A METHOD FOR THE EXPERIMENTAL DETERMINATION OF THE HOROPTER.

BY CHRISTINE LADD-FRANKLIN.

If the diagram of Plate III. be held in a horizontal plane in front of the face, with the arrow directed towards the bridge of the nose, and at such a distance that the circle, if produced, would go, roughly speaking, through two points a little below the centres of the eyes, an optical illusion will present itself. If one looks at the intersection of the middle cross, there will still be seen a cross on the plane of the paper, but there will be seen in addition a third line, which, if the paper is at the right distance from the eyes, will seem to stand up in a nearly vertical position, half above the plane of the paper and half below it. When the position is right for the middle cross, it is also right for all the others, and if the eyes are converged steadily upon the middle stick, the other crosses will also present nearly vertical sticks, visible by the lateral portions of the retina. The phenomenon is also pretty well preserved if the point of fixation wanders from one to another of the circular row of sticks. If the paper is gradually moved farther away from the eyes, the illusory stick may be made to look exactly vertical, but the position is not then quite right for the lateral portions of the field.

There are two points to be explained in this illusion: the presence of the third line and its upright position. Take a single pair of crossed lines, as in Fig. 2, hold them in a horizontal plane, and at such a distance that with the right eye shut, 1, and with the left eye shut, 2, looks like the projection of a vertical line. Now, with both eyes open, fixate a point at some distance beyond them (by sticking in a pin at that point if necessary). The lines will be seen double, as two entirely separate crosses. Let the point of fixation approach nearer to the intersection of the cross, and the double images will be brought nearer together until they partly overlap, and the appearance of Fig. 3 will be produced, where the image seen by the left eye is drawn in dotted lines, and the image seen by the right eye in uninterrupted lines. As the fixation point is brought still nearer to the intersection of the cross, the left-eye image of line 1 and the right-eye image of line 2 (which are parallel if the card is held at the right distance) come still nearer together, until the intersection is fixed and they exactly coincide. At the moment that they coincide, they leave the plane of the paper and become a single line in space, its lower end directed more or less exactly towards the feet of the observer. (Its exact position depends upon the position of the apparent vertical meridians for the given fixation point, which is different for different individuals.) As R_2 and L_1 unite, R_1 and L_2 present the appearance of a cross with the vertical line pass-

Fig 2.

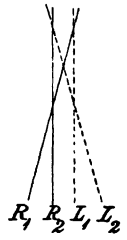

Fig 3.

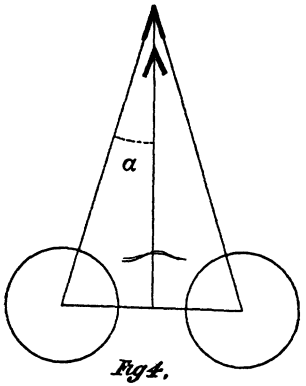

Fig 4.

ing through their intersection. If we apply the construction for the cyclopean eye,[1] what takes place will be represented by figures 4 and 5. Fig. 4 gives the position of the eyes and of two pairs of lines, cutting respectively in the fixation point and nearer than the fixation point. (For simplicity only the near half of each cross is drawn.) The picture seen by the right eye, shifted through the angle α gives the right hand half of Fig. 5, and in the same way the right eye's image furnishes the left hand half. The cyclopean eye, then, sees two parallel lines coincident when, and only when, the fixation point is at the intersection of a cross. It will be noticed that the angle seen between the lines of the cross is twice as great as the angle drawn.

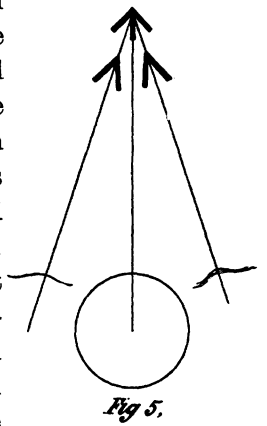
Fig 5.

This illusory line is seen as one, then, because images of two different lines fall upon corresponding rows of points in the two retinas. The reason that it seems to be nearly vertical is that the only line in the median plane which is capable of throwing its images upon corresponding rows of points is the

[1] Hering: Beiträge zur Physiologie, I., p. 43. 1861.

nearly vertical line. Look at a single line drawn in the median plane upon a sheet of paper, held near the eyes and horizontally before them. To the right eye alone its near end will seem shifted towards the left, to the left eye alone towards the right; it is only when the plane of the paper is directed towards a transversal line through the feet that the given line seems to either eye alone to be in the median plane. It is imposible that any single real line should throw its images upon the apparent vertical meridians unless it is in the intersection of the planes through those meridians respectively and the fixation-point. If images are artificially thrown upon those meridians by two different but exactly similar lines, the mind, which is entirely unaccustomed to having such tricks played upon it, cannot escape the conclusion that it is looking at a single line in that position. The illusion is a remarkably persistent one; no degree of clearness of understanding of its origin will enable one to avoid thinking that the middle stick is out of the plane of the paper, provided he has good double vision, and has the power of steadily fixing the intersection of the cross. But this two-eyed illusion is very little in need of explanation after it has been noticed that there is a corresponding one-eyed illusion. In Fig. 6, the lines are all drawn so as to pass through a common point.

