ionization measurements will be made with a modified Ebert apparatus and conductivity measurements will be made with a modified Wilson apparatus.

The meteorological equipment will include thermometer screen with thermometers; mercury barometer, aneroid and barograph; mercury in steel thermographs for dry and wet bulb temperatures and for sea temperatures; an Assmann psychrometer and an Aitken nucleus counter.

An oceanographical laboratory will be provided, aft of the aft magnetic observatory. Echo-sounding apparatus will be carried.

It is expected that the *Research* will be launched in February 1939 and will be ready for her first cruise in the following October. She will carry six officers, four scientific workers and twenty-two petty officers and men. On her first cruise she will first visit Washington, in recognition of the assistance given by the Carnegie Institution; after calling at the South American ports, she will cross the Atlantic and make observations in an area in the South Atlantic between, and south of, Tristan da Cunha and Cape Town. In this area there has been a large decrease in recent years in the secular change of the magnetic declination. The *Research* will then make a double traverse of the Indian Ocean, first on approximately a great circle track to Perth and then returning on a more northerly track, calling at Cocos Island, Colombo, Seychelles, Mauritius and Durban, where she is due to arrive about November 1940. The subsequent course has not been decided upon in detail, but may include a third crossing of the Indian Ocean and a return via the Pacific and the Panama Canal. The Indian Ocean will be the area to be the most completely observed on the first cruise, since it is in this area that there is the greatest uncertainty in the magnetic data.

H. S. J.

Eye and Brain as Factors in Visual Perception*

By Dr. R. H. Thouless

THAT we see with our eyes is known to everyone and has been known for a long time. That we see also with our brains is less generally realized, and the implications of this fact are relatively recent importations into the theory of vision. The full statement of the physiological mechanism of vision would include not only the sensitive retinal surface and the visual areas of the cortex but also the whole system, which includes retina, optic nerve, visual area of the cerebral cortex, and other sensory areas of the brain as well.

Transmission Theory of Vision

It is possible, of course, to study vision in such a way that everything except the activity of the retina is neglected altogether or relegated to a secondary position, and it was in this way that the scientific study of vision began. This is the point of view which we find in the work of Helmholtz and in much of the experimental research into vision which has followed his deservedly great authority. The basic assumption is that the essential process of vision is the formation of an optical image on the retina and its transmission to the visual centres of the brain by means of the optic nerve. Differences between the sensations transmitted to the brain and the finished perception which appears in experience were attributed to the action of the higher processes of judgment and the influence of past experience.

This theory of vision, which we may call the 'transmission theory', has behind it not only the weight of the authority of the great originators of the experimental study of vision; it has also the advantage of being the view of the man in the street. Its truth seems to many to be so axiomatic that its denial may have the appearance of wilful paradox.

It is, nevertheless, now clear that the transmission theory is wrong, and that a wholly different way of approaching the problems of visual perception is necessary if we are not to be led astray. To say this is not to deny the greatness of the achievements of those investigators in the past whose work on vision was guided by this theory. Within a certain limited field, it proved itself a fruitful guide to research. This field was that of the sensory physiology of the retina. If we wish to discover what is happening on the retina, we must arrange conditions of experiment so as to cut out, so far as possible, the complicating effects of the cerebral components of the visual part of the nervous system. This was what was done when the early experimenters made observations through tubes or on black backgrounds. So such workers as Helmholtz, König, Abney and a host of others made a firm foundation for a science of vision in the sensory physiology of the retina. The error, however, has sometimes been made of mistaking the foundations for the completed building. When we get rid of tubes and black backgrounds

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and open both eyes to look at objects surrounded by other objects, we find that what we see follows other and far more complicated principles than the laws of sensory physiology.

