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# THE DIRECTIONS OF THE APPARENT VERTICAL AND HORIZONTAL MERIDIANS OF THE RETINA AND THEIR MODIFICATION FROM PHYSIOLOGICAL AND PATHOLOGICAL CAUSES, WITH A DESCRIPTION OF THE CLINOSCOPE.

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(*Four figures in the text.*)

*Comparison of Data Regarding Retinal Meridians.*—If the point of regard of the two eyes is fixed in the median and in the horizontal plane and at infinite distance, while the head of the observer is in the primary position, it might be assumed that the vertical meridian of each retina would coincide with a plane perpendicular to the plane of regard and that the horizontal meridian would coincide with the plane of regard.

Yet in respect to a proposition so apparently simple and involving questions of great importance, practical as well as theoretical, the views of the ablest investigators have been at variance; for while Helmholtz concedes that the horizontal retinal meridians so nearly coincide with the plane of regard that they may be considered as practically identical with it, he characterizes the vertical meridians as *apparent* vertical meridians, and he reasons from his own experiments, and those of Volkmann, that these apparently vertical meridians as a matter of fact, in normal eyes, converge downward to the extent of $1\frac{1}{4}°$ each, making thus an angle between the vertical meridians of the two eyes of $2\frac{1}{2}°$ with the lower extremities of the meridians approaching each other.

Basing his calculations on this proposition and on the law

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of Listing, Helmholtz deduced his remarkable demonstration of the horopter in its various positions.

Meissner also found a tilting of the apparent vertical meridians, but worked out a different theory of the horopter.

Hering, however, found no convergence of the vertical meridians and of course arrived at a conclusion quite different from that of Helmholtz.

A subject of great physiological interest then has been thrown into confusion by the variation of data from which learned and conscientious investigators have drawn their conclusions. It has become the custom of recent writers to mention the subject of the horopter as one having no physiological value, or even to speak of it with a measure of disdain. The illustrious Helmholtz has been accused of a waste of time on his own part, and a demand for a waste of energy on the part of his disciples in their attempts to follow his analytical reasoning and his abstruse mathematical formulæ.

We shall make no mistake if we regard this subject to which Helmholtz devoted so much time and research as one which, when rightly comprehended, is of weighty interest to the practical ophthalmologist, and that it is by no means a subject of scientific curiosity only.

*Leaning of the Vertical Meridians in Paralyses.*—There is another field of research in respect to the position of these vertical and horizontal meridians which will perhaps appeal more directly, in the present state of our knowledge, to the practical ophthalmologist, and that is in regard to the degree and direction of their tilting in cases of paralysis or paresis of the motor muscles of the eye. At present, in the diagnosis of paralysis of these muscles, it is customary to observe the fact of the tilting of images, but of the exact extent little or no notice is taken. Although there are means of arriving at a rough estimate of this leaning, I believe that in no text-book on ophthalmology is it recommended to employ even these rude methods.

It may also be a subject of practical interest, indeed in certain cases it is such, to determine the extent of torsion which a patient may be able to induce and especially to determine, as far as possible, the muscles on the action of which the torsion depends. Yet we have no satisfactory and convenient means for determining this torsion, nor have we satisfactory means of developing the control of patients over the function.

We have thus various inducements to a greater facility in the theoretical study and the practical examinations of the relative positions of the vertical and horizontal meridians of the eyes.

*The Plane of Regard in Different Individuals.*—The question of the normal adjustment of the plane of regard of the individual with respect to the primary position of his own head when the minimum of nervous energy is directed to the muscles of the eyes, has never been taken sufficiently into account in the experiments of those who have interested themselves in the problems of corresponding points of the retinas and of the horopter, yet here is an element of great, in fact of essential, importance in the investigation. Daily experience with the use of the tropometer shows that many persons have the eyes normally so adjusted that in a passive state the plane of regard, the head being in the primary position, would be materially and often excessively above the horizontal plane. It is not unfrequently the case that repeated and well conducted examinations show that the normal deviation above the horizontal plane reaches from 8° to 10° of arc, and in some instances these figures express only a part of the truth. There is another large class of persons who show as clearly that the deviation of the plane of normal direction is materially below the horizontal plane.

It need hardly be said that, in an investigation in which the law of Listing plays the principal rôle, such peculiarities must be taken into consideration, and that, in the absence of a due regard to the normal plane of direction as shown by the tropometer, there can be, as there have been, only confusion and results of uncertain value from the researches of investigators.

The first element of accuracy in these researches then must be a knowledge of the relation of his normal direction of regard to the horizontal plane on the part of the observer.

If an observer should be subject to the condition which I have called anophoria,[1] that is, a condition in which there is a tendency for the eyes when not under the exercise of the will to deviate upwards, and if with this tendency there should be a necessity for slight convergence, then in the primary position the vertical meridians, supposing them to be vertical, should, according to the law of Listing, take substantially the position which was recognized by Volkmann and Helmholtz.

