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COMMUNICATED BY PROFESSOR GEORGE M. STRATTON.

III. VISIBLE MOTION AND THE SPACE THRESHOLD.

BY PROFESSOR GEORGE M. STRATTON.

For some time it has been argued that the perception of motion has no immediate connection with the discrimination of positions in space. It is held that the two processes are psychologically independent, and that we become aware of motion by a direct and simple sense of the motion itself, and not by appreciating that the object occupies distinct localities.

This paradox is supported in part by the fact that a movement in the out-lying portions of the visual field can be readily seen when the movement has a far less extent than is required to give to two motionless objects a perceptible difference of position,—a fact apparently first observed by Exner. To state the matter in the words of Professor James: “One’s fingers when cast upon the peripheral portions of the retina cannot be counted—that is to say, the five retinal tracts which they occupy are not distinctly apprehended by the mind as five separate positions in space—and yet the slightest *movement* of the fingers is most vividly perceived as movement and nothing else. It is thus certain that our sense of movement, being so much more delicate than our sense of position, cannot possibly be derived from it. * * * Movement is a primitive form of sensibility.”¹

¹ ‘Principles of Psychology,’ II., 172.

One may rightly have some antecedent hesitancy, I believe, in regard to James' interpretation. Even admitting the facts he offers, one need by no means draw his conclusion. For the alleged sense of motion, if it really is a sense of *motion*, brings in a spatial report. The changes of which it makes us aware are preceptibly different from alterations merely of intensity or of color. Even though we may be unable to tell the direction of the motion, the motion itself is a change of position, and is dimly appreciated as such. Instead of saying, then, that the experiments cited are evidence that the sense of movement is so much more delicate than the sense of position, it would be more exact to say that they show that the discrimination of positions during movement is much finer than the discrimination of positions at rest. It is not really an antithesis between 'motion' and 'differences of position,' but between differences of position under two contrasting sets of conditions, motion being but a special mode of testing our power of local discrimination. The truth seems to be that there are various ways of measuring this power—among others, by the simultaneous presentation of two lights in different places, by their successive presentation, or by a continuous movement of a single light from one position to another. We have no right to assume (as Professor James seems to do) that the first of these methods is the only one that gives the true space-threshold, and that the results of the third, if finer, are indications of a process different in kind. The second method also gives finer results than the first, and yet no one, so far as I know, has thought that the finer space results obtained by successive stimulation implied some special and primitive form of sensibility different from that which is involved in discriminating simultaneous impressions. Why, then, should we jump to this conclusion when the conditions of space-perception are only slightly altered farther, making the successive stimulation spatially continuous instead of discrete?

Admitting the facts adduced, then it by no means follows that we have a primitive sense of movement, independent of spatial discrimination. But at least so far as space is concerned, the facts themselves are not unquestionable. Some experiments

by Stern, reported in 1894,¹ already raised a doubt here. Stern found that when retinal irradiation was decidedly reduced, the shortest perceptible movement was not appreciably less than the space-threshold as determined without movement. He consequently inferred that there was no ground for assuming a specific and unique sense of movement. But the test of motionless space-discrimination used by Stern is itself perhaps not fully convincing. He departed from the method employed by Helmholtz and others—the method by parallel lines brought closer and closer together until they almost fused—and, instead, took as the threshold that width of a single dark line that was just doubtfully perceptible against a light background. The assumption here seems to be that the line is a gap or interruption of the white surface, and implies a local discrimination of the two borders of white against the line which divides them. But if we regard black as a positive impression, as it would seem we must, there would appear to be no reason why a consistent development of this method would not require us to accept the apparent diameter of a just perceptible fixed star as a still more accurate measure of local discrimination. The width of the dark line in Stern's experiments is probably of importance only in a secondary way, by affecting the intensity of the impression of black. This suspicion is strengthened by the fact that with some slight improvements in the conditions of observation in our laboratory, while still remaining true to the general principle of Stern's method, the threshold takes an astonishing drop. One of my students, Mr. Gilbertson, finds that the width of the black line visible against white, instead of being 15'' angular measure, as Stern found under his conditions, may be even less than 2.5''.

