

SOME PRELIMINARY EXPERIMENTS ON VISION WITHOUT INVERSION OF THE RETINAL IMAGE.¹

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Two important theories of upright vision hold that the inversion of the retinal image is necessary for the perception of things as upright. According to the first, which we may call the projection theory, objects are projected back into space in the directions in which the rays of light fall upon the retina. And the crossing of these lines of direction within the eye requires that if the object is to be projected right side up the retinal image must be inverted. The second theory, which may be termed the eye-movement theory, holds that the movements of the eye and our perception of the direction of such movements are the means by which we judge of the spatial relation of objects in the visual field. Upper and lower, according to this theory, mean positions which require an upward or downward movement of the eye to bring them into clear vision. But an upward movement of the eye brings into clear vision only what lies below the fovea on the retina. So that here too the perception of objects as upright requires that their retinal images be inverted.

The purpose of the experiments, of which only the preliminary ones are here reported, was to throw some light, if possible, on the correctness of this assumption. *Is* the inverted image a necessary condition of our seeing things in an upright position? The method of approaching the problem was to substitute an upright retinal image for the normal inverted one and watch the result.

This was done by binding on the eyes a simple optical con-

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trivance constructed on the following principle: If two convex lenses of equal refractive power be placed in a tube at a distance from each other equal to the sum of their focal distances, the eye in looking through the tube sees all things inverted, but in other respects the image remains unchanged. The image cast on the retina is as if the whole field of view had been revolved on the line of sight through an angle of 180° . All light other than that which comes through the lenses must, of course, be carefully excluded by making the instrument fit exactly the inequalities of the face by means of black linings and pads. For if light were permitted to enter the eyes otherwise than through the lenses, the observer would be subjected to both upright and inverted images, and the purity of the experiment would be lost.

The size of the visual field was a matter requiring some care. The size and refractive power of the lenses are the determining factors here, and in the desire to obtain a reasonably large visual field one is tempted to use large thick lenses. But they are soon found to be too heavy to wear on the head for a considerable length of time. I found it best, therefore, to modify the instrument above described, by substituting *two* double convex lenses (placed close together on the same axis line) for each of the lenses in that description. I had thus for each eye a short adjustable tube, and at either end of the tube a pair of good lenses of equal focal length. The instrument by this means gave a clear field of vision with a compass of 45° , and at the same time was light enough to be worn without discomfort.

At first I hoped to use the two eyes together in the experiment; but without automatic convergence of the two tubes the strain in reaching a superposition of the two optic images was found to be too severe. The distress in the eyes made it seem best to experiment on monocular vision alone, which could be done without interfering in the least with the principle or purpose of the research. The lens for the left eye was consequently covered with dull black paper; the eye could then remain open and the disadvantage of bandaging be avoided.

In the preliminary experiment here reported, I bound the instrument on my face at 3 o'clock in the afternoon, and wore it without interruption until 10 o'clock in the evening. The in-

strument was then removed, with closed eyes; the latter were thoroughly blindfolded, until with closed eyes again the next morning the apparatus was replaced in position. From 9:30 in the morning until about 10 o'clock in the evening of this second day, the instrument was again worn continuously, and then the eyes blindfolded as before. The third day the instrument was worn from 10 o'clock in the morning until noon, and then removed. The time during which the experience under the artificial conditions actually lasted—the total time less that in which the eyes were blindfolded—was therefore about $21\frac{1}{2}$ hours—a time, of course, altogether too short from which to expect very pronounced results in undoing a life-long habit of interpreting visual signs, but which, nevertheless, gave interesting indications of what would result if such an experience were considerably extended.

The time was spent entirely indoors, watching the scene on the street below, watching the movements of my feet and hands, experimenting on the changes which occurred in the visual field in connection with particular movements of the head or of the whole body, grasping and handling seen objects—in short, trying to crowd as varied an experience as possible into the brief time at my disposal.

The course of experience was something as follows: All images at first appeared to be inverted; the room and all in it seemed upside down. The hands when stretched out from below into the visual field seemed to enter from above. Yet although all these images were clear and definite, they did not at first seem to be real things, like the things we see in normal vision, but they seemed to be misplaced, false, or illusory *images* between the observer and the objects or things themselves. For the memory-images brought over from normal vision still continued to be the standard and criterion of reality. The present perceptions were for some time translated involuntarily into the language of normal vision; the present visual perceptions were used simply as signs to determine how and where the object would appear if it could be seen with restored normal vision. Things were thus *seen* in one way and *thought of* in a far different way. This held true also of my body. For

the parts of my body were *felt* to lie where they would have appeared had the instrument been removed; they were *seen* to be in another position. But the older tactual and visual localization was still the *real* localization.

All movements of the body at this time were awkward, uncertain, and full of surprises. Only when the movement was made regardless of visual images, by aid of touch and memory alone—as when one moves in the dark—could walking or movements of the hand be performed with reasonable security and directness. Otherwise the movement was a series of errors and attempts at correction, until the limb was finally brought into the desired position in the visual field. The reason for this seems partly to have been that the reconstruction of the visual field in terms of the normal visual experience—the translation before spoken of—was never carried out in all the details of the picture. In general, or in the main outlines, things might be referred to the positions they would have in normal vision, but the new visual field was in many of its details accepted just as found, and was acted upon without any translation whatever. So that when movements were made as if the visual signs meant just what they had meant in normal vision, the movements of course went astray. The limb usually started in the opposite direction from the one really desired. Or when I saw an object near one of my hands and wished to grasp it with that hand, the *other* hand was the one I moved. The mistake was then seen, and by trial, observation, and correction, the desired movement was at last brought about.