Should the observer, on the other hand, be subject to the opposite condition, should the normal direction be below the horizon, the vertical meridians (still supposing them

[1] As the terms Anophoria, Anotropia, Katophoria, and Katotropia will appear repeatedly in this discussion, it will be proper to define them. They were first suggested as expressing the conditions referred to in this article in a series of articles commenced in *Annales d'Oculistique*, April, 1895, and concluded in the number for July, 1895.

In those articles it was shown that, irrespective of the condition which had been known as hyperphoria (a tendency of one visual line to rise above the other), there were very many cases in which both eyes were so adjusted that with the minimum of nervous and muscular impulse the visual plane would fall materially below, or rise materially above the plane of the horizon, while the head is exactly in what is known as the primary position.

In moderate cases, in which the tendency of both visual lines is to rise above the plane of the horizon or to sink below it, no deviation of each eye singly upwards or downwards can be detected when a card is slipped before one or the other while the eyes are directed in the horizontal plane. But if the patient is examined by the tropometer the upward rotation of both eyes is found either excessive or deficient. To such cases the terms Anophoria (a tending upwards of both visual lines) and Katophoria (a tending downwards of both visual lines) were applied.

These include by far the greatest number of cases of the class of conditions in which the eyes are not normally adjusted for the horizontal plane.

There is a lesser number of cases in which, if the subject of the examination is caused to look at a distant object in the horizontal plane and a card is slipped in front of either eye, that eye will be seen to rise above the other or to fall below it, giving for the moment a vertical squint, with the covered eye deviating from the line of regard in the vertical direction up or down, and with the deviation of each eye in the same direction. If one eye rises under such circumstances and the other falls there is a different condition, known as Hypertropia, but if each of the two rises or falls as above described, the condition is known as Anotropia (a turning of the visual lines upward) or Katotropia (a turning of the lines downward).

It will be seen that the distinction between Anophoria and Katophoria on the one hand and Anotropia and Katotropia on the other is one of degree rather than one of kind. In the first the eyes can not be seen to deviate up or down, in the last the deviation is plainly seen.

In cases in which the eyes are adjusted for the plane of the horizon, the rotation upwards is about 33° of arc and the downward rotation about 50°. In Anophoria the rotation upward is in excess of 33°, often about 40°, and in Katophoria it is somewhat less than 30°. In the condition of Anotropia the upward rotation often reaches 55° of arc, and I have seen a few cases even more extreme. In these, however, a lateral squint usually results.

really vertical) should tilt outwards and downwards; while one who had an adjustment of the eyes for the horizontal plane and with no heterophoria, would, the supposition remaining as above, find no deviation of the meridians in either direction.

Thus it becomes not only possible but quite probable that the conflicting results of the study of the horopter may have been the outcome of the ocular peculiarities of those who have attempted it, and that these peculiarities are such as one accustomed to the use of the tropometer observes daily and which may be accurately determined. They may, therefore, be introduced as elements in the problem.

*Requisites for Determining the Position of Meridians.*—Passing now to the consideration of the means for determining the position of these meridians, we find from what has preceded that certain requisites are essential. They are:

1st. A knowledge on the part of the observer of the adjustment of his eyes in respect to anophoria or katophoria and a due allowance for the influence of this condition in respect to the direction of the plane of regard in making the experiments.

2d. A means by which the exact position of the head may be known and maintained. The head-rest which I have devised for the tropometer will serve this purpose. By means of this instrument two selected points of the cranium serve as fixed points, so that various observers are enabled to make exactly the same adjustment of the head, an essential condition, but one for which no provision has been previously made.

3d. The blending or the comparison of the images in the field of regard of the two eyes should be accomplished with the lines of regard of *the two eyes parallel.* This cannot be accomplished by the use of the ordinary Brewster's stereoscope, for this demands a distinct convergence of the optic axes. The same is true generally for those who have not exophoria in fixing the eyes in such a way as to blend stereoscopic images without the aid of an instrument. The majority of such persons, when they succeed in blending the stereoscopic images without instrumental aid, do so by converging the eyes to a point one half the distance of the point of regard.

*The Clinoscope.*—For the accomplishment of all these conditions I have devised the instrument which I am about to describe and which I have called the *Clinoscope*. This instrument appears to meet the demands not only of the physiological investigator in his theoretical researches in respect to the horopter, but supplies a means for practical examinations of the retinal meridians, the necessity for which has not been hitherto felt and for which no provision has been made.

The instrument appears to me to be essential to all the investigations to which I have referred, and by its use we shall, I doubt not, be able to establish such correct data as to enable us to harmonize the conflicting views of the inquirers who have left the subject of the horopter to be regarded, not as a subject of practical importance, which it is, but as an individual peculiarity varying with the experimenter, and therefore of little, if any, physiological interest. By correct methods of examinations into the phenomena the subject may be placed, where Helmholtz believed it should be, on a firm basis of scientific accuracy and uniformity.

