THE PSYCHOLOGICAL REVIEW.

STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF THE UNIVERSITY OF CALIFORNIA.

I. A NEW DETERMINATION OF THE MINIMUM VISIBLE AND ITS BEARING ON LOCALIZATION AND BINOCULAR DEPTH.

BY PROFESSOR GEORGE M. STRATTON.

The smallest lateral difference of place that is visible has until recently been given as about 50''-60'' angular measure. The method employed by Helmholtz and others¹ in reaching this result was the well-known one of bringing two parallel lines together until they finally are just distinguished as *two*—on the same general principle by which Weber determined the tactile space-threshold, by finding the distance between two compass-points that just cease to merge into *one*.

But by a different method it is now evident that a lateral difference² of place of about 7'' of arc can be directly perceived.

Instead of using lines or points side-by-side, the experiments which give this result were made with lines end-to-end, so arranged that the upper of two perpendiculars could be moved at will to the right or left while still remaining exactly parallel to the lower line, as shown in Fig. 1. The observer had simply to judge whether the upper line was continuous with the lower, or to which side it had been displaced. In the initial trials the lines were narrow slits of light surrounded by

¹ See Helmholtz: *Physiologische Optik*, 2d ed., pp. 256 et seq.

² In contrast with a difference in depth or a difference not of itself perceptible, but evident merely by reason of stereoscopic effect.

a black ground—each line not more than half a millimeter wide and some 10 cm. long, and observed in a half-darkened room from a distance of 18 meters.

FIG. 1.

But the surprising fineness of discrimination made it impossible to work with accuracy from so short a distance ; so that finally the observer was placed 120 meters away, and the lines were changed to narrow white strips, part of the time 10 mm., part of the time 8 mm., wide, each 50 cm. long, on a dull-black ground. Each line with its ground was mounted on the face of a plate of glass, the two glasses placed edge to edge in a frame ; and, by sliding the upper plate upon the lower, lateral shifts were made by steps

of 1 mm. At first the ordinary procedure of 'minimal changes' was adopted, but it soon became clear that suggestion was playing too large a rôle, and resort was had to a compromise between this method and that of 'right-and-wrong cases,' which might be called a method of serial groups, to be described more fully at another time. Taking as the threshold the point where 80%, or more, of correct judgments occurred, the following results were obtained :

SUBJECT A. (187 judgments).

THRESHOLDS FOR DISPLACEMENTS TO THE

RIGHT.	LEFT.
2. mm.	5. mm.
4. "	6. "
3. "	5. "
Aver. 3. mm.	Aver. 5.3 mm.
General average 4.1 mm.	

SUBJECT D. (277 judgments).

THRESHOLDS FOR DISPLACEMENTS TO THE

RIGHT	LEFT.
4. mm.	6. mm.
3. "	5. "
2. "	5. "
4. "	5. "
Aver. 3.2 "	Aver. 5.2 "
General average 4.2 mm.	

Taking 1 mm. as equivalent, approximately, to 1.7 seconds of arc, where the radius is 120 m., we get a fraction over 7 seconds as the threshold of space-distinction under these conditions.

The experiments were begun with some doubt whether there was a direct perception of a *spatial* difference here; whether, for instance, some purely intensive change—some apparent dimming or strengthening of the impression from the adjacent ends of the lines where the displacement occurred—might not serve to suggest indirectly a spatial inequality. But anyone making the observation is soon convinced that what he sees is not of this character, but that the two lines seem to form a single line no longer straight. He seems to compare the position of one of the lines with an imaginary extension of the other, and to notice that the two, in this way, do not coincide. As a check, however, the observers throughout the experiments were kept in ignorance of the actual direction of the displacements, and the threshold was not considered as reached until the direction could be told by them; so that if their judgments had been based on anything other than the perceptible position of the lines, the fact of a break or shift in general might perhaps have been inferred, from some intensive difference in the light, but it is difficult to see how, from that alone, the subjects would have been able to tell correctly to which side the line had been moved. There seems, moreover, to be nothing inherently suspicious in the striking disparity between these results and those obtained by the older method. In the threshold obtained in Helmholtz's way these finer measurements are not reached simply because the diffusion of the stimulus from the two lines side-by-side makes a fairly uniform blur on the retina between them, and within the limits of the blur two separate objects can no longer be distinguished. But when the lines are arranged as in the present experiment, any such interference by mere diffusion is greatly lessened, and the localities can be clearly and correctly distinguished.

The result thus obtained is interesting in several ways. In the first place, it probably removes the grounds for inferring, as yet, that stereoscopic depth at its minimum is a *subconscious* result of the spatial conflict of the two images. My own ex-

periments with the pseudoscope¹ had shown that an angular difference of 24 seconds between the two impressions was sufficient to give a binocular relief. Still later, Bourdon,² experimenting with needles at short range, found that a difference amounting to but five seconds produces a perceptible depth-effect. As long as the conscious lateral threshold was counted as above 60 seconds, one would be tempted from these results to believe either that stereoscopic depth was not due primarily to a lateral space-discrimination of the two images, or else that the plastic effect must depend on a subconscious action, since the disparities in the image were smaller than could be consciously noted. The present reduction of the conscious lateral threshold to about 7 seconds leaves but a small margin upon which to base such conclusions, particularly when one takes into account the wide contrasts in the (non-essential) conditions of the experiments. Bourdon would seem entirely justified, however, in concluding that binocular depth cannot be due to our detecting double images, if by double images we are to understand outlines that are distinguishable *side-by-side*. But the depth-effect may still be due to the presence of double images in the sense of outlines that are felt not to be coincident when positions are compared *end-to-end*. There certainly is a difficulty in that ordinary stereoscopic vision seems hardly to provide the conditions for comparing outlines in this way. It is barely possible, however, that the curious phenomenon of retinal rivalry may be useful just herein, that by the successive emerging and disappearance of parts of the outlines in the two projected fields of view something comparable to the conditions of the present experiment is brought about, and an exceedingly fine perception of lateral incongruity results.

