'0	42'1
	Esophoria	27'3	16'8	23'3
by MR	Exophoria	22'5	34'2	33'3
	Orthophoria	40'4	27'2	22'7
	Esophoria	37'1	38'6	44'0

Examination of this table shows that the effect of darkness on the RG is a progressive increase in the exophoria percentages, and decrease in those of esophoria. On the MR, the effect is an increase in both the exophoria and esophoria percentages. Taking the results of Fig. 3 and Table XIV together, it becomes apparent that the MR will always be expected to give a higher reading than the RG in cases of esophoria, but the difference is greatest in light conditions. Further, the MR will give a higher reading than the RG in cases also of exophoria, the difference being, as before, greatest in light conditions, but only in exophoria above a certain RG limit. This limit is the abscissa of the point in which each line in Fig. 3 cuts the horizontal axis, and is 0.16^Δ, 0.85^Δ, and 1.29^Δ for the series 1, 3 and 4 respectively.

In a further attempt to assess the effect of darkness on the MR, a series D, of 82 consecutive cases, all of which had been passed fit at an earlier examination, was used as material, although it was thus a heavily selected sample. The MR was done as in series 4, and then a 150-watt light was switched on above the candidate's head and a second MR reading taken. The distribution is given in Table XV. The correlation coefficient is 0.980 for this series.

TABLE XV
Distribution of Cases: Series D

		In Darkness															Exo		
Eso		6'5	5	4'5	4	3	2'5	2	1'5	1	0'5	N	0'5	1	1'5	2	3	4'5	Total
In Light	Exo 4'5																	1	1
	3																1		1
	2															2			2
	1												1	3					4
	0'5											1	10	1					12
	N										1	14	2						17
	0'5									1	5	3		1					10
	1									12	4	1							17
	1'5							1	2	1									4
	2						2	1	2	1									6
Eso	2'5						1												1
	3					2													2
	4			1	1														2
	5		2																2
	6'5	1																	1
	Total	1	2	1	1	2	3	2	4	15	10	19	12	3	3	2	1	1	82

Study of the distribution shows that most of the variations occur in the range between exophoria and esophoria of 1.5^a measured in the dark, and that the tendency in this range is chiefly a shift towards esophoria in the light. In only three cases did the variation exceed 0.5^a, and in one of these there was a change of the type of heterophoria. It must be concluded that the effect of darkness on the test was obscured by other factors, which are probably that the test is not perfectly consistent and that the "in light" reading was taken second. These results are given purely to emphasize the difficulties inherent in any such comparisons, and are discarded because the series is small compared to the others, which give an unequivocal contrary conclusion.

Collecting the results of these series together, the first striking

thing is in the percentages of heterophoria shown in the three series. The RG gains something in darkness, for there is a reduction in the esophorias and an increase in the exophorias. What that something may be is difficult to say, for the effect appears to be merely a shift towards exophoria, without any notable increase in the total percentage showing any deviation. It is patently not any greater efficiency at suspending fusion, for that would be accompanied by a clear reduction in the orthophorics.

By contrast, the MR shows a marked improvement in efficiency. Turning to the distribution tables for series 1, 3 and 4, four types of cases have to be considered. These are the cases where the RG shows exophoria and the MR shows (1) more exophoria and (2) less exophoria, orthophoria or esophoria, and the cases where the RG shows esophoria and the MR shows (3) more esophoria and (4) less esophoria, orthophoria, or exophoria. The percentages of each type occurring in the three series are set out in Table XVI.

TABLE XVI

Percentages of types where heterophoria differs in the two tests:
Series 1, 3 and 4

Type	RG	MR shows bias over RG towards	Series 1	Series 3	Series 4
1	Exophoria	More Exophoria	15·7	20·3	18·9
2	Exophoria	Less Exophoria	7·5	11·4	16·4
3	Esophoria	More Esophoria	31·1	31·2	29·6
4	Esophoria	Less Esophoria	3·4	1·5	4·4

The most obvious characteristic of this table is the progressive increase of Type (2), with increasing darkness. This must be due to darkness causing either the RG to show more exophoria, or the MR to show less exophoria. That it is not the latter is proved by two facts, the increase of Type (1), and the increase of exophorics tested by the MR as shown in Table XIV.