AN ALTERNATIVE WAY OF TREATING VISUAL PERCEPTION

We place on a table an elliptical object with its long axis pointing directly to and from the observer. If his head is directly above the object, it will, of course, look elliptical. If now he moves his head from the position directly above, but still keeping it in the vertical plane passing through the long axis, the object will at first still look elliptical, but with a smaller apparent elongation than when it is viewed from directly above. If the head is now lowered, but still kept in the same plane, the apparent shape of the object becomes nearer and nearer to a circle. It then becomes truly circular and, if the head is still further lowered, the object appears elliptical again, only now with the really longer axis apparently the shorter.

So far everything appears to be as one would predict on the transmission theory by the elementary principles of perspective. Measurement of the actual angles at which these various appearances are found reveals, however, a considerable discrepancy from the expectations aroused by the transmission theory. At the height, for example, at which the ellipse looks circular, it is found that the retinal image is not of a circle but of an ellipse with the vertical axis much shorter than the horizontal, thát is, an ellipse flattened in the opposite direction. It is as if the shape that is seen (the phenomenal shape) is in between the real physical shape of the ellipse and the shape that is projected on the retina (which we may call the stimulus shape). The expectation on the transmission theory would be that the stimulus shape and the phenomenal shape would be identical. Plainly they are not, and the discrepancy is large enough to show clearly without any great refinement of measurement.

We are led from consideration of this experiment to the same conclusion as was arrived at by Werthiemer as a result of his experiment on phi-movement, that the 'sensation' corresponding to the conditions of local retinal stimulation, as an element in a complex perception, is a mere fiction. Although it is clear that the conditions of local retinal stimulation affect the resultant perception, we can find no trace of evidence that they do so by being transmitted to the brain as 'sensations'.

The transmission theory is easily intelligible because it can without difficulty be explained by a physical analogy. Photographs might be transmitted telegraphically by forming an image on a plate made up of a large number of small photo-electric cells each of which is connected by a wire with a corresponding reproducing cell at the other end. This is not, of course, the method actually used for the telegraphic transmission of photographs, but it is physically a possible one. If the receiving electric cells are replaced by the retinal organs, the transmitting wires by the fibres of the optic nerve, and the reproducing cells by the nerve cells of the visual centres of the cerebral cortex, we have a perfect analogy to the physiological process of vision on the transmission theory.

Yet this advantage of simplicity and easy intelligibility must be given up if the transmission theory does not fit the facts. We have so far criticized it only in connexion with one experiment. Perhaps this will be a convenient place to summarize the whole case against it.

First, there is a physiological difficulty as to the mechanism of transmission. Such a method of transmission as is suggested by the above analogy would require a number of wires equal to that of the receiving cells. This condition is not fulfilled by the visual system, since the number of retinal end-organs is two hundred times as great as the number of fibres in the optic nerve.

Secondly, a breach in the transmitting part of such a system would lead to a corresponding gap in the received picture. This expectation is not fulfilled in vision. We might explain away on the transmission theory the fact that we do not see a gap in the part of the monocular visual field corresponding to the blind spot, but Fuchs has shown that similar completion may take place over a blind area of the retina caused by an acquired destruction of part of the optic nerve.

Thirdly, if this theory were true, it would be necessary that differences in the picture at the sending and at the transmitting end should always accompany one another. The experiment already discussed has given one example of that not being the case, since the impression of a circular shape may be given either by the circular retinal image given by a circular object at right angles to the line of vision, or by a retinal image which is a flattened ellipse if this is made by an object which is itself an elongated ellipse viewed at a suitable angle of inclination.

There are plenty of other examples of this in visual perception ; indeed, except in those conditions of simplified perception which were characteristic of the early investigation of visual 'sensations', exact correspondence between the details of the retinal image and of what is perceived is the exception rather than the rule. In Rubin's reversible figures, for example, we may have a pattern which is seen either as a row of black **T**'s on a white ground or as a row of white fleurs-de-lys on a black background. Thus we have a single stimulus pattern on the retina giving rise to two wholly different perceptions. The after-image of a circle, moreover, will look large or small as it is projected on to a far or a near object respectively, although the area of retinal activity remains unchanged. If a subject seated below the object glass of a projection lantern looks at a picture projected on to an inclined screen, he sees the picture as distorted, although it is easy to demonstrate that his retinal image is identical with that which he would have received if the screen had been at right-angles to his line of vision.