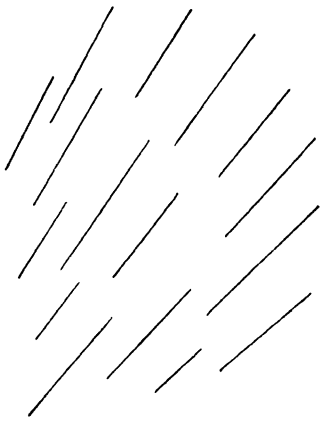

Fig. 6.

With a little trouble, one eye can be put in the position of this point,—it is only necessary that the paper be held so that, with one eye shut, the other eye sees all the lines leaning neither to the right nor to the left. After a moment, one can fancy the lines to be vertical staffs standing out of the plane of the paper. Fig. 7 is a modification of Zöllner's pattern, and, if looked at in the ordinary way, presents his well-known illusion. The short lines are not parallel, however, but each set passes through a point outside of the paper. If the paper be held horizontal, and if one eye be shut and the other put in the place of one of these points, the lines going through it will seem to be vertical, the other lines remaining horizontal. If the eye be now put in the place of the other point, the vertical and the horizontal lines will change places. I put a sheet of paper like this in position one day before the eye of a little girl eight years old, and asked her what she saw; she said a once, "I see two fences and two railway tracks."

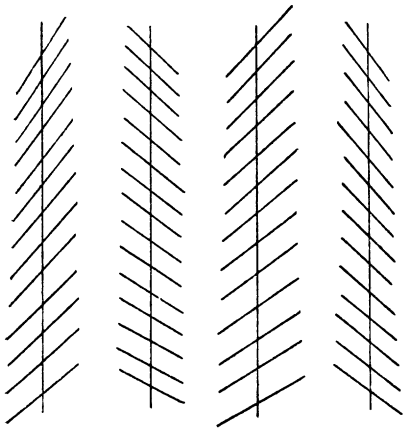

Fig. 7.

This illusion I take to have a purely mental origin. When a line lies anywhere in a plane through the apparent vertical meridian of one eye, and is looked at with that eye only, then, if we do not know how long it is and if it does not present any characteristic reflections, we have no very good means of knowing

how it is directed in that plane,—the only means we have, in fact, is the amount of change of accommodation that takes place as we look from one end of it to the other. Now of the lines in nature which lie anywhere within such a plane, by far the greater number (trees, edges of buildings, flag-staffs, pendulums, &c.), are vertical lines; hence we are peculiarly inclined to think that a line which we perceive to be in such a plane is a vertical line. But to see a lot of lines at once, all ready to throw their images upon the apparent vertical meridian, is a thing that has hardly ever happened to us, except when they have all been vertical lines. Hence when that happens, we have a still stronger tendency to think that what we see before us *is* a group of vertical lines.

This illusion in regard to vertical lines is sometimes met with in nature. If one looks through a narrow tube at a small portion of china-matting, the straws of which run towards the feet, it cannot plainly be made out to be horizontal. There is a picture by Boughton in Mr. Walters' gallery in Baltimore, in which the paint which represents the surface of water is laid on with vertical strokes of the brush. If it be looked at with one eye, and with the hand held so as to cutoff the adjoining shore, it looks much more like a vertical wall than a level surface of water.

If, when looking at the one-eye lines, both eyes are suddenly opened, the sticks are instantly thrown down. In Fig. 7, however, the double images of the lines can be separated after a few minutes, and the appearance of vertical lines crossed by others is presented. But although the head be kept perfectly motionless, the vertical lines are tipped a little out of

their former position. The same effect is still more noticeable if two long parallel lines, at the exact distance apart of the eyes of the observer, are held horizontally before the eyes. To either eye alone, if the other be shut off by a screen, one or the other line looks perfectly vertical; but, with both eyes open, as soon as the vertical lines are distinguished, they are seen to have their nearer ends brought nearer together. This shifting may also be produced by forcible convergence of a shut eye, and an easy modification is thus furnished of a more difficult experiment of Le Conte's (*Sight*, page 186). It shows that though one eye looks at a near point, the outward rolling of convergence does not take place if the other eye is at rest.