It is therefore a legitimate conclusion that while darkness does not produce any specific bias in the MR, it has a marked effect on the RG, causing it to show a greater exophoria. Certainly these results are in flat contradiction to Dolman's view that the exclusion of extraneous retinal images increases the fusion tendency with the MR (Dolman 1919). It is natural to expect a greater reduction of fusion tendency in darkness, because the fixing eye is deprived of its monocular stereopsis, and thus there is less stimulus to the monocular fusion reflex which was tentatively proposed earlier

(Part I). This occurs in despite of the greater stimulation of the fixation reflex by the contrast between object and background. Theoretical expectation is thus borne out by practical experience.

Section IV

Lastly, out of the 1054 cases which have been tested by the examiners C, H, and S, 25 have shown hyperphoria of 1^Δ or more, by one or other test. Of the seven cases not examined by C, three were contributed by H, and four by S. No cases have been included here which were excluded from consideration on the

TABLE XVII

Cases showing, by either test, 1^Δ Hyperphoria or more

RG reading	MR reading	Number for Examiner	
		C	H and S
o	R: 1	4	2
o	L: 1	5	1
o	R: 1·5	2	o
o	L: 1·5	5	o
o	R: 3	1	o
o	R: 13	o	1
R: 0·5	R: 1	o	1
R: 1	L: 1	o	1
L: 1·5	L: 1·5	1	o
L: 2	L: 2	o	1

grounds specified earlier. The details are set out in Table XVII, and it will be seen that, of the 25, only 4 showed any hyperphoria by the RG. When with this is taken the fact that an artificial hyperphoria up to 1^Δ is easily produced by the RG (see Part II), it is clear that the RG is substantially useless in hyperphoria. Its capabilities in revealing a lateral heterophoria are therefore yet more suspect, for a hyperphoria is much less easily controlled by the fusion reflex, much more symptom-producing, and correspondingly much more easily uncovered.

Note.—Since the above was written, the following striking case has been examined. The RG showed esophoria 0·5^Δ, with no

hyperphoria, but the MR gave esophoria 11^{Δ} , and right hyperphoria 7.5^{Δ} . The condition was parietic in origin and there were no symptoms.

Section V

The conclusions which may be drawn from the foregoing experiments are, of necessity, less certain than could be desired, simply because the rigidity of laboratory technique could not fully be realised in clinical practice. It is possible, however, to reach some definite results, without fear of contradiction by subsequent work more completely controlled.

The series M and G show clearly the constancy of the Maddox rod test, and equally clearly the inconsistency of results obtained by the red-green test. Practical experience, also, of the tests leads to a distaste for the latter, for two reasons. Much greater difficulty is experienced by the candidate in declaring the appearance of orthophoria—which, perhaps, runs parallel with the marked instability noted by many candidates—and the amount of preliminary explanation which the examiner must give is both wearisome and more extensive than is required for the rod test.

The effect of darkness on the red-green test is seen to be a shift towards exophoria, which is much more unsatisfactory than its effect on the Maddox rod. For, in the former test, the degree of the shift is incalculable, while the degree of fusion suppression by the rod may readily be inferred from the percentages of the types of heterophoria obtained under given conditions.

The principle of obtaining both images falling on the maculae when the eyes are in the fusion-free position is seen to be necessary for the adequate revelation of any latent deviation, and for its full manifestation. The comparison between series 1 and 2 shows this beyond cavil. Moreover, adequate time must be given for the appearance of orthophoria to be reasonably constant, to which end the method outlined in the description of series 1 may be commended.

The present practice of assuming the excess of the reading by the Maddox rod test over that by the red-green test to be 1^{Δ} is fallacious. The average excess is about half of this figure, but even this only remotely resembles the truth. A much nearer approximation is obtained by using a "best-fit" line, and this line must be determined for each given set of conditions.

It appears, therefore, reasonable to conclude that the red-green test is unsatisfactory for the following reasons:—

- (1) Inadequate suppression of the fusion tendency.
- (2) Inconsistency of results.
- (3) Indeterminability of the effect of variations in the ancillary conditions of the test.

- (4) Inconvenience in the practical application of the test.
- (5) Inability to uncover a hyperphoria.

Of the Maddox rod test, the following conclusions may be stated :—

- (1) The suppression of the fusion tendency is good, and is increased by darkness.
- (2) The variability of the test is very small.
- (3) Care is essential to various points of detail, but is amply repaid in the consistency of the results.

Envoi

I wish to express my thanks to the many friends who have helped me in this work by translation, by comment, criticism, and advice, and by co-operation and encouragement. While distinctions are invidious I should be churlishly ungrateful were I not to make special mention of Dr. A. Bradford Hill, on whose statistical knowledge I have made extensive calls, and of the Librarian and his staff at the Royal Society of Medicine, whose readiness to help has surpassed the high hopes born of previous experience of their skill. I dare only hope that they, and those unnamed others, may at least not be disappointed.