Such facts as these are not easily reconcilable with the theory of simple transmission of a retinal picture to the brain. That there is a close relationship between the condition of physiological stimulation of the retina and of the resulting pattern of visual perception is, of course, obvious and is denied by nobody, but the relationship may not be of the kind suggested by the analogy with telegraphic transmission.

A better analogy for the modern view of perception is, I suggest, the construction of one of the charts published with weather forecasts. The lines of equal pressure on the charts are constructed from information received from various land stations and ships, just as the perceptual picture constructed by central activity depends on information received from the sense organs. If no information as to barometric pressure is received from a certain area, this does not mean that the corresponding area must be left blank, but that the person constructing the chart must fill it up by guess-work, which he generally does by constructing smooth curves consistent with the other information. In the same way, in Fuchs's experiments, it was found that central perceptual activity tended to fill in areas from which no information was received from the retina by simple completions providing 'good continuation' with the figure received on the rest of the retina.

The analogy of the construction of a weather chart suggests a possible way of looking at the process of visual perception which is alternative to the transmission theory and which, I think, gives a much better account of the experimental facts. It regards the mind (or the brain acting to some extent as a unitary whole) as active in perception, responding to information given by the sense organs and not merely reproducing a pattern of stimulation from the sense organs.

INDIVIDUAL DIFFERENCES IN VISUAL PERCEPTION

Let us now return to the experiment with the inclined ellipse to note a particular feature in it which is, I think, a characteristic of the perceptual processes that has often been ignored. This feature is the wide range of individual differences. Apart from such obvious differences as errors of refraction, colour-blindness, etc., the optical system of different individuals' eyes and consequently the conditions of local physiological stimulation on the retina for a given arrangement of external objects is very much the same. The perceptual responses of different individuals are, however, widely different, so that any two of us in the same physical surroundings may create from them a very different phenomenal world.

If two or three people perform the experiment I have just described, we shall find that the height at which they say the apparent shape of the inclined ellipse is circular is different to an almost incredible extent. One may see the ellipse as circular when his head is only a few inches from the table, so that his retinal image is of a very much flattened ellipse, while another sees the ellipse as circular when he is looking well down on it, so that his retinal image is itself not very far from circularity. The first individual shows a very great effect of the real shape of the ellipse in determining its apparent shape, the second shows a relatively smaller effect of the real shape on apparent shape.

That these are real individual differences and not merely accidental variations in measurement is shown by the fact that they show great consistency from one time to another. I once retested, after an interval of two years, a group of twenty-five subjects for each of whom I had measured the apparent shape of an inclined object. They differed widely amongst themselves at each test, but the agreement between the two sets of tests was extraordinarily high. The coefficient of correlation was 0·92, which is as high as one expects to get in psychological measurements.

There are, then, genuine and large individual differences between different persons in the apparent shapes of inclined objects. We may add that there are similar individual differences in the apparent sizes of objects at different distances and of the apparent whiteness of objects under different illuminations. In both of these cases, the same general law holds. If an object is moved to twice its previous distance from our eyes, it does not look half its previous size. It may, for different individuals, look threequarters of its previous size or nineteen-twentieths. With rare exceptions (which I shall mention later) the law holds that the apparent size is in between the retinal size and the real size. In the same way, if a piece of white paper is put into shadow so that it reflects less light to the eyes than a brightly lighted piece of black paper, it does not necessarily look less white than the black paper, although it may do so if the shadow is very deep. The seen whiteness is in between the 'real' whiteness and the stimulus intensity of the retinal image. Again, in this tendency to see objects in their real whiteness irrespective of illumination, we find wide individual differences. I have suggested that we should call these effects "the tendency to phenomenal regression to the 'real' characters of objects"