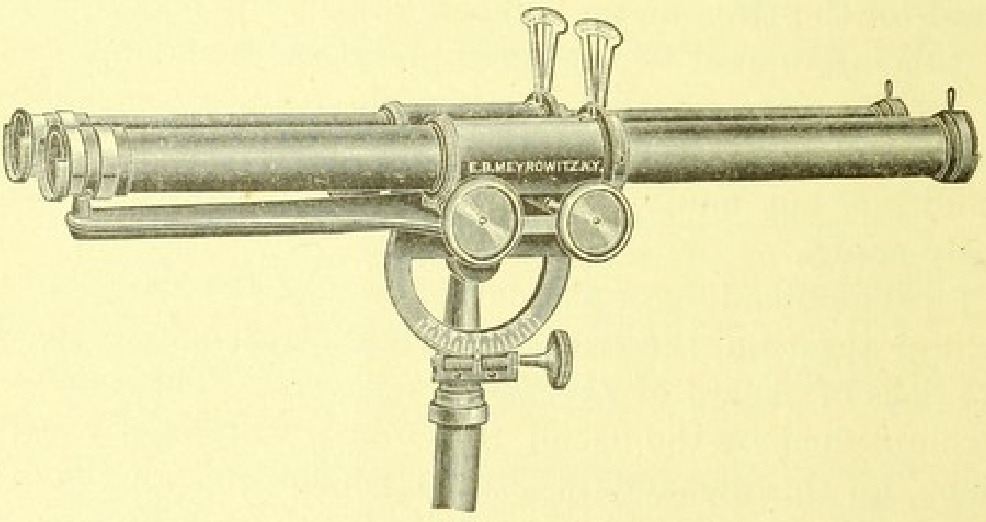


FIG. 1.

The instrument (Fig. 1) consists of two hollow cylinders, each about 2.50 centimetres in diameter and one half metre in length. The tubes are mounted on a brass platform, which holds them firmly in the same horizontal plane at a distance of 6.50 centimetres between the centres at the fixed points. The attachment to the platform permits the tubes to be adjusted in parallelism, in convergence, or in divergence in the plane of the platform. The platform is attached by a movable joint to the upright standard, so that the instrument may be given any desired dip, and a scale and pointer indicate, as in the case of the clinometer, the dip with respect to the horizon.

The tubes are rotated upon their longitudinal axes by means of thumb-screws, as seen in the figure, and a pointer and scale at the upper side of the tube marks the rotation with accuracy.[1]

At the proximal end of each tube is a clip in which, if desired, the observer may insert a glass for the correction of his refraction or any glass from the trial case.

At the distal end is another clip and provision for maintaining precise positions of the diagrams to be used in the investigation. These diagrams are haploscopic figures calculated to aid in the various experiments which may be made. These may be varied according to the wish of the investigator.

Below are represented two pairs of these diagrams. They are designed on ground-glass, but they may be made on thin paper and applied to glass disks.

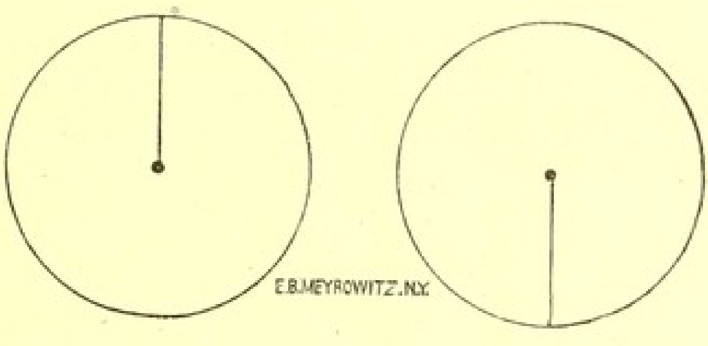


FIG. 2.

Fig. 2 represents two pins, one to be seen by each eye. As the trained observer looks into the tubes the two disks blend and the two pins unite as one long pin, but with the

[1] Since this article was written a form of clinoscope with magnifying lenses, but in other respects the same as here described, has been constructed. The advantages of the lenses, however, are doubtful.

head in the middle of its length. As the upper part of this united image is seen by one eye and the lower part by the other eye, each component of the long pin will appear vertical when that part of the line is brought to coincide with the vertical meridian of the corresponding retina. An adjustment of the tubes by rotation on the long axis will show the true direction of the meridian, vertical or horizontal (depending on the position of the diagrams), of each eye upon the scale above the tubes. Fig. 3 represents another

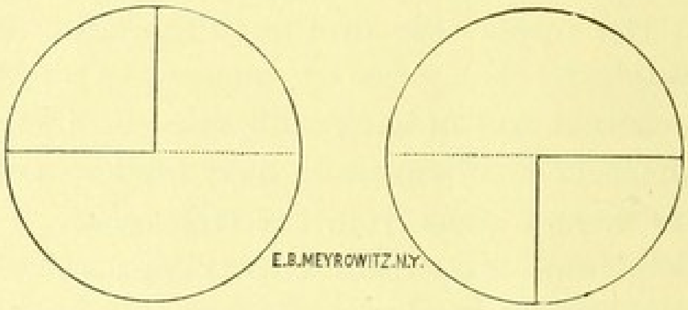


FIG. 3.

pair of diagrams in which both vertical and horizontal lines are included in the combined figure. In the disks themselves the lines represented here by black dots consist of a series of faint red dots. The perfect union of both the vertical and horizontal lines in a given plane would indicate a corresponding direction of the vertical and horizontal meridians in that plane.