BIBLIOGRAPHY

- ABRAHAM (1931a).—*Amer. Jl. Ophthal.*, Vol. XIV, p. 656.
 — (1931b).—*Arch. of Ophthal.*, N.Y., Vol. V, p. 766.
 AIKEN (1894).—*Med. Rec.*, N.Y., Vol. XLVI, p. 511.
 AIR PUBLICATION 130 (1936).—"Medical Examination for Fitness for Flying," London.
 APPLEMAN (1931).—*Amer. Jl. Ophthal.*, Vol. XIV, p. 36.
 BAILEY (1904).—*Ann. Ophthal.*, Vol. XIII, p. 509.
 BALDINO (1920).—*Arch. Ottal.*, Vol. XXVII, p. 57.
 — (Abstract, 1921).—*Zentralbl. ges. Ophthal.*, Vol. IV, p. 70.
 BALL (1913).—*American encyclopedia and dictionary of ophthalmology*, Vol. II, p. 866.
 BALLANTYNE (1914).—*Ophthal. Rev.*, Vol. XXXIII, p. 165.
 — (1922).—*Glasgow Med. Jl.*, Vol. XCVII, p. 321.
 BANISTER (1898).—*Ann. Ophthal.*, Vol. VII, p. 17.
 BARRETT (1921).—*Med. Jl. Aust.*, Vol. I, p. 131.
 — (Reprint, 1921).—*Med. Prac.*, Vol. CXI, p. 278.
 BARTELS (1908).—*Zeitschr. Augenheilk.*, Vol. XIX, p. 101.
 — (Abstract, 1908).—*Ophthalmoscope*, Vol. VI, p. 722.
 BAXTER (1874).—*Arch. Ophthal. N.Y.*, Vol. XXIII, p. 8.
 — (1898).—*Ophthal. Rec.*, Vol. VII, p. 130.
 BEISBARTH (1932).—*Amer. Jl. Ophthal.*, Vol. XV, p. 1013.
 BENJAMIN (1928).—*Nav. Med. Bull. Wash.*, Vol. XXVI, p. 578.
 BERENS (1935).—*Brit. Jl. Ophthal.*, Vol. XIX, p. 661.
 BERENS, LOSEY, and HARDY (1927).—*Amer. Jl. Ophthal.*, Vol. X, p. 910.
 BERLIN (1871).—*Klin. Monatsbl. f. Augenheilk.*, Vol. IX, p. 34.
 — (Abstract, 1871).—*Ann. d'ocul. Paris*, Vol. LXVIII, p. 233.
 BERRY (1890).—*Rev. gén. d'ophtal.*, Vol. LXVIII, p. 233.
 — (1912).—*Edin. Med. Jl.*, Vol. IX, p. 399.
 BEYNE (1932).—*Arch. Ophtal. Paris*, Vol. XLIX, p. 379.
 BICHELONNE (1923).—*Arch. Med. Pharm. Milit.*, Vol. LXXVIII, p. 315.