In the two-eyed illusion of Plate III. all the lines are drawn so as to pass through one or the other of two points on the circle produced, and at a distance apart equal to the average distance between the two eyes. When the eyes take the place of these points, each eye sends to the brain information of a vertical line at the intersection of a cross, and their combined testimony is too strong to be in the least shaken by the knowledge that no such line exists.

If one has experience in uniting double images, the diagram may be held in various different positions, and a single line, variously situated in space, may still be recomposed. If it is held nearer to the eyes, the line declines into the plane, and if farther away, it becomes exactly vertical. If it is rotated in a horizontal plane, the line sinks down into coincidence with one branch of the cross, to rise again and fall into the other branch. If it is rotated into a vertical plane, the line points forward on top.

Looked at from underneath, the line is inverted; its top has now a slight indistinctness, which its bottom had before, for its top comes from the near portion of the cross, and accommodation becomes defective more rapidly coming in than going out.

When the line looks vertical it is not seen single throughout, although, if it is short, one is not easily aware of that fact. Support the plate on a table nearly on a level with the eyes, and fix the teeth in a head-holder[1] at such a distance as to make a line look vertical; its top may now be pricked in two by the point of a cambric needle; this cannot be done if the line is directed towards the feet. The divergence of its images is, in fact, the mark by which we know its degree of verticality. An actual vertical stick we see double at top and bottom, if we look at the middle of it, but our fingers have convinced us in so many millions of instances that the stick is not split, that we have come to quite overlook the visual splitting as splitting, but to give it its full significance as *sign of a vertical line.* It is really perceived, though not for itself, but only as part of a sensation-complex.[2]

This illusion derives its chief interest from the fact that it furnishes a very delicate means for determining whether we see double or not. When, in Fig. 2, the fixation point is near the actual intersection of the cross, the pair of parallel lines appear one on either side of the intersection of the imaginary cross, that is of the lines L_1 and R_2. When the fixation point is very near, the parallel lines are too

[1] Helmholtz, Physiol. Optik, p. 517.

[2] Stumpf: Ueber den psychol. Ursprung der Raumvorstellung, p. 270.

close together to be distinguished as separate lines, *but it can still be detected that the one which is seen is not at the intersection of the apparent cross*, and that is sufficient to show that the actual intersection is seen double. In the drawing of Plate I., the circle represents the theoretical horopter circle, which passes through the fixation point and the points in the eyes in which the sight lines intersect. The sight lines (*visirlinien*) are lines through points which appear to be in the same straight line—that is to say, the centres of whose diffusion circles coincide. They all cross in a point, which is in the image of the pupil formed by the cornea, and about 4 mm. in front of the mean nodal point.[1] The drawing must be supported on a horizontal table, and the head must be in a comfortable position and such that to one eye one set, and to the other eye the other set of lines lean neither to the right nor to the left. (If that cannot be done, it is because the drawing does not fit everybody's eyes). Some of the crosses do not cut on the circle. If one fixates one that does, and attends to the image in the lateral field of one that does not, then the latter can be made out to present the appearance above described. One sees now one and now the other of the vertical parallel lines, riding now on one and now on the other of the legs of the cross, and although one does not *see* the intersection double, one *infers* that he sees it double from the fact that he sees an apparent intersection with the line not going through it. So slight a separation of double images as this, one is quite unable to detect by any of the ordinary means. The effect

[1] Hering, Phys. Optik, p. 466.

can be obtained, for a certain distance around, by a person who has good control of his attention, but has had no experience at all in optical experiments; he can, at least, perceive that if he looks hard at the stick on the right of the middle one, for instance, the perfection of the illusion for the stick on the left is quite broken up. But the tangent to the circle at the first goes through the second; hence he has proved that the locus of points seen single is not the straight line tangent to the horopter circle at the fixation point. The imaginary sticks form sufficiently interesting objects of attention to enable one to fixate them without any trouble. They also serve to take the place of a head-holder. The drawing can be made at ease with a circle of any convenient radius, and with the distance between the fixed points calculated for the observer from his interocular distance and the given convergence. The head can then be got into the required position and held there simply by the appearance of the lines.