By the aid of such figures the trained observer is able to perfectly unite the figures before the two eyes without the aid of convergence or divergence and without the assistance of mirrors or prisms. By means of the adjusting screws experiments may be made with the visual lines directed in the plane of the horizon, above or below it and at any given inclination in these directions. Also in case the observer is exophoric or esophoric, or for other reasons which may occur to him, the tubes may be adjusted in divergence or convergence, and in case of hyperphoria a correcting prism may be placed in a clip next the eye.

All these exact conditions being observed, we may repeat the experiments of Volkmann and Helmholtz in regard to the lines of correspondence with an elimination of the elements of error which were involved in their investigations.

The inquirer, learning from the use of the tropometer the peculiarity of his own adjustments with respect to the horizon, adjusts the dip of the clinoscope to conform to his own normal plane of regard. Suppose that his rotations are found to be for the positive ascensional (upwards) 40° of arc, for the negative ascensional (downwards) 43°. My observations have shown that the positive ascensional rotation should be 33°, and the negative ascensional 50°. This being correct, it is evident that the adjustment of the observer in this case is for a plane 7° above the horizon, and the clinoscope must be correspondingly adjusted while the head is prevented from accommodating itself to this adjustment by being held in place by the tropometer head rest.

*Are the Apparent Vertical Meridians really Vertical?*— I shall designate the inclinations of the retinal meridians which Helmholtz describes as "converging and descending," etc., as *declinations*, positive (+) and negative (−). These declinations will be recorded on the scales above the tubes, and when the declination is + the pointer will be directed externally to the 0° point, and when − internally to that point. Thus, in case of a result corresponding to the "converging and descending" inclination of the apparent vertical meridian, as found by Volkmann and Helmholtz, the pointers will indicate, Declination, + $1\frac{1}{4}$° each.

In my own case, after a great number of examinations, continued through many years, I have failed to find even a slight degree of esophoria, exophoria, or hyperphoria; and examinations made since the introduction of the tropometer have not shown a material departure from the standard which I have mentioned above. Thus, the experiment in my own case in regard to the direction of the apparent vertical meridians should be conducted with the tubes of the clinoscope directed horizontally, and with the head in the primary position, the glabella and the depression in the superior maxillary bone just below the nose being exactly in a vertical line.

Under these conditions, with the diagrams of Fig. 2 I find no declination of the meridians as shown by the pointers on the scales; indeed, the slightest movement from the 0° mark by either of the pointers is usually instantly detected.

If, on the other hand, the tubes are directed downwards 20°, in order to bring the lines of the two tubes into one line exactly vertical and straight, the pointers may require to be moved slightly out, giving a + declination. The declination is — if the tubes are directed upwards to a corresponding extent. But in either case it is very slight, and sometimes no declination follows the tilting of the tubes. If, however, I produce an artificial hyperphoria, placing a prism of 4° or 5° with its base down before either eye, a declination of the lines at once occurs and to a marked extent.

The principle holds good in cases of persons whose eyes are normally directed above the horizontal plane (anophoria), or below that plane (katophoria). In the first class the declination, if at all manifested when the plane of regard is in the horizontal plane, is + for each eye if the two eyes are similar, but if they differ, the eye which is best adapted to fixation at the distance of the diagrams will sometimes require the pointer of the tube through which that eye sees to be at the 0° mark while the other pointer will register a declination of one or more degrees. A marked condition of hyperphoria will exaggerate the declination according to the rule. If the instrument is inclined to the horizon in conformity with the excess of upward rotation, the registration is either at 0° or more nearly approaching it than when the instrument had no inclination to the horizon. That it sometimes still shows some declination would appear to indicate that the full degree of anophoria or hyperphoria has not been determined and corrected. Corresponding phenomena are observed in katophoria.

When the question of a perfect union of exactly vertical and exactly horizontal lines simultaneously in the clinoscope is investigated, my own observations do not correspond with the results obtained by Helmholtz. In the experiments of Helmholtz, when two horizontal lines blended there was not a blending of lines exactly at right angles to them. Thus it was necessary for him, in order to obtain perfect and simultaneous union, to give to the vertical lines an inclination converging and descending of $1\frac{1}{4}°$ for each eye. In my own case, with the clinoscope the red dots in the diagram Fig. 3 are exactly in the solid horizontal line, while the vertical lines are completely and firmly blended.

A much more difficult test, but one which will be perhaps more satisfactory to one who is skilled in such inquiries, is that of the well known diagram of Helmholtz, which is reproduced here on the diminished scale necessary for use in the clinoscope (Fig. 4).