- BIELSCHOWSKY (1911).—*Klin. Monatsbl. f. Augenheilk.*, Vol. XLIX, p. 772.
 — (Abstract, 1911-12).—*Ophthalmology*, Vol. VIII, p. 388.
 — (1934).—*Arch. Ophthalm. N.Y.*, Vol. XII, p. 805.
 — (1935).—*Arch. Ophthalm. N.Y.*, Vol. XIII, p. 569.
 — (1936).—*Arch. Ophthalm. N.Y.*, Vol. XV, p. 589.
 — (1938).—*Amer. Jl. Ophthalm.*, Vol. XXI, pp. 843, 1129, 1219, 1329.
 BISSELL (1892).—*Jl. Ophthalm. Oto. Laryng.*, Vol. IV, p. 127.
 BJERKE (1909).—*Arch. d'ophtal. Paris*, Vol. XII, p. 312.
 — (1910).—*Von Graefe's Arch. Ophthalm.*, Vol. LXXVII, p. 518.
 BRAILEY (1919a).—*Brit. Jl. Ophthalm.*, Vol. III, p. 161.
 — (1919b).—*Trans. Ophthalm. Soc. U.K.*, Vol. XXXIX, p. 41.
 BROOME (1919).—*Jl. R. Nav. Med. Serv.*, Vol. V, p. 175.
 BROUGHTON (1902).—*Ann. Ophthalm.*, Vol. XI, p. 12.
 — (Abstract, 1903).—*Rev. gén. Ophtal. Paris*, Vol. XXII, p. 36.
 BUMSTEAD (1892).—*Ann. Ophthalm.* Vol. I, p. 84.
 — (Abstract, 1892).—*Ann. d'ocul. Paris*, Vol. CVIII, p. 312.
 BURIAN (1939).—*Arch. Ophthalm. N.Y.*, Vol. XXI, p. 486.
 CAMPOS (1911).—*Rev. gén. Ophtal. Paris*, Vol. XXX, p. 529.
 CANTONNET (1917).—*Prac. Méd.*, Vol. XXV, p. 686.
 — (1918a).—*Arch. Ophtal. Paris*, Vol. XXXVI, p. 155.
 — (1918b).—*Med. Prac.*, Vol. CVI, p. 305.
 — (1919).—*Arch. Ophtal. Paris*, Vol. XXXVI, p. 705.
 — (1930).—*Prat. Méd. franç.*, Vol. XI, p. 123.
 CHAVASSE (1939).—Worth's "Squint," London.
 CHENOWETH (1933).—*Jl. Iowa. St. Med. Soc.*, Vol. XXIII, p. 262.
 CLARK (1927).—*Amer. Jl. Ophthalm.*, Vol. X, p. 574.
 CLEMENTS (1924).—*Nav. Med. Bull. Wash.*, Vol. XX, p. 350.
 — (1926).—*Proc. Roy. Soc. Med.*, Vol. XIX, p. 15.
 COOKE (1901).—*Ann. Ophthalm.*, Vol. X, p. 594.
 CRIDER (1935).—*Jl. Exp. Psychol.*, Vol. XVIII, p. 152.
 DEAN (1895).—*Ophthalm. Rec.*, Vol. V, p. 449.
 — (1936).—*Arch. Ophthalm. N.Y.*, Vol. XV, p. 692.