This diagram, then, is sufficient to prove, even to the inexperienced observer, that the horopter is a circle when the fixation point is median and nearly in the primary plane. The experiment may be varied by having movable crosses which can be shifted about on the plane of the paper, but in that case the angle should also be made capable of being changed, which can be done if it is made by threads wound about a bit of cardboard. To determine the points seen single very far around in the lateral field, something brighter would have to be substituted for black lines—flat strips of platinum made white hot by an electric current, for instance. I have not yet carried out this experiment. The lines suffice for a

point-to-point determination, of from twenty to thirty degrees at a time, and this would amount to exactly the same thing, if the horopter circle went through the centres of rotation of the eyes. As it is, a motion of the fixation point along the circle, as drawn, changes a little the position and the size of the horopter circle. There are, of course, difficulties in the way of carrying out the test for remote portions of the retina. Besides the difficulty of seeing anything distinctly, there come in differences of perspective, and hence of the apparent size of an object large enough to be seen at all; the error of accommodation, which is particularly great for vertical lines;[1] the inclination of the horizontal meridians for near convergence; and the difference in strength between the nasal and temporal halves of the retina, which Schön has shown to be a factor of critical importance in all phenomena of double vision.[2]

The best experimental determination of the horopter which has hitherto been made is that of Schön (l. c). He arranges two openings in screens with lights behind them in such a way that lines of direction cut on a point of the horopter circle, and the image of an opening is then perceived at that point. I have repeated this experiment, but I do not find that the single image cannot be got when the point of convergence changes within certain limits. The same result can be more simply accomplished by a row of strings, with weights on the bottom of them, suspended from a rod. The points of suspension for

[1]Fick, Physiol, Optik, p. 80.

[2]Archiv f. Opthalmologie, XXII., 4, p. 31, and XXIV., 1, p. 27 and 4, p. 47.

any observer may be determined beforehand, by drawing, in the way made clear by Fig. 8. The

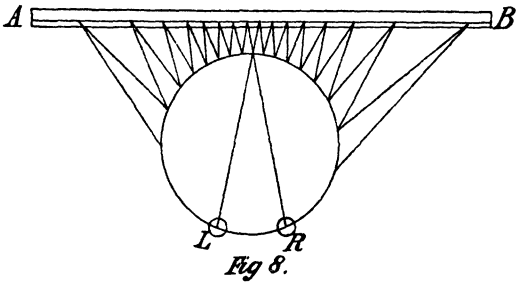

Fig 8.

strip of paper AB is cut off and nailed on to a strip of wood, and the points on it determine the points of suspension for the pendulums. To avoid the error produced by the opposite obliquity of vision of the two eyes, the half strips of paper and of wood should be inclined at an angle equal to the supplement of the angle of convergence (Fig. 9). When the eyes are brought into the right position, the strings can all (with the exception of the two outer ones) be brought into a cylinder of startling reality; after a few moments, their minutest fibres can be seen as distinctly as if one were looking at a cylinder of actual strings. *But it is not necessary that they should be at their constructed distances apart.* If they are hung at equal intervals, for instance, they are just as easily brought in, but they appear then in the shape of a plane. In this way they constitute a form of a well-known and much-discussed experiment.[1] All but the one looked at of the phantom

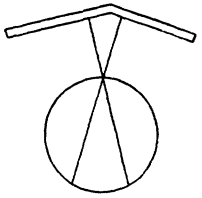
Fig 9.

[1] Hering, *Physiol. Optik*, pp. 398-403. Helmholtz, *Optique Physiologique*, pp. 827-835. LeConte Stevens, *Am. Jour. of Science*, 3, XXIII, p. 298. The slight curvature of the plane appears in the actual strings as well as in the phantom ones.

strings are now seen double, *but it is no easier to distinguish that they are seen double than it would be if they were actual strings.* They may be hung at various slightly irregular positions, and they then form various irregular surfaces, but there is no reason for saying that one rather than another of these various surfaces is a *Kernfläche* (Hering, l. c). It is even possible to set one of them to vibrating from side to side between its neighbors, without being able to perceive that one is seeing double. What happens then, is represented in Fig. 10. As the actual string A moves from *a'* to *a''*, the two phantom strings which it assists in forming make long excursions in and out, as is indicated for one of them by the two small circles of the figure. It is plain then, that the difficulty of making ourselves conscious of what points in space we see absolutely single is not at all obviated by this device. The same thing might be concluded from the fact that it led Schön to see the horopter of points as a circle, and Hering to see the horopter of upright lines as very nearly a plane. That difficulty is quite overcome, however, by such an arrangement as that illustrated in Plate I. I propose to apply it to the determination of the horopteric curve for non-primary positions of the fixation-point.

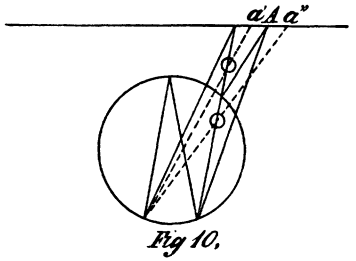

Fig 10.

PLATE III.