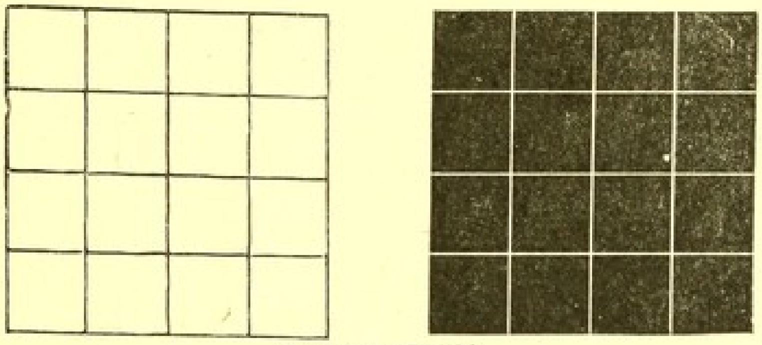


FIG. 4.[1]

On the theory that the horizontal retinal meridians are really horizontal, and that the apparent vertical meridians converge in descending $1\frac{1}{4}°$ each, he constructed this diagram, in which the vertical lines are given, the declination corresponding to the assumed declination of the retinal meridians. In case the vertical meridians actually tilt to the extent of $1\frac{1}{4}°$ each, the vertical and horizontal lines of the two sides of the diagram should blend perfectly and remain blended.

I have never been able under normal conditions to hold both these sets of lines together at the same instant while the plane of regard is horizontal and the figures are at right angles to it; for if the attention is given to uniting the vertical lines the horizontal lines are not perfectly united but have an inclination equal to that overcome for the vertical lines. If the union of the horizontal lines is maintained

[1] Although the engraver has represented these diagrams in quadrilateral form, they should be in circular form similar to Figs. 2 and 3.

there is a declination of the vertical lines which separate thus V. This declination is, in the diagrams of the size here represented and at the distance of one half-metre without an instrument or at the distance of the clinoscope when it is used, exactly equal to the diameter of one of the lines, so that, for instance, when the horizontal lines are maintained in exact union, a vertical black line which at its upper extremity is in contact with the white line, and at its right, will at its lower extremity touch the white line but on the left side. Thus the black line crosses from the right side to the left in the distance of the length of the lines. It is also interesting that, although the union of the black and white squares always gives the effect of lustre, no such effect is ever perceived, even at the centre, where the lines are superimposed as the result of the blending of the vertical lines when the horizontal lines are blended.

I am, however, able to induce a condition with the clinoscope in which a very close approximation to a union, if not an absolute union, of all the lines can be effected. If I place a prism of about 4° with its base down before either eye, thus causing an artificial hyperphoria of about that amount, the images of the tubes separate for a moment but soon unite and when union of the disks is effected the vertical and horizontal lines of the two sides become almost, if not quite blended. In what manner a declination of one set of lines should be induced, while the other set is subject to no change, is not altogether clear, but it is certain that the two sets of lines under these circumstances appear to me to make a more perfect union than when no prism is employed.

A still more perfect blending is effected if the diagram is seen through a stereoscope which is so placed that the plane of regard is downwards 20° and the card on which the diagram is printed is inclined away from the observer, making an angle with the plane of regard of about 120°. Under these circumstances the union is almost complete.

The phenomenon is, in this case, not so difficult to explain, for by the rules of physiological optics the horizontal lines would remain unchanged while the vertical lines would undergo a change of direction and with the required degree of the angle of inclination of the card the union should be accomplished.

This principle can be illustrated by a simple experiment varied from that of Meissner. A fine metallic thread is suspended in a good light with a weight at its lower extremity to hold it tense and vertical. The observer, with his eyes at a distance of one foot from the thread which is in the median plane and with the head in the primary position, looks at the thread at a point exactly on the level with his eyes. The thread will appear single only at the point of direct regard, above and below it will be double, crossing like an X at the point of regard.

If we would unite the thread in its whole extent, the weight may be drawn toward the observer so that the thread no longer extends vertically but with its lower extremity nearest the observer. This experiment might at first appear to oppose the view that in looking down the declination of the vertical meridians is inwards and downwards, for the lines diverge from the centre downwards. But it must be remembered that the right-hand leg of the cross is seen by the left eye and *vice versa.*

Carrying the experiment farther, I find that with the thread at the distance of 15 inches and with the gaze in the usual direction of reading, the thread doubles until its deviation is about 45° with the horizon. Thus it would appear that for eyes adjusted in the position of my own, a book or manuscript should rest at an angle of about 45°. If the page is laid flat on the table the head must be carried forward, or if the page is raised to a position nearly perpendicular with the horizon the book must be raised to the level of the eyes before the confusion is arrested.

As a matter of clinical experience, I find that persons having the condition of anophoria combined with hyperphoria, and especially if with these conditions there is a tendency to exophoria, the vertical meridians have a positive declination of from 1° to 3°. On the other hand, with katophoria and a similar combination of conditions there is a negative declination. In some cases of very considerable hyperphoria the declination reaches a still higher degree.

*The Horopter from the Practical Point of View.*—The position of the corresponding points of the two retinas being determined, the points in space which may present themselves simultaneously upon these corresponding points of the two retinas may then be also determined. The total of the points upon which images in a given fixed position of the eyes can fall upon corresponding points of the two retinas is called the *horopter.* All objects perceived at these corresponding points are seen single, but objects the images of which fall upon non-corresponding points are seen double. The proportional extent of the field of view in a given position of the eyes in which images are seen singly is less than that in which they are seen doubly, yet it is only when examinations of a critical nature are made that the perception of the double images is recognized.