 DOBSON (1937).—*Trans. Ophthalm. Soc. U.K.*, Vol. LVII, p. 228.
 DOLMAN (1919).—*Arch. Ophthalm. N.Y.*, Vol. XLVIII, p. 503.
 — (Reprint, 1919).—*Trans. Amer. Ophthalm. Soc.*, Vol. XVII, p. 235.
 — (1920a).—*Amer. Jl. Ophthalm.*, Vol. III, p. 258.
 — (1920b).—*Arch. Ophthalm. N.Y.*, Vol. XLIX, p. 194.
 DUANE (1889).—*N.Y. Med. Jl.*, Vol. L, p. 113.
 — (1895).—*Arch. Ophthalm. N.Y.*, Vol. XXIV, p. 258.
 — (1901).—*N.Y. Med. Jl.*, Vol. LXXIII, p. 890.
 — (1904).—*Ophthalm. Rec.*, Vol. XIII, p. 562.
 — (1905a).—*Ann. Ophthalm.*, Vol. XIV, p. 301.
 — (1905b).—*Ophthalmology*, Vol. II, p. 1.
 — (1914).—*N.Y. Med. Jl.*, Vol. XCIX, p. 409.
 — (1918).—*Trans. Coll. Phys. Philad.*, Vol. XL, p. 247.
 — (1919).—*Arch. Ophthalm. N.Y.*, Vol. XLVIII, p. 1.
 — (1927).—*N.Y. St. Jl. Med.*, Vol. XXVII, p. 535.
 DUKE-ELDER (1932).—"Text-Book of Ophthalmology," London.
 DUNNINGTON (1931).—*Amer. Jl. Ophthalm.*, Vol. XIV, p. 1140.
 ELLIOTT (1915).—*Ophthalmoscope*, Vol. XIII, p. 600.
 EVANS (1908).—*Ophthalmoscope*, Vol. VI, p. 954.
 FERRI (1884).—*Gior. Accad. Med. Torino*, Vol. XXXII, p. 62.
 — (Abstract, 1885).—*Rev. gén. Ophtal. Paris*, Vol. IV, p. 35.
 FIELD (1911).—*Arch. Ophthalm. N.Y.*, Vol. XL, p. 526.
 FINK (1927).—*Amer. Jl. Ophthalm.*, Vol. X, p. 168.
 FISCHER (1922).—*Von Graefe's Arch. Ophthalm.*, Vol. CVIII, p. 251.
 — (Abstract, 1922-23).—*Zentralbl. ges. Ophtal.*, Vol. VIII, p. 452.
 — (1926).—*Arch. f. Augenheilk.*, Vol. XCVII, p. 174.
 — (Abstract, 1926-27).—*Arch. f. Augenheilk.*, Vol. XVII, p. 107.
 FOLINEA (1922).—*Arch. Ottal.*, Vol. XXIX, p. 37.
 — (Abstact, 1922).—*Arch. Ottal.*, Vol. VII, 531.
 FOX (1923).—Reprint from Perceval, 1922. *Amer. Jl. Ophthalm.*, Vol. CVI, p. 110.
 FRIEDENWALD (1936).—*Arch. Ophthalm. N.Y.*, Vol. XV, p. 283.