For this reason it seemed well to try some experiments in which the threshold of motion and that of local discrimination might be compared without so much doubt as to the really spatial character of this local discrimination. The experiments here reported fall into two groups, the first with indirect, the second with foveal vision.

¹Die Wahrnehmung von Bewegungen vermittelt des Auges, *Zeitsch. f. Psychol. u. Physiol. d. Sinnesorg.*, VII., 321.

FIG. 1.

I. *Experiments with Indirect Vision.*—The observer, in Fig. 1, sat in a half-darkened room and judged the character of the light-stimulus seen through a narrow vertical slit t about $\frac{1}{2}$ mm. wide in a screen S before him. The fixation point f was 5° to the right of the slit in one set of experiments and 30° to the right in the other, the distance from the observer to the screen being in these two cases 2 m. and 1 m., respectively. When the aim was to determine the threshold of motion, a bright point of light moved from a fixed position upward or downward in the slit, while the local discrimination was tested by two separate motionless points of light which appeared the one above the other and in immediate succession. The extent of movement, in the one case, and of spatial separation in the other, were of course accurately varied to determine the threshold.

This variation, along with a constancy of those conditions that should remain constant, was brought about by an arrangement behind the screen, consisting chiefly of a pendulum P carrying a smaller slitted screen S' , which in swinging past the slit t allowed light to pass to the observer from a white surface w evenly illuminated by an electric lamp, L . The pendulum was so controlled by the electromagnets e and e' as to give a single swing from a fixed point 10° from the vertical and be caught at the end of its course on the other side. The back-swing in preparation for the next experiment was concealed from the observer. The length of the pendulum was regulated to give a single oscillation in one second.

In Fig. 2 there is represented in diagram the screen S' that was carried by the pendulum when the aim was to give the observer a moving point of light. The main feature of this

screen was a movable circular disc D , from whose center, c , there passed to the periphery a slit cp , $\frac{1}{2}$ mm. in width, forming an arc of the circle whose radius was the distance from C to the point of suspension of the pendulum (70 cm.). When the

FIG 2

disc was so set that the center of this arc coincided with the point of suspension of the pendulum, the point of light which came to the observer as this arc-slit swung past the vertical slit l in the stationary screen S in Fig. 1 had no apparent motion whatever. A change of the disc's position, however, so that the slit took the position cp' , would cause an apparent upward motion of the point of light, the extent of which in angular measure, from the point of view of the observer, could readily be calculated. A scale in terms of such angular measurement was placed along the circumference of the disc so that this could be set for any extent of motion desired. But since it seemed best to keep the duration of the movement exactly the same as the duration of the stimulus in the corresponding set of experiments with motionless points, this constancy, in spite of the varying positions of the disc, was maintained by the fact that the screen S' was continuous behind the disc D with the exception of an opening $klmn$, whose boundaries kl and mn were radii of the circle mentioned above, the center of which was the point of suspension of the pendulum. It need only be added that this screen was wide enough to conceal the surface w in Fig. 1, when the pendulum was at either limit of its excursion.

For the experiments on the discrimination of position without movement, a different screen was substituted upon the pendulum, yet with a similar arc-slit similarly centered. But in this case, instead of revolving the slit about a central point, one half of the slit could be shifted slightly up or down, along the radius of the circle of which the arc was a portion, as in

FIG 3

Fig. 3. As the pendulum made its single swing, there thus appeared to the observer in immediate succession two separate points of light, the amount of whose separation could be accurately varied by the experimenter.

In the preliminary experiments, the well-known method of 'minimal changes' was employed, but the observers soon showed themselves so much influenced by expectation that no reliable determination of the thresholds seemed possible by this means. The method of 'serial groups,' hereinafter described, was found more satisfactory. The adoption of successive stimuli to measure the local discrimination without movement, was for the purpose of avoiding some of the worst difficulties from irradiation. Two points of light when presented simultaneously will often produce a blur that is perceptibly extended (and consequently spatial), and yet two separate nuclei of light are not distinguished within this vague extent. According to the usual method of interpreting the results, we should here be below the space-threshold, although, of course, we are not. What Tawney has already justly insisted on with regard to

tactual impressions,¹ that the perception of two points is not a true measure of the threshold, might consequently be repeated with respect to vision. The fusion of the two points is largely obviated by the use of successive stimuli so that the intensity of the first impression is perceptibly lessened by the time the second is at its height.

