ON MONOCULAR VISUAL SPACE.

By W. HEINRICH.

Professor of Psychology and of Methodology of the Natural Sciences in the University of Cracow.

1. OUR attitude towards the psychology of space-perception is closely related to the development of philosophical views since Descartes. For if sensory qualities are subjective modifications, space-perception, too, must be subjective—the product of psychical activity.

This point of view is responsible for the lines along which the methods of investigating space-perception have hitherto been pursued. The existence of geometrical space was presupposed, and an attempt was made to find out the sensations (or sensory characters) corresponding to every position in geometrical space. Moreover, as the quality of such sensations was regarded as dependent mostly on the quality of the stimulus or on the specific nature of the nerve stimulated, it was necessary to invoke the aid of the sense-organ in question, e.g. the eye, and the sensations (or sensory characters) arising in that organ and its muscles. Thus arose that line of investigation which inquired into the characters of sensations corresponding to the geometrical determination of the place of origin of the stimulus in order to discover, by this means, the connexion between subjective space-perception and geometrical space. Helmholtz and Hering differ, *inter alia*, in the different geometrical constructions which they employ as a means of ascertaining this connexion. And it is to this general attitude that we must attribute the assertion that monocular visual space is merely bidimensional.

2. This is not the place to trace in detail the origin of the formulation of the problem. I have already dealt with it elsewhere¹, and I hope soon to return to it in a different connexion in the Transactions

¹ *Teorje i wyniki Badań psychologicznych.* Warsaw, 1902, Vol. I. pp. 25–86.

of the Academy of Sciences in Cracow. I have there come to the conclusion that the problem of space-perception may be experimentally approached in a way different from any hitherto attempted, and that the conceptions of the *relation between geometrical space and space-perception*, which have hitherto been employed, are by no means the only, and still less the only correct, ones available. I have also shewn there that all attempts to create space-perception synthetically from spaceless qualities must end fruitlessly. It is not the province of psychology to discover a mechanism that allows of the construction of the totality of psychical life from simple elements. Its aim is on the one hand to analyse the given facts of experience (subjective analysis), and on the other to determine the connexion between these facts of experience and the changes both in the environment of the experient and in his organism (objective analysis).

If the field of psychology be thus limited, then in our present subject, viz. space-perception, the following problem arises. We have, as given, the spatial order of the surrounding world,—a tridimensional order alike in binocular and in monocular vision. We construct the geometrical space and we ask, what is the relation between the spatial order that confronts us and the geometrical space which we construct? It by no means follows that this relation must be discoverable on purely geometrical lines.

If further we take into consideration the reports provided by the subject of the experiments, we may say that our entire problem consists (a) in determining the connexion between the function of the sense-organ of the experient and the position of objects in the outer world, and (b) in formulating the connexion between these data and the experient's reports concerning the spatial order confronting him¹. It has been the aim of our experiments to discover for this connexion other relations than those which have hitherto been sought for.

3. In the course of Dr Loria's experiments², which were designed to discover the planes which by means of the dioptric apparatus of the human eye are in optical correspondence with the retina, the subject of the experiment spontaneously declared that as soon as the objects exhibited were placed on a line the points of which, with a given accommodation of the lens, formed a sharp retinal image, these objects

¹ I have developed this standpoint in *Psychologia uczuc*, Cracow, 1907; see also *Bulletin de l'Academie des Sciences de Cracovie*; *Psychologie des sentiments*, Janvier, 1908.

² *Bulletin de l'Academie des Sciences de Cracovie*, Octobre, 1907, and *Zeitschrift für Psych. und Phys. der Sinnesorgane*, Bd. 40, 1905.

were seen as lying equidistant from the eye and every change from this position was interpreted as increasing or decreasing the distance of the object moved in relation to a fixed standard object.

It was evident that these observations could be utilised as a starting-point for the investigation of visual space; and accordingly I have made it my special object to examine the matter more closely.

4. The problem was as follows.—The form of the line had first to be determined (first of all in the horizontal meridian) which is such that the points composing it appear equidistant from the subject. The determination must then be made of the positions of points in the same plane, which appear to the subject as lying nearer or further than that line. (I speak here of points, but I actually used very minute lines in these experiments.)

The experiments were arranged as follows. The experimenter looked with one eye into a tube 25 cm. long and about 5 cm. in diameter. This tube was provided with a screen, measuring about 40 cm. from side to side, so that all objects were concealed from the subject, and his vision was confined to what he could see by looking through the tube.