The horopter resolves itself in all situations not into a large flat or concave field but into lines. In certain situations these lines resolve themselves into a portion of a circle and a straight line. In other situations, with the necessary declinations of the retinal meridians, these lines of the horopter become exceedingly complicated in respect to their direction.

It is not the purpose of this paper to discuss the details of the horopter and especially not to enter upon a solution of its technical situations in the various positions of the plane of regard. It will suffice for our present purpose to point out some of the practical considerations attending this subject.

The position of the horopter of Helmholtz, occupying the ground on which we walk, notwithstanding the opinion of Helmholtz that this would be an extremely favorable position, would in fact be a most unfavorable one; for an individual with the horopter thus located would be forced, in order to obtain clear vision in the path in which he walks, to look directly at the horizon with the head erect. Such an adjustment of the head and eyes would be quite impracticable. In practice, a person having a declination of $+ 1\frac{1}{4}°$ each eye would find it necessary, when directing the eyes to the ground at 10 or 15 feet in advance of him, to carry the head in front and bend forward in order to avoid too strong a depression of the plane of regard in relation to the head. And this is exactly the position taken in walking of persons who have the condition of anophoria, especially if it is associated with even slight hyperphoria.

On the other hand, those who have unequal katophoria walk with the head tilted back, the chin high in air, in order, doubtless, to adjust the position of the eyes for a horopter lying in the path they are about to tread.

It is not, however, in walking that the position of the horopter is most important. It is at the distance of and in the direction of reading and of work in the position of reading that the most urgent necessity for a favorable position of the horopter may be found. The subject of anophoria, especially of unequal anophoria, one whose eyes are adjusted high and with the complication of hyperphoria, must carry the head far over the page in order that the depression of the plane of regard may be accomplished without the greater contraction of the depressor muscles of the eyes which would be demanded were the head held only slightly inclined.

To such a person, with the head in a position nearly upright, the images of horizontal lines seen by the two eyes would be inclined to cross and thus cause confusion. To avoid such confusion the head must be thrown far forward or an irksome voluntary effort directed to the torsional muscles must be brought to bear.

The position of the horopter is also and in a corresponding manner unfavorably modified in cases in which too great effort is required on the part of the elevator muscles in order to adjust the eyes for a given plane of regard.

The muscles which principally influence torsion are, notwithstanding their comparative size, less able to exercise constant exertion than those which act in a more direct manner upon the vertical and lateral movements. Hence a position of the horopter demanding considerable torsion through the influence of the oblique muscles is a position resulting in fatigue and often in pain and exhaustion.

In the case of one whose eyes are adjusted for the horizontal plane and who has no heterophoria, the horopter, with the head in the primary position and the gaze directed in the horizontal plane, will be in the circle of Müller and in a line which extends from the ground upwards. Practically this may be regarded as a straight line but in fact it is a portion of a circle which cuts the circle of Müller. If the gaze is directed downward, as in walking, with the objective point a few feet in advance, the horopter will be in the position supposed by Helmholtz to be the normal one for the direction of the eyes in the horizontal plane, that is, the ground on which we walk. For in that case there will be a convergence with a depression of the gaze and a resulting rotation on the optic axes and at the distance at which one would usually look in walking, the declination of the retinal meridians would be about $1\frac{1}{4}°$.

If the eyes are adjusted (as they are in a very large proportion of those having very vertical profiles, an extreme of the condition known to anthropologists as the *orthognathous face*) with the visual lines tending above the horizontal plane, it becomes necessary, or, at least, conducive to the ease of seeing to bend the head forward to a marked extent in order to avoid an excessive action of the depressor muscles and the consequent tilting of the vertical meridians. This tilting if not excessive, and in the case of those who have excellent torsional powers, may be neutralized while the head is carried nearly erect. Yet in extreme cases of anophoria and especially in those cases which reach the condition of anotropia, in which either eye may be seen to deviate upwards if covered, while the other is directed to a distant object in the plane of the horizon, the carriage of the head far in advance and bent downwards is imperative in walking or working. Such exceptions as come within this rule will be mentioned as we proceed.

On the contrary, the chin must be raised in order to locate the horopter along the ground in the case of marked katophoria or katotropia. The facial lines of these katophoric persons are as well marked as those of the anotropic class. With katophoria we find as a rule a "weak" chin and strong facial angles. The profile is more or less that known by anthropologists as *prognathous.*

Exceptions to the general rule for the carriage of the head have been mentioned. These may occur in the condition of anophoria or katophoria. In some conditions of extreme upward tendency of the eyes and especially with more or less exophoria in which there is a marked difference in the upward rotations, on account of the difference of the two eyes in relation to the plane of regard and the tendency to diverge, it becomes more easy in certain positions for these people to adjust for the lower of the two eyes than to correct by torsion the marked declination of the vertical meridians which occurs in certain other relations of the visual axes. Even in these cases the carriage of the head is much of the time characteristic according to the rule. A similar class of reasons sometimes influences the carriage of the head against the usual rule in the condition in which the visual plane is normally depressed.

*Torsion and its Psychological Effects.*—Movements of the eyes which are habitually associated may, by an effort of the will, be isolated.