But the substitution of successive for simultaneous impressions brings what some might consider a vitiation of the results. The two points of light, even when well separated, give the psychological impression of continuous motion; the light seems to leap from the position of the first point to that of the second. At the beginning it was thought possible to separate those judgments in which an apparent motion entered, and treat them as a questionable group by themselves. But when once the suggestion of motion becomes fairly lodged in the observer's mind, it occurs so persistently and over such a range that this attempt was renounced. Since there is no objective movement here, however, and the whole thing is really a matter of suggestion pure and simple, and seems to me to imply an underlying space-discrimination as the basis of the suggestion itself (as I have urged at the beginning of this paper), the judgments with subjective motion have been freely employed in computing the thresholds. Those to whom these reasons do not seem sufficient may have no such scruples over the second group of experiments on foveal vision; not even suggested movement there enters into the judgment.

The results of the experiments with indirect vision were as follows:

Observer	Angle of Observation	Number of Determinations.	Discrim. of Position		Perception of Motion	
			Threshold	M. V	Threshold.	M. V
A	5°	6	9.2'	1.6'	10.4'	1.4'
	30°	5	29.0'	5.2'	29.0'	3.2'
Bd	5°	6	7.9'	.7'	8.3'	1.9'
	30°	3	18.3'	2.2'	21.7'	5.6'
Bl	5°	3	7.5'	3.3'	6.6'	2.2'
	30°	4	63.7'	8.7'	70.0'	10.0'

¹ 'The Perception of Two Points Not the Space Threshold,' PSYCHOL. REVIEW, II., 585

The table indicates that where the conditions are practically equal, the perception of movement has no advantage over the discrimination of position without objective movement. So far as indirect vision is concerned, the theory that the two processes are psychologically independent here finds no support.

II. *Experiments with Direct Vision.*—The second group of experiments dealt with the same problem as the preceding, with a change merely in the method of investigation and with a different portion of the retina—the foveal instead of the excentric region of sight. On account of the extraordinary nicety of our space discrimination under these conditions, the observer was placed in a distant building where there was an unobstructed view of one of the laboratory windows, the distance of his station from the object to be observed amounting by accurate survey to 120 m. The observer faced the north, and the portion of the laboratory towards which he looked sent back no direct glare from the sun; preliminary experiments showed the need of regarding these things. The distance of the observer's station, it is true, was inconvenient in many ways, but this was more than offset by the greater ease of observation. The naked eye could now be employed, and all the difficulty was avoided that comes from the use of a reducing lens, such as Stern found necessary. The fact that the threshold of movement easily ran down to about one half of what he reports shows the advantage of these conditions. For the perception of motion a strip of white bristol-board, 8 mm. wide by 50 cm. long, was mounted vertically on a dead-black frame which could be moved horizontally before a larger dead-black background. From the observer's station the frame itself was invisible, and all that one saw was the white line on the large black field. The movement of the line was controlled by runners and guides and adjustable stops on the frame, so that the motion was kept horizontal and its excursion varied by steps of 1 mm. The experimenter moved the frame by hand, and during any single observation kept the extent of the movement constant, and continued the oscillations from the moment just before the exposure of the line until the observer had signalled his judgment. In order to insure full justice to this side of the investigation, the *rate* of movement

had, also, of course, to be taken into account; otherwise some velocity might be selected that would not be the most favorable to perception. For this reason the experiments on motion were subdivided into five groups, with a rhythm, respectively, of 60, 100, 180, 300, and 450 single swings to the minute. The rates were maintained with reasonable accuracy by the aid of an adjustable pendulum invisible to the subject of the experiment.

For the corresponding set of experiments on the discrimination of position without movement the conditions were in all respects the same, except that for the moving frame with its single vertical line two vertical lines end-to-end against the dark background were substituted. Of these two lines the lower was fixed, while the upper was capable of being shifted from continuity with the lower line to any position to the right or left, remaining throughout parallel, however, to its original position. The actual settings varied by steps of 1 mm., and the observer had simply to judge whether the two lines at any given setting were continuous, or in what respect they spatially differed.¹

The results of the two sets of experiments under these conditions were as follows:

DISCRIMINATION OF POSITION WITHOUT MOVEMENT.
Thresholds in mm.