As I moved about in the room, the movement of the visual images of my hands or feet were at first not used, as in normal vision, to decide what tactual sensations were to be expected. Knocks against things in plain sight were more or less of a surprise. I felt my hand to be in a different position from that in which I saw it, and could not, except by cool deliberation, use its visual image as a sign of impending tactual experience. After a time, however, repeated experience made this use of the visual image much less strange; it began to be the common guide and means of anticipation. I watched my feet in walking, and saw what they were approaching, and expected visual and

tactual contact to be reported perceptually together. In this way the limbs began actually to feel in the place where the new visual perception reported them to be. The vivid connection of tactual and visual perceptions began to take away the overpowering force of the localization lasting over from normal vision. The seen images thus became *real things* just as in normal sight. I could at length *feel* my feet strike against the *seen* floor, although the floor was seen on the opposite side of the field of vision from that to which at the beginning of the experiment I had referred these tactual sensations. I could likewise at times feel that my arms lay between my head and this new position of the feet; shoulders and head, however, which under the circumstances could never be directly seen, kept the old localization they had had in normal vision, in spite of the logical difficulty that the shape of the body and the localization of hands and feet just mentioned made such a localization of the shoulders absurd.

Objects lying at the moment outside the visual field (things at the side of the observer, for example) were at first mentally represented as they would have appeared in normal vision. As soon as the actual presentation vanished, the new relations gave way to the old ones brought over from the long former experience. The actual present perception remained in this way entirely isolated and out of harmony with the larger whole made up by representation. But later I found myself bringing the representation of unseen objects into harmonious relation with the present perception. They began now to be represented not as they would appear if normal vision were restored, but as they would appear if the present field of vision were widened or moved so as to include them. In this way the room began to make a whole once more, floor and walls and the prominent objects in the room getting into a constant relation to one another, so that during a movement of the head I could more or less accurately anticipate the order in which things would enter the visual field. For at first the visual search for an object outside of the immediate sight was quite haphazard; movements were made at random until the desired object appeared in sight and was recognized. But now the various lines of visual direc-

tion and what they would lead to were more successfully held in mind. By the third day things had thus been interconnected into a whole by piecing together the parts of the ever-changing visual fields.

As to the relation of the visual field to the observer, the feeling that the field was upside down remained in general throughout the experiment. At times, however, there were peculiar variations in this feeling according to the mental attitude of the observer toward the present scene. If the attention was directed mainly inward, and things were viewed only in indirect attention, they seemed clearly to be inverted. But when, on the other hand, full attention was given to the outer objects, these frequently seemed to be in normal position, and whatever there was of abnormality seemed to lie in myself, as if head and shoulders were inverted and I were viewing objects from that position, as boys sometimes do from between their legs. At other times the inversion seemed confined to the face or eyes alone.

On removing the glasses on the third day, there was no peculiar experience. Normal vision was restored instantaneously and without any disturbance in the natural appearance or position of objects.

The experiment was of course not carried far enough to see the final aspect the experience under these conditions would assume. But the changes which actually occurred, even the transitory feelings the observer at times had, give hints of the course a longer experiment of this kind would take. I might almost say that the main problem—that of the importance of the inversion of the retinal image for upright vision—had received from the experiment a full solution. For if the inversion of the retinal image were absolutely necessary for upright vision, as both the projection theory and the eye-movement theory hold, it is certainly difficult to understand how the scene as a whole could even temporarily have appeared upright when the retinal image was *not* inverted. As was said, all things which under the conditions could be seen at all repeatedly appeared to be in normal relation; that is, they seemed to be right side up. Only certain parts of the experience (*i. e.*, head and shoulders), upon which under the circumstances vision could give no report at all,

because these parts could not be brought directly into the visual field, seemed to be in abnormal relation to the scene. That these parts of the body should have stubbornly refused to come into harmony with the new arrangement is easy to explain. The only visual experience I had had of them was the *normal* visual experience, and this remained firm in memory without the possibility of displacing it by repeated contradictory visual perception under the new conditions. But of those parts of the body which could be seen, the new appearance and localization was able to drive the old from the field, because the new localization by sight showed a perfect and constant relation to the reports by muscular and tactual perception. No doubt the merely tactual experience of the unseen parts of the body and of their relation to the seen parts must inevitably have produced in time a new indirect visual representation of these unseen parts which would displace the older representation brought over from normal vision. The gradual organization of the whole experience would certainly produce this result, although it would undoubtedly require more time in the case of the unseen parts of the body than in that of the parts plainly visible.

In fact, the difficulty of seeing things upright by means of upright retinal images seems to consist solely in the resistance offered by the long-established previous experience. There is certainly no peculiar inherent difficulty arising from the new conditions themselves. If no previous experience had been stored up to stand in opposition to the new perceptions, it would be absurd to suppose that the visual perceptions in such a case would seem inverted. Any visual field in which the relations of the seen parts to one another would always correspond to the relations found by touch and muscular movement would give us 'upright' vision, whether the optic image lay upright, inverted, or at any intermediate angle whatever on the retina. Only after a set of relations and perceptions had become organized into a norm could something enter which was in unusual relation to this organized whole and be (for instance) upside down. But a person whose vision had from the very beginning been under the conditions we have in the present experiment artificially produced, could never possibly feel that such visual perceptions were inverted.