If we test a group of subjects in their tendency to phenomenal regression for shape, for size, and for whiteness, we find that those who have a large tendency to see the 'real' size of an object tend also to have a large tendency to see the 'real' shape and the 'real' whiteness. The correlations between these tendencies are about 0·6, which shows that they have a considerable factor in common. We can thus speak of individuals as having high phenomenal regression if their perceptions of apparent shape, size and whiteness are largely determined by the 'real' characters of the objects looked at, while those whose perceptions are determined relatively more by the conditions of retinal stimulation (that is, who see objects getting much smaller as they go farther away, and so on) we shall describe as those of low phenomenal regression.

Practical Consequences

It may be asked whether the kind of thing we have been talking about has any practical importance. It certainly may have. We test for such differences in the sensory physiology of the eye as colour-blindness because they may lead to practically important incapacities, and it is very likely that individual differences in the cerebral side of perception may also affect an individual's practical capacities. Some years ago I suggested that a person of high phenomenal regression might be expected to drive a car more easily through traffic than one with low. He sees a gap in the traffic in something near its real size before he drives up to it, whereas the person with low phenomenal regression sees it as smaller than it really is when it is at a distance. Neither, of course, adjusts his driving to the apparent size of the gap; both must make a judgment as to its real size. The person with low phenomenal regression has, however, a much larger gulf between appearance and reality to bridge by means of judgment. Judgment being a slower and more uncertain process than perception, he may be expected to drive through gaps with more difficulty and less certainty than the individual who can trust to his immediate impression of size. The individual with high phenomenal regression may therefore be expected to drive more easily and better through traffic. This prediction appears to have been justified by a research in motor-car driving by the National Institute of Industrial Psychology, when it was found that a test of phenomenal regression showed a correlation with driving ability.

The effect of drugs on individual organization of phenomenal space is an interesting problem. I have made only preliminary experiments on one subject in the hope that someone better equipped to experiment on drugs will take the inquiry further. The indication I obtained was that (as might be expected) alcohol decreased phenomenal regression while caffeine increased it. I think that it might be worth while for those investigating the effect of alcohol on motor-car driving to consider the possibility of disturbance of spatial perception as well as of speed of motor responses. That a change of spatial organization can affect driving I am sure from personal experience. I was driving one night towards Buxton suffering from the effects not of alcohol but of fatigue (which probably affects spatial organization in the same way as alcohol). At one point, I found my perception of the road so much disturbed that I had to stop my car and get out. The road seemed to narrow almost to a point in front of me; I seemed to be driving not on a parallel-sided track but into a funnel. I recognize the condition now as one of extreme reduction of phenomenal regression. One result of this condition was an almost irresistible impulse to drive in the centre of the road. A persistent tendency to drive on the crown of the road is a common fault; I suggest it may be a fault characteristic of an individual with low phenomenal regression, and that if this were proved to be its origin, an understanding by the driver of the cause of his fault would put him into the way of correcting it.

Conclusion

The change that has taken place in the psychological study of vision during the last twenty-five years may be expressed in a summary way as a change from the time when it was treated as if vision were a function of the eye alone to a time when the eye and higher centres are regarded as co-operating in visual perception. The psychology of vision is not and cannot be merely the sensory physiology of the eye. At the present time, these wider aspects of visual perception offer a more fruitful field of research than do those of sensory physiology which have been so adequately dealt with in the past. Particularly, I should like to suggest that individual differences in visual perception and the statistical study of these differences is a field the surface of which has scarcely yet been scratched. Let us hope that in the next twenty-five years, psychologists may be as successful in resolving the many remaining problems of visual perception as were the great Helmholtz and his contemporaries in making a scientific study of the sensory physiology of the eye.