The further end of the tube was closed by a plate in which there was a horizontal slit measuring 7 mm. in breadth. The subject looked through this slit on to a uniformly lighted white surface of smooth cardboard which formed the background. Between the tube and this background two black threads of uniform thickness were introduced as objects of observation. These were kept strictly vertical by the aid of conically pointed weights, the points of which indicated on the table positions which were the perpendicular projections of the positions of the points in the horizontal plane of the eye. This position was noted on the cardboard upon the table.

By constructing radii and arcs from that point which marks the perpendicular projection of the eye on to the plane of the table, and drawing the corresponding arcs, we can completely determine the position of the points in the visual plane projected on the plane of the table in terms of the corresponding radius and arc. This projection is identically similar with the position of the various points in the horizontal plane of the eye, with the eye as centre, and the direction of fixation as the principal radius.

In the accompanying figures the radii are $0^{\circ}96$ distant from each other. The arcs are 1 cm. distant from one another.

5. When the observer looks through the tube, he sees a uniform background and nothing more. In the middle of this one black thread

is introduced first of all. When this thread is fixated by one eye, it occupies in space an indeterminate position as regards distance, a feature which Hering clearly explained many years ago. If now a second line be introduced on one side of the field of vision, while the eye is still fixating the central thread, the spatial position of this second line can be determined relatively to the other. The one appears further or nearer than, or equidistant with the other. These judgments are immediate; it is very easy to show that *they are independent of the absolute and relative thickness of the threads and of their relative distinctness*¹.

In the following investigations Mr Jan Kurtz acted as the observer. His eye had 2.5 D of myopia, and the experiments for determining the accommodation curves, carried out according to Dr Loria's methods, gave curves having a very steep descent. Mr Kurtz had been well practised in indirect vision, as he had previously taken part in other experiments.

The following was the procedure. Mr Kurtz fixated the central line and was asked whether the lateral line appeared as nearer or further than or as equidistant from the central line. Meanwhile of course his eye was kept absolutely at rest. The lateral line was then pushed either along the radii or along the arcs; and in this way² were determined the curves expressing the equidistance of the lateral lines from the central ones. These curves are here produced in natural size; they represent the data obtained.

6. Figure 1 shows the results obtained when the fixation mark was 35 cm. distant (the thread being 0.3 mm. thick). As Mr Kurtz had 2.5 D of myopia, this point lay within the range of his accommodation. Mr Kurtz fixated the mid-point of the central thread; the lateral thread was then moved to and fro until he reported that the two threads were equidistant. The curve will be seen to descend very abruptly when the lateral thread is at a distance of 30 cm., the point falls on the radius 5; that is to say, the fall amounts to fully 5 cm. when the lateral displacement is 4°.8. Leftwards the descent is somewhat less abrupt than rightwards. At a distance of 35.8 cm. the point falls on the radius 1; that is to say a radial displacement of 0.2 cm. corresponds to a lateral displacement of 0°.96. Strictly speaking, the curve is not

¹ To show it, we made some series of experiments with threads of different thickness, and got always the same curves, without any difference.

² We marked on the cardboard table the points, reported as appearing at the same distance as the central point.

a line but a very narrow area which continuously widens towards the periphery. The width of this area indicates the range within which the reports 'equidistant' occur. With the arc 30 cm. distant from the eye, the breadth of this space is 1.5 mm.; that is to say, when the thread is moved along the arc so that the apex of the weight remains on the black surface, the report 'equidistant' *is always returned*. The report continues similarly unaltered so long as, while moving along the radii, the thread remains within the black area. The area narrows towards the fixation centre. At the arc 33 cm. from the eye, it is only 1 mm. broad—measured along the arc. At the arc 34.5 cm., it is only 0.5 mm. broad; at the arc 34.8 cm. only 0.3 mm. broad. The sensitiveness for the positions of 'equidistance' is therefore extraordinarily delicate¹. *Any position within the curve* is always reported *nearer*, any

FIG. 1.

position *outside* the curve *further*. That is to say, when the eye fixates the middle of the central thread, and when the laterally seen thread is so placed that the apex of the weight lies *outside* the curve, the lateral thread always appears to lie *further* away than the central. When on the other hand the thread is so placed that the apex of the weight lies *within* the curve, then the reply always is that the lateral thread is *nearer* than the central.

¹ In some later experiments with Miss R. who has very sharp vision, the width of the curve of equidistant position is sensibly smaller, i.e. the sensitiveness to the position of equidistance is more delicate than with Mr K.

Thus the geometrical distance of the threads from the eye is absolutely unimportant. For example, the point of intersection of the arc 31 with the radius 5 is described as lying further than the central fixation point at the distance 35 cm.; whereas the point of intersection of the arc 34 and the radius 1 is described as lying nearer than the fixation point.