But perhaps a more important bearing of the experiment is on the general problem of visual localization. It seems highly improbable that so minute a displacement is discerned by noting some muscular jog or unevenness in running our eyes up and down the line, when one recalls that the fovea itself is some

¹A Mirror Pseudoscope and the Limit of Visible Depth, *PSYCHOLOGICAL REVIEW*, Vol. V., p. 632.

²L'acuité stéréoscopique, *Revue Philosophique*, January, 1900.

300 times broader than the retinal image of the space-inequality here perceptible. In view of this relatively wide expanse of the fovea, it seems highly questionable whether the eye, in running up and down such a pair of lines would regularly take one course when the lines exactly met and a perceptibly different course when one line was displaced 7". The eye naturally moves by twitches and jerks, even when following a straight line; the breadth of the fovea is such as to permit considerable roving without 'losing' the line. So that so small a dislocation in the objective line would probably be no incentive to an exactly corresponding change in the movement of the eye. And even supposing that a dislocation of 7" in one of the lines did regularly tend to draw the eye by so much out of its course; how should we be able accurately to interpret so slight a variation of muscular action, as clearly due to an objective spatial inequality, when much greater movements—likewise involuntary, are constantly occurring without our interpreting them as due to a spatial variation in the object we are observing?

If, on the other hand, we pass from the muscular apparatus and look to the minute elements in the retina to explain such discriminations, even these seem much too gross to account for the marvellous fineness of our judgment. Rows of cones in the mosaic of the fovea lie apart a distance corresponding to at least an angular measurement of 30". To explain our power to detect a spatial difference one-fourth of this, it will be necessary to assume either that the rods and cones are not the ultimate spatial elements in the retina, or else that the *minimum visible* may be considerably less than the distance between the center of the adjacent sensory elements.

And, after all, it is not difficult to see how this latter might well be the case. We must, however, first give up the notion that the light, even when it falls upon a single cone, or row of cones, affects only those elements upon which it directly falls. In every case the stimulation is probably diffused in all directions; a responsive wave runs through the neighboring elements, as is evidenced, for instance, by the fact of simultaneous contrast. Now if C and C' be adjacent elements, and b the boundary between them, then it seems not improbable that if a ray

fall somewhere within the limits of C its effect upon C' will be different according as its point of incidence is nearer or farther from b . It would probably excite C' more intensely the nearer it fell to the limits of this cone; and, on the other hand, its

FIG. 2.

effect upon C' , a neighbor on the opposite side of C , would correspondingly decline. In such an event there would be a difference of nervous result with every change, however small, of the point of incidence, instead of a change occurring only in case the stimulus passed to an entirely different cone. There would then be a difference of intensity of the

diffusive effect upon neighboring elements, a different degree of whatever kind of reaction may be characteristic of each, and consequently a change of 'local sign' even when the difference of place of the excitation is considerably less than the diameter of a single element. The local signs in the retina alone, quite apart from the muscular mechanism, would thus form an absolutely continuous series, and would furnish the data for any degree of spatial discrimination we may discover. The retinal sign of position is thus conceived, not often the analogy of our electric signal boxes, when one unalterable mark is given (a falling numeral, for example) whenever the same terminal is affected; but we should have to symbolize it rather by some more complicated contrivance: where nothing less than several neighboring numbers dropped on each occasion, but each of these appeared with differing clearness according as its particular terminal was near or far from the immediate origin of the disturbance. The relation of the various intensities could in this case be a sign both of direction and of distance; and the exact seat of the exciting cause be determined with a degree of accuracy depending on the fineness of discrimination for intensive differences and for catching their interrelation, rather than upon the number and distance apart of the several terminals; in other words, the threshold would not depend on the purely anatomical meas-

urements, if we may drop the figure and return to the retinal fact.

The present experiment, then, tempts one to believe that the local signs are of this exceedingly complicated character. The mental process of localization, or of space-distinction, cannot be justly described (it would seem) as an association merely between a particular quality of sensation and a particular place. Nor is it entirely sufficient to amend this and say that the mind must also take account of the various intensities of the quality which is spatially significant. The complication seems to go still a degree higher, so that the *interrelation* of numberless intensities of different retinal sensations would seem to be the intricate process involved in even the simplest visual perception of space. When we bear in mind that the fully organized perception without doubt includes also extra-retinal data, it is evident how complex an activity our spatial consciousness is.

II. THE EFFECT OF IMPERCEPTIBLE SHADOWS ON THE JUDGMENT OF DISTANCE.

BY KNIGHT DUNLAP

The conscious effect of stimulation of such low intensity as to be imperceptible presents an attractive and almost unexploited field for experimental work. The experiments of Jastrow and Pierce on small differences of sensation,¹ and some previous work of my own, suggested the possibility of obtaining important results from an experiment planned to show directly the effects of the presence or absence of an imperceptible stimulation.

The Müller-Lyer figure was selected as the foundation for such an experiment. If we have the segments of the principal line in the illusion-figure distinctly marked, but the angular lines of an intensity just below the threshold of perception, we have the simple materials for determining whether or not these imperceptible lines will produce in any degree the ordinary illusion-effect. If such an effect is produced, then we have

¹ Memoirs of the National Academy of Sciences, Vol. III., p. 76.