When the eyes are turned to one side and upwards or downwards there occurs also an apparent rotation on the optic axes. This peculiar apparent rotation of the eyes is rarely made as an independent movement, for it depends upon the passing of the eyes from one fixed position to another and the consequent change in the relation of the cornea to the cranium. But there is required in directions of the line of regard other than these oblique directions just mentioned an actual turning upon the optic axes. Thus, in directing the gaze upward with much or little convergence or downward with convergence of any degree, this rotation on the optic axis—torsion—occurs.

It is a fact long familiar to students of physiological optics that this power of torsion may be demonstrated in a number of ways, convenient among which is that of uniting two linear figures with the stereoscope and giving to one of them a gradual turn. The images will for a time continue united, but at length, when the rotation of the figure has been carried as far as the rotation of the eyes on the axes can follow, the images will separate. If, while the images of the two sides of the sterecoscopic card are held united, but when the parallelism of the vertical and horizontal lines is, to a considerable extent, lost, the observer closes the eyes for a moment and then opens them, the images will be seen double with the vertical lines diverging above or below. After a little, the images may again adjust themselves and complete union may be re-established.

While the rotation thus demanded may be isolated from the movements with which it is usually associated, it is not, under ordinary conditions, possible to isolate the action of a single pair of muscles for its production.

That the oblique muscles play the principal rôle in the act of torsion, under circumstances such as have been mentioned, is unquestioned. They are not, however, the only agents in the rotary movements for the superior and inferior recti lend important aid in the act.

Many well known experiments show that the greater the convergence and the greater the depression of the plane of regard, the greater will be the angle of declination of the retinal meridians. In convergence with depression of the plane of regard, the vertical meridians will converge below, forming an angle thus, V; while in convergence with elevation of the plane of regard, the angle will be reversed, thus, Λ.

These phenomena occur when the eyes are normally approximately adjusted for the horizontal plane without the aid of voluntary effort. In very well marked anophoria or katophoria the results may not be uniform with the rule as just stated.

Under approximately ideal circumstances then, in convergence with depression, the eyes rotate outwards upon the optic axes, while in convergence with elevation they rotate inwards. Supposing the eyes to be absolutely free from the condition of anophoria or katophoria, there should with convergence in the horizontal plane, the head being exactly in the primary position, be no torsion. In most persons, however, there is an inclination, when examining a line of any length, to permit the attention to pass toward the lower part of the line and thus we have reported results, even where there may be no anophoria, which are due to a depression of the plane of regard simultaneously with convergence. With the use of the clinoscope, this error of observation is, of course, eliminated.

The rotation which inclines the upper extremity of the vertical retinal meridian inwards is effected by the superior oblique and the superior rectus, while the inferior oblique and inferior rectus combine their action in tilting the vertical meridians outwards.

It is impossible, while all the muscles are active to determine the proportionate influence of any individual muscle in the act. In the case of paralysis of one of the oblique muscles or of one of the vertically acting recti, a somewhat closer estimate may be made, but even then, while the corresponding muscle of the opposite side remains intact, there is, necessarily, an important element of uncertainty. A complete paralysis of all the oblique muscles, the others retaining their function, or of all the vertically acting recti under corresponding circumstances would be required to eliminate the sources of the error incidental to the question of proportionate influence of each of the muscles concerned in the torsional rotation.

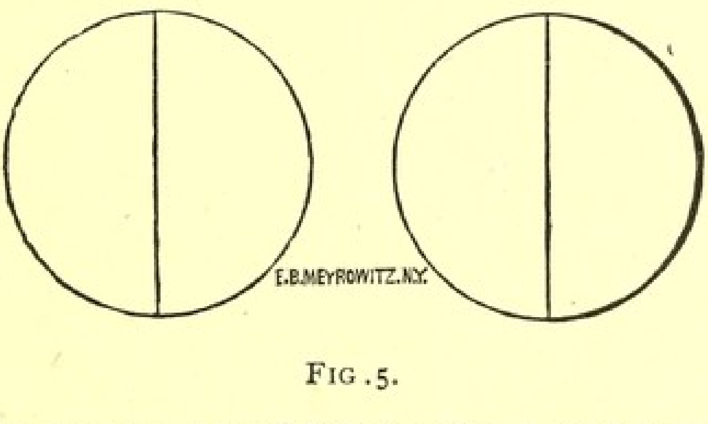


FIG. 5.

As to the extent to which torsion can be carried, it is greater in convergence than in parallelism of the eyes. Hence it is greater when the ordinary form of stereoscope is used in its determination than when the images of the two eyes are caused to blend without an instrument, or when some instrument is employed which does not, like the Brewster stereoscope, induce a convergence.

For examination of the power of torsion, the clinoscope affords a means attended with a much greater degree of facility and of accuracy than any which has been suggested. In using the instrument for this purpose, the lines which occupy but half the field of each tube are no longer useful, but straight lines crossing the middle of the field and extending to its extremities (Fig. 5) are required.