- FURUYA (Abstract section, 1938).—*Bull. Nav. Med. Ass. Japan*, Vol. XXVII, p. 2.
 ——— (Abstract, 1937-38).—*Bull. Nav. Med. Ass. Japan*, Vol. XL, p. 678.
 GAUDENZI (1896).—*Ann. Ottal.*, Vol. XXV, p. 277.
 ——— (Abstract, 1896).—*Zentralbl. prak. Augenheilk.*, Vol. XX, p. 118.
 GEORG, TEREN and LOWELL (1923).—*Amer. Jl. Ophthal.*, Vol. VI, p. 833.
 GUAITA and BARDELLI (1899).—*Ann. Ophthal.*, Vol. VIII, p. 538.
 HAESSLER (1938).—*Amer. Jl. Ophthal.*, Vol. XXI, p. 272.
 HANSEN GRUT (1890).—*Trans. Ophthal. Soc. U.K.*, Vol. X, p. 1.
 HANNA (1895).—*Ophthal. Rec.*, Vol. V, p. 313.
 HANSELL (1891).—*Amer. Jl. Med. Sci.*, Vol. CI, p. 377.
 HANSELL and REBER (1912).—"The Ocular Muscles," Philadelphia.
 HARMAN (1909a).—*Ophthal. Rev.*, Vol. XXVIII, p. 9.
 ——— (1909b).—*Trans. Ophthal. Soc. U.K.*, Vol. XXIX, p. 54.
 ——— (1910).—*Trans. Ophthal. Soc. U.K.*, Vol. XXX, p. 52.
 HAZEN (1900).—*Ophthal. Rec.*, Vol. IX, p. 137.
 HERBERT (1893).—*Ophthal. Rec.*, Vol. III, p. 234.
 ——— (1894).—*Ophthal. Rec.*, Vol. IV, p. 313.
 HESS (1911).—*Arch. Ophthal. N.Y.*, Vol. XL, p. 218.
 HOLDEN (1887a).—*Arch. Ophthal. N.Y.*, Vol. XVI, p. 295.
 ——— (1887b).—*Arch. Ophthal. N.Y.*, Vol. XVI, p. 403.
 HOWE (1901).—*Comp. Rend. d. 13me Congres Internat. d. Méd. (Sect. d'Opht.)*
 Vol. XII, p. 188.
 ——— (1906).—"The Muscles of the Eye," London.
 ——— (1912).—*Jl. Amer. Med. Assoc.*, Vol. LIX, p. 1024.
 ——— (1914).—*N.Y. St. Jl. Med.*, Vol. XIV, p. 93.
 HUBBELL, (1899).—*Ophthal. Rec.*, Vol. VIII, p. 373.
 ——— (Reprint, 1900).—*Jl. Amer. Med. Assoc.*, Vol. XXXIV, p. 403.
 HUGHES (1907).—"Squint and Ocular Paralysis," London.
 ——— (1934).—*Arch. Ophthal. N.Y.*, Vol. XI, p. 229.
 IRVINE and LUDVIGH (1936).—*Arch. Ophthal. N.Y.*, Vol. XV, p. 1037.
 JACKSON (1893a).—*Jl. Amer. Med. Assoc.*, Vol. XXI, p. 737.
 ——— (1893b).—*Med. News*, Vol. LXIII, p. 454.
 ——— (1893c).—*Ophthal. Rec.*, Vol. III, p. 105.
 ——— (1894).—*Ophthal. Rev.* Vol. XIII, p. 21.
 JAMESON-EVANS (1922).—*Trans. Ophthal. Soc. U.K.*, Vol. XLII, p. 332.
 KLETZKY (1920).—*Amer. Jl. Physiol. Opt.*, Vol. I, p. 343.
 KOYLE (1905).—*Ophthal. Rec.*, Vol. XIV, p. 411.
 KRUKOFF (1871).—*Ann. d'ocul. Paris*, Vol. LXVII, p. 268.
 LAUDER (1910).—*Cleveland Med. Jl.*, Vol. IX, p. 768.
 LE FEVER (1903).—*Ophthal. Rec.*, Vol. XII, p. 530.
 LEWIS (1897).—*Ann. Ophthal.*, Vol. VI, p. 325.
 LIVINGSTON (1932).—*Brit. Jl. Ophthal.*, Vol. XVI, p. 577.
 ——— (1934).—*Trans. Ophthal. Soc. U.K.*, Vol. LIV, p. 337.
 ——— (1935).—*Proc. Roy. Soc. Med.*, Vol. XXIX, p. 59.
 ——— (1939a).—*Trans. Ophthal. Soc. U.K.*, Vol. LIX, (i), p. 129.
 ——— (1939b).—*Brit. Orthop. Jl.*, Vol. I, p. 71.
 LORING (1868).—*Trans. Amer. Ophthal. Soc.*, Vol. I, p. 101.
 ——— (Abstract, 1869).—*Ann. d'ocul. Paris*, Vol. LXIV, p. 46.
 MADDOX (1886).—*Jl. Anat. London*, Vol. XXI, p. 21.
 ——— (1890a).—*Ophthal. Rev.*, Vol. IX, p. 129.
 ——— (1890b).—*Ophthal. Rev.*, Vol. IX, p. 287.
 ——— (1907).—"Test and Studies of the Ocular Muscles," Philadelphia.
 ——— (1912a).—*Ophthalmoscope*, Vol. X, p. 124.
 ——— (1912b).—*Ophthal. Rev.*, Vol. XXXI, p. 179.
 ——— (1913).—*Trans. Ophthal. Soc. U.K.*, Vol. XXXIII, p. 223.
 ——— (1915).—*Ophthal. Rec.*, Vol. XXIV, p. 223.
 ——— (1920).—*Arch. Ophthal. N.Y.*, Vol. XLIX, p. 229.
 ——— (1921).—*Brit. Jl. Ophthal.*, Vol. V, p. 433.
 ——— (Reprint, 1922).—*Amer. Jl. Physiol. Opt.*, Vol. III, p. 25.
 ——— (1929).—*Trans. Ophthal. Soc. U.K.*, Vol. XLIX, p. 2.
 MAGNANI and LAVAGNA (1899).—*Ann. Ottal.*, Vol. XXVIII, p. 404.
 MARLOW (1897).—*Ophthal. Rec.*, Vol. VI, p. 115.
 ——— (1915).—*N.Y. St. Jl. Med.*, Vol. XV, p. 429.