7. Figure 2 shows the results of investigations when the fixation point was 45 cm. distant, i.e. beyond the range of accommodation. The relations here are quite analogous to those of Fig. 1. The breadth of the surface, showing the range of the reports 'equidistant,' is somewhat greater in linear measurement, but the angular breadth is unchanged. At 40 cm. the breadth of the area amounts to 2 mm.; at 44 cm. the

FIG. 2.

breadth of the area is only 1 mm. All points within the curve are described as lying nearer, all points without the curve as lying further, than the central fixation point.

8. Interesting results were obtained from the subject of these experiments when the fixation line was 60 cm. and 80 cm. distant (see Figures 3 and 4). In place of one curve we have three curves, having the same significance. Here too the curves are really areas, lineally broader than those of Figures 1 and 2, but as regards angular breadth of approximately the same size. All judgments, concerning points *within the curve I and outside the curve III*, are unequivocal; thus, for

FIG. 8.

FIG. 4.

points within the curve I the report *nearer than the fixation point*, while for points outside the curve III the judgment 'further than the fixation point is always given.' In the spaces between curves I and II and between curves II and III, the reports are irregular, being sometimes 'nearer,' sometimes 'further.' The nature of the reports usually depend upon the direction of procedure. Thus, starting from the curve II and moving outwards, we obtain the report 'further,' and moving inwards the report 'nearer,' until the next curve is reached, whereupon 'equidistant' answers are once again obtained. When, on the other hand, the lateral thread is moved irregularly in the space between the curves, the replies are irregular. Within the areas of the curves themselves there is *always* a uniform report of 'equidistance.'

9. When the subject attends to the central and lateral threads placed in the 'equidistant' position, a periodical displacement of their reciprocal positions is observed. Mr Kurtz describes these oscillations in the paper following.

10. It remains to make some general remarks about the facts that have been observed. I see very clearly that these experiments only serve as a starting point for future inquiries. On the other hand, some important conclusions may be deduced from the results here given. I should like also to point out certain general considerations which will guide me in future experiments.

A. The present investigation once and for all disproves the old assertion that monocular space-perception is only bidimensional. The immediate awareness of tridimensionality,—the accuracy with which the relative position of the threads is perceived,—affords strong argument for reversing the previously accepted opinion. All the subjects investigated¹ agree in maintaining that the tridimensionality of monocular space is an immediate datum of perception. No essential difference then exists between monocular and binocular space-perception; both are tridimensional. The only difference between them is that near objects appear more plastic in binocular than in monocular vision. But with distant objects this difference does not exist. The facts observed are evidently inexplicable either by Hering's or by Helmholtz's theory of the relation between geometrical space and perceived space.

B. The direction, in which the explanation of the facts here given is to be sought, is indicated by the very nature of the facts. Our investigations started from the observation that points which, with a

¹ We began a series of experiments upon other individuals, which are not here described.

given accommodation of the lens, form sharp images on the retina, are simultaneously perceived as lying equidistant¹. In the experiments which have been here described the converse method was adopted of determining the position of those points which appeared to be equidistant. If we may suppose the line formed by these latter points is identical with the line formed by those points which produce a well-defined image on the retina (this hypothesis, likely as it seems, has yet to be proved²), then we reach the following fundamental conclusion.

Points in space, which in a given state of accommodation of the lens in monocular vision form well-defined retinal images, represent a surface which serves as a fundamental surface in relation to which the position of other points in the third dimension is determined. The points outside such a surface are regarded as more distant, those within it as lying nearer.

The images of the points outside the surface are diffusion circles. With these diffusion circles such factors as the degree of diffusion, light-intensity, etc., will become of importance; and these factors contribute to the appearance of depth. In other language, the image formed on the retina by means of the human dioptric apparatus must include all those factors which correspond to the report of depth. An analogy may make this clearer. It is well known that, in a picture representing objects in spatial order, every object must have its local tone. It is this local tone, and not the geometrical perspective, which determines the position of the object in space. Any object not in the projected line does not fit into the space of the picture. Something analogous may be supposed to occur in the case of the image formed on the retina. Yet another example. The images of objects formed by means of a badly constructed system of lenses appear on a screen as ill-defined. Yet the whole image is characterised by an exaggerated effect of depth.

I think the time has not yet come to give further details. There are facts enough which appear to support the correctness of the train of thought which I have set forth. These however must be examined in regular order. The foregoing remarks serve to show the path I intend to follow in future experiments.

¹ Cf. above, p. 67 *fin*.

² It is impossible to investigate by the method used by Dr Loria the central part of the field of vision, but the curves, as obtained here, if prolonged to the periphery coincide with the curves furnished by the method of Dr Loria.