If the lines are adjusted vertically and the tubes are then rotated each in the positive direction (upper extremities of the lines outwards), the mental conception of the position of the line formed by the union of the two is modified in an interesting manner. As soon as the tubes are thus rotated outward, the line, so long as it is held as a single line, begins to assume a direction approaching the horizontal. The lower extremity points in toward the observer and the upper extremity outwards from the tube. If the observer has good powers of torsion, the line will at length appear to point almost horizontally directly in and out and to be materially elongated, as though it were an arrow to be shot outwards and slightly upwards.

With a good power of torsion, the lines may be held in union until each of the pointers marks $+ 11°$. Thus between the vertical retinal meridians of the two eyes an angle of 22° with its apex down is formed.

If the rotation is carried in the negative direction, a torsion of about an equal extent or possibly 2° or 3° less is induced, and, in this case, the line assumes again an approximation to the horizontal position, now pointing from within outwards, but outwards and downwards. There is a peculiarity attending this rotation of the eye upon the optic axis which is not found in the other rotations. Let us suppose that we wish to learn, for example, the power of abduction in overcoming a prism with the base out. With the object, the flame of a candle at a distance of twenty feet, a prism of 8° is overcome and the flame seen by each eye blends into one. Now it makes little, if any, difference whether in the experiment we use a prism of 8° before one eye or of 4° before each eye. We cannot exceed the amount of abduction by the use of a prism of 4° before one eye and 5° before the other, any more than we can by replacing an 8° prism before one eye by a prism of 9°.

In the rotation under discussion, however, it is different. If one is able to induce with the clinoscope a torsion of 20° with the two eyes, he cannot, while maintaining the vertical position of one of the lines in the clinoscope, rotate the other to an extent equal to that to which the two were rotated. I find that with one line remaining vertical I can rotate the other either in the positive or negative direction about 14°, which is, however, more than half what I can accomplish with equal rotations of both tubes.

If the right tube remains with the vertical line at 0° and the left tube is caused to rotate outwards, the combined image points outwards, upwards, and to the left. If the left tube is stationary at 0° and the right tube rolls out, the line points outwards, upwards, and to the right.

It is an interesting as well as an important practical fact, and one to which little attention has been given, that horizontal lines can not be held in union while being rotated from the horizontal direction to an extent nearly equal to that in which vertical lines can be held in union. If vertical lines can be held in union with a rotation of 20° or more, horizontal lines become double with a total rotation for both tubes of from 6° to 8°. Indeed, it requires some practice to hold the lines in union with a rotation of each tube either out or in to the extent of 3°.

If the tubes rotate out, the line appears concave, bending outwards at the centre or convex according to the will of the observer. If the rotations are negative the line is convex or concave as before.

*Bearing of these Principles on the Horopter.*—The fact of the difference in the ability to hold vertical and horizontal lines in union can be seen to constitute an important element in experiments such as those by which Volkmann and Helmholtz investigated the directions of the different retinal meridians. For while there is an imperious necessity for holding the horizontal lines approximately so in order to unite the two images, a very considerable latitude is permitted in respect to the position of the vertical lines, and the torsional act may overcome an important normal deviation.

The principle holds in stereoscopic vision, that the visual recognition of form and of the third dimension is not the direct result of an instantaneous image formed on each retina, but the result directly, or indirectly, of a series of muscular adjustments. That both form and depth may be perceived instantaneously is true, but doubtless in such instantaneous realizations of the actual dimensions of objects there is a mental acceptance of the phenomena which experience has taught to be the result of impressions received upon the two retinas, provided time is allowed for the usual rapid ocular movements.

The fact of difference in torsion for horizontal and vertical lines has its practical application in many directions. A single example may be introduced here as an illustration of this important principle. The question of the form and proportions of printed type, in order to produce the most perfectly legible characters and a page which can be read with greatest ease, has long interested those who are interested in the progress of the art of printing in its relation to the preservation of the functions of the eyes. Experience has, independent of any theory, taught practical men engaged in the art of typography, that the height of letters must be considerably greater than their breadth. In the ordinary type used in America and England the vertical length of all the letters of a line aggregates rather more than thirty millimetres to every twenty millimetres of breadth of letters. In the French typography the height of the letters is still greater. A little examination of different styles of typography will convince a careful investigator that broad, low letters are less easily held in perfect binocular union than the form more nearly approaching the gothic style.

In what precedes I have gone over a number of somewhat closely related subjects more with the view of indicating the directions in which exact investigations are to be made than with the purpose of fully discussing either of the topics introduced. The questions relating to the corresponding points of the retinas have been recognized as fundamental to the solution of the problems of the situations and the character of the horopter. If by the aid of the clinoscope combined with the knowledge gained by the tropometer, we can arrive at a more uniform basis of facts respecting the horopter, much will be accomplished.

The observations of the last two years have led me to assign a most important place to the subject of the horopter. That it is a practical subject, ranking by the side of that of refraction, although a much more difficult and obscure field of research, is a conviction which has grown with every month of investigation since its real meaning, the meaning which could only be revealed by the practical use of the tropometer, has been pressed upon my attention.

This is not the occasion and I do not propose here to review the many directions in which the question of the position of the horopter becomes practical. This is a subject which may become the theme of another paper.