- MARLOW (1918).—*N.Y. Med. Jl.*, Vol. CVIII, p. 936.
 — (1920).—*Brit. Jl. Ophthalm.*, Vol. IV, p. 145.
 — (1921).—*Amer. Jl. Ophthalm.*, Vol. IV, p. 238.
 — (1930).—*Brit. Jl. Ophthalm.*, Vol. XIV, p. 385.
 — (1927).—*Brit. Jl. Ophthalm.*, Vol. X, p. 567.
 — (1934).—*New. Eng. Jl. Med.*, Vol. CCX, p. 309.
 — (1936).—*Arch. Ophthalm. N.Y.*, Vol. XVI, p. 982.
 MÁRQUEZ (1935).—*Rev. gén. d'ophtal. Paris*, Vol. XLVI, p. 275.
 — (Reprint, 1935).—*Arch. Oftal. Hisp.-Amer.*, Vol. XXXV, p. 561.
 MARTIN (1904).—*Ophthalm. Rec.*, Vol. XIII, p. 111.
 — (1937).—*Wis. Med. Jl.*, Vol. XXXVI, p. 186.
 — (1938).—*Amer. Jl. Ophthalm.*, Vol. XXI, p. 161.
 MARX (1908).—*Von Graefe's Arch. Ophthalm.*, Vol. LXIX, p. 184.
 — (Abstract, 1909).—*Ann. d'ocul. Paris*, Vol. CXLII, p. 402.
 MERLIN (1939).—*Vestnik Oftal.*, Vol. XIII, p. 352.
 — (Abstract, 1939).—*Zentralbl. ges. Ophthalm.*, Vol. XLIII, p. 588.
 NORRIS and OLIVER.—"System of Diseases of the Eye," London and Philadelphia.
 NORTON (1894).—*Ophthalm. Rec.*, Vol. IV, p. 435.
 O'BRIEN (1925).—*Jl. Amer. Med. Assoc.*, Vol. LXXXV, p. 1295.
 O'CONNOR (1924).—*Brit. Jl. Ophthalm.*, Vol. VIII, p. 449.
 — (1929).—*Calif. West. Med.*, Vol. XXXI, p. 253.
 OSTWALT (1893).—*Rev. gén. Ophthalm. Paris*, Vol. XII, p. 300.
 PANNI (1903).—*Ann. Ottal.*, Vol. XXXII, p. 880.
 — (Abstract, 1903).—*Zentralbl. prakt. Augenheilk.*, Vol. XXVII, p. 442.
 PARINAUD (1893).—*Bull. Soc. franç. Ophthalm.*, Vol. XI, p. 93.
 PASETTI (1911).—*Ann. Ottal.*, Vol. XL, p. 706.
 PERCEVAL, FOX *et alia* (1922).—*Brit. Med. Jl.*, (ii), 1249.
 PETER (1928).—"The Extra-Ocular Muscles," London.
 PRINCE (1893).—*Arch. Ophthalm. N.Y.*, Vol. XXII, p. 372.
 — (1894).—*Ophthalm. Rev.*, Vol. IV, p. 22.
 — (1898).—*Jl. Amer. Med. Assoc.*, Vol. XXX, p. 197.
 PYLE (1903).—*Ophthalm. Rec.*, Vol. XII, p. 324.
 RANDALL (1890).—*Trans. Amer. Ophthalm. Soc.*, Vol. V, p. 362.
 REBER (1914).—*Ophthalmoscope*, Vol. XII, p. 592.
 REIJNDERS (1922).—*Ned. Tijdschr. Geneesk.*, Vol. LXVI, ii, p. 2051.
 — (Abstract, 1923).—*Zentralbl. ges. Ophthalm.*, Vol. IX, p. 275.
 REXROAD (1928).—*Amer. Jl. Psychol.*, Vol. XL, p. 426.
 RILEY (1902).—*Med. Rec. N.Y.*, Vol. LXI, p. 455.
 RÉMY (1906).—*Rec. d'ophtal.* Vol. XXVIII, p. 520.
 — (1908).—*Rec. d'ophtal.*, Vol. XXX, pp. 203, 350, 438.
 RISLEY (1912).—*Ophthalm. Rec. N.Y.*, Vol. XXI, p. 337.
 SAVAGE (1891).—*Ophthalm. Rec. N.Y.*, Vol. I, p. 228.
 — (1901).—*Ophthalm. Rec. N.Y.*, Vol. X, p. 453.
 SCHANZ (1912).—*Zeitschr. Augenheilk.*, Vol. XXVII, p. 367.
 SCHENCK (1917).—*Jl. Ophthalm. Otol. Laryng.*, Vol. XXIII, p. 668.
 SCHIÖTZ (1899).—*Ann. d'ocul. Paris*, Vol. CXXI, p. 21.
 SCHURR (1939).—*Proc. Roy. Soc. Med.*, Vol. XXXII, p. 366.
 SHAW (1916).—*Jl. Ophthalm. Otol. Laryng.*, Vol. XXII, p. 1004.
 SHEARD (1920).—*Amer. Jl. Physiol. Opt.*, Vol. I, p. 234.
 SMITH (1907).—*Ohio Med. Jl.*, Vol. II, p. 254.
 STARR (1898).—*Ann. Ophthalm.*, Vol. VII, p. 389.
 STEVENS (1887).—*Arch. Ophthalm. N.Y.*, Vol. XVI, p. 150.
 — (1888).—*Med. Rec. N.Y.*, Vol. XXXIII, p. 511.
 — (1890).—*Med. Rec. N.Y.*, Vol. XXXVII, p. 108.
 — (1891).—*Ophthalm. Rec. N.Y.*, Vol. I, p. 215.
 — (1892a).—*Ann. d'ocul. Paris*, Vol. CVII, p. 23.
 — (1892b).—*N.Y. Med. Jl.*, Vol. LV, p. 80.
 — (1893).—*Ophthalm. Rec. N.Y.*, Vol. III, p. 294.
 — (1906).—"The Motor Apparatus of the Eyes," Philadelphia.
 STILLING (1885).—*Arch. f. Augenheilk.*, Vol. XV, p. 73.
 — (Abstract, 1885).—*Rev. gén. d'ophtal. Paris*, Vol. IV, p. 363.
 STIRLING and MADDOX (1913).—*Ophthalmoscope*, Vol. XI, p. 660.
 STOCK (1922).—*Ber. deutsch. ophthalm. Ges.*, Vol. XLIII, p. 291.