Observer S.		Observer Y.	
Left	Right	Left	Right
4	4	6	3
7	5	4	6
3	5	5	6
7	5	6	6
3	3	7	4
4	6		
Av. 4.3	4.3	5.6	5.0

The thresholds for the discrimination of position without movement are slightly higher than those obtained in my previous study already referred to, but the difference is not such as to call for any special comment. The thresholds for the perception of movement, as affected by the rate of move-

¹ For a more detailed account of this method, see my 'New Determination of the Minimum Visible and its Bearing on Localization and Binocular Depth,' *PSYCHOL. REVIEW*, VII., 429.

PERCEPTION OF MOVEMENT.
Thresholds in mm.

Single Oscillations per Minute.	60	100	180	300	450
Observer S.	11	6	4	4	4
	16	4	4	4	5
	14	7	4	4	4
	8	5	4	4	6
Av.	12	5.5	4	4	4.75
Observer Y	25	14	7	4	7
	15	14	5	6	7
	18	8	6	6	6
	16	12	6	5	6
Av.	18.5	12	6	5.2	6.5

ment, take a somewhat different course from those reported by Stern.¹ This investigator worked with rhythms of 144, 84 and 72 vibrations to the second, and found *merkwürdigerweise* (as he says) that the slowest movement was the one most distinctly perceived. In my own results, it will be seen that the lower rates, those of 60 and 100, are markedly unfavorable to perception, with a decided improvement as we pass to 180 and 300, the threshold again rising slightly as the rate is still farther increased. Virtue here seems again to lie in the mean. The lower rates require a considerable excursion before they can be distinguished from rest, while the most rapid oscillations tend to produce a mere indistinctness rather than a perceptible swaying of the object. I am quite at a loss to account for our divergent results here, unless it be that by the word '*Schwingungen*,' which Professor Stern uses without modification, he means '*double vibrations*.' In this event his lowest rate would be about midway between my 100 and 180, and he would have caught only the dip of the threshold as it comes out of the region where the rapidity of the impressions produces blur, without his rates becoming slow enough to show the upward trend of the threshold again farther on. My own subjects, like his, never knew beforehand the rate that was being used, so the discrepancy cannot be explained in this way. Possibly the difference is in some way connected with the fact that his observers had to look through the lens of a microscope.

¹ *Zeitschrift für Psychologie u. Physiol. d. Sinnesorg.*, VII., 347.

For observer *S*, the most favorable rates of motion give a threshold of 4 mm. (about 6.8'' angular measure) as against 4.3 mm. (about 7.3'') for the discrimination of place—a net advantage, for motion, of .3 mm. or .5'' of arc, on the average. If, however, we were to disregard averages and look at the individual determinations, it would appear that the space discrimination occurred as low as 3 mm. (5.1'' of arc); while in no case does motion become perceptible below 4 mm. For observer *T*, the mean threshold for position without movement is 5.3 mm. (9''); while the most favorable rate of motion gives 5.2 mm. (8.8'') on the average. Here again the minimum thresholds for position are below the smallest for movement. Thus, from one point of view, motion has a slight advantage over discrimination without movement, which advantage, however, is reversed when the numbers are differently regarded. But in either case the difference is too slight to serve as a sufficient basis for entirely differentiating the psychological processes involved.

The results here, then, are in substantial agreement with those obtained in indirect vision by an independent method. The doctrine that visual motion is a primitive form of sensibility independent of local discrimination finds no experimental warrant. The perception of motion seems to be nothing more nor less than the perception that a sensation is changing its space relations, the motion itself furnishing a decidedly favorable, but by no means unique, set of conditions for appreciating such differences of space relationship. This does not imply that the detection of movement always involves a deliberate comparison of positions; for the discrimination often undoubtedly occurs at a single psychic stroke. But even this apparently simple stroke is really a complex act. It implies a relational activity of the mind which interprets and gives character (crude and confused though it be) to the incoming sensations, so that they are no longer blank impressions, but are impressions which mean for us *movement*. The experiments thus go to support the view that a fact of space can never be conveyed to the mind in the form of a pure sensation divested of all relationship.