- STOCK (Abstract, 1923).—*Zentralbl. ges. Ophthalm.*, Vol. X, p. 100.
- STRAUB (1892).—*Ophthalm. Rev.*, Vol. XI, p. 97.
- STREBEL (1921).—*Schweiz. med. Wschr.*, Vol. LI, p. 1138.
- (Abstract, 1921).—*Ophthalm. Yearbook*, Vol. XIX, p. 36.
- STUTTERHEIM (1932).—*Brit. Jl. Ophthalm.*, Vol. XVI, p. 20.
- (1933).—*Brit. Jl. Ophthalm.*, Vol. XVII, p. 394.
- SWAB (1930).—*Amer. Jl. Ophthalm.*, Vol. XIII, p. 1054.
- TALBOTT (1929).—*Calif. West. Med.*, Vol. XXX, p. 100.
- TAYLOR (1932).—*Jl. Iowa St. Med. Soc.*, Vol. XXII, p. 267.
- THORNE (1930).—*Milit. Surg.*, Vol. LXVI, p. 175.
- THOMSON (1924).—*Trans. Ophthalm. Soc. U.K.*, Vol. XLIV, p. 239.
- TSCHERNING (1920).—"Physiologic Optics," Philadelphia.
- VALK (1912).—*Ophthalm. Rec.*, Vol. XXI, p. 639.
- VAN DER HOEVE (1932).—*Trans. Ophthalm. Soc. U.K.*, Vol. LII, p. 1.
- VERHOEFF (1899).—*Johns Hopkins Hosp. Bull.*, Vol. X, p. 87.
- (Reprint, 1899).—*Trans. Amer. Ophthalm. Soc.*, Vol. VIII, p. 490.
- (Reprint, 1926).—*Amer. Jl. Physiol. Opt.*, Vol. VII, p. 39.
- VON DER HEYDT (1918).—*Illinois Med. Jl.*, Vol. XXXIII, p. 329.
- WALTER (1916).—*Arch. Ophthalm. N.Y.*, Vol. XLV, p. 172.
- WELLS (1926).—"The Stereoscope in Ophthalmology," Boston.
- WEYMOUTH (1916).—*Ophthalm. Rec. N.Y.*, Vol. XXV, p. 271.
- WHITE (1936a).—*Amer. Jl. Ophthalm.*, Vol. XLIX, p. 653.
- (1936b).—*Penn. Med. Jl.*, Vol. XXXIX, p. 943.
- WHITNALL (1921).—"The Anatomy of the Human Orbit," London.
- WHITTINGHAM (1940).—*Jl. R. Nav. Med. Serv.*, Vol. XXVI, p. 15.
- WILLIAMS (1901).—*Trans. Amer. Ophthalm. Soc.*, Vol. IX, p. 388.
- (Abstract, 1904).—*Ophthalm. Rec.*, Vol. XIII, p. 334.
- WOODS (1920).—*Sth. Med. Jl.*, Vol. XIII, p. 126.
- (Abstract, 1919).—*Jl. Amer. Med. Assoc.*, Vol. LXXIII, p. 1795.
- WRAY (1912).—*Trans. Ophthalm. Soc. U.K.*, Vol. XXXII, p. 162.
- YOUNG (1926a).—*Virginia Med. Mon.*, Vol. LIII, p. 25.
- (Abstract, 1927).—*Ophthalm. Yearbook*, Vol. XXIII, p. 51.
- (1926b).—*Virginia Med. Mon.*, Vol. LIII, p. 233.
- YULE and KENDALL (1937).—"An Introduction to the Theory of Statistics," London.
- ZENTMAYER (1911).—*Trans. Amer. Ophthalm. Soc.*, Vol. XIII, p. 521.

SURGICAL CURE OF AN UNUSUAL DETACHMENT OF THE RETINA

BY

E. C. ZORAB

R.A.M.C.

THE following case is reported here so that the somewhat remarkable cure effected by Professor Weve, of Utrecht, should not go unrecorded.

The Rev. G.E.Q., aged 42 years, was seen by Mr. Freeman Heal, of Luton, in September, 1939, for routine change of spectacles. He was a high myope, but with correction could see 6/9 with the right eye. The sight of the left eye had been lost many years before as the result of a detached retina. Three weeks later, without any trauma, his sight suddenly failed when a large shadow came across it from left to right. He went back next day to Mr. Freeman Heal