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## STUDIES FROM THE LABORATORY OF THE UNIVERSITY OF CHICAGO.

COMMUNICATED BY PROFESSOR JAMES ROWLAND ANGELL.

### THE PENDULAR WHIPLASH ILLUSION OF MOTION.

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I. In an article entitled 'The Participation of the Eye Movements in the Visual Perception of Motion,'<sup>1</sup> Mr. Dodge reviews the historical trend of opinion in assigning a less and less importance to the factor of eye movement in mediating the visual consciousness of motion; he further takes the extreme radical position in this trend of thought by denying to eye movements any function at all; he maintains the thesis that eye movements alone can not mediate any consciousness of visual motion. "Not only, however, is there no independent consciousness of the eye movements, adequate to the refinement of the visual perception of motion, but the character of the eye movements which occur when we view a moving object furnishes evidence that, if our consciousness of them were complete and exact, it would be either useless or misleading as a datum in the visual perception of motion" (p. 3). In speaking of the results of one of his tests, he maintains that it "serves at once to show the utter inability of the pursuit movement either to subserve the perception of motion of the fixated point or to correct the exaggerated data from the displacement of the retinal image of the nonfixated point" (p. 14).

A crucial test of the theory would involve the elimination of all other possible functioning factors, the perception of an

<sup>1</sup> PSYCH. REV., 1904, pp. 1-14.

isolated moving object whose stimulation remains stationary upon the retina. Professor Dodge contends that these ideal conditions are obtained in his pendulum test. Two lights of weak intensity are placed on the two arms of a counterbalanced pendulum. One of these swinging lights is followed by the eyes, while the other is perceived peripherally. Former photographic tests have demonstrated that the image of the fixated light is not displaced on the retina during the last quarter of its swing. According to the theory, the fixated light should appear motionless during these ideal conditions, while of course the second light would still be seen in motion during this period. As a matter of fact, the experiment gave the expected results; the peripherally perceived light was seen to move an appreciable time after the fixated light came to a full stop; this second light appeared to make 'a gratuitous whiplash excursion' of its own. "We have already called attention to the fact that the end of every pursuit sweep is freer from corrective movements than its beginning. This is conspicuously true of the pursuit sweeps by which the line of regard follows a swinging pendulum. Photographs of such sweeps give no indication of corrective movements either negative or positive within the last quarter of the swings studied." He further says that the conditions of the experiment are such that it 'constitutes a faultless experimental test of our conclusions' (p. 13).

There is no doubt as to the genuineness of the whiplash phenomenon. Mr. Dodge has well described it. Also, is it obvious that the theory will satisfactorily explain the illusion, nor, so far as I know, is there any reason for questioning the statement that ideal conditions obtain during this part of the swing.

Mr. Dodge further maintains that the illusion is 'capable of only one explanation,' *i. e.*, in terms of his theory. If this be true, it would logically follow that the phenomenon is proof positive of the truth of his theoretical position. The only escape from the inevitable logic of the situation is to question his proposition that no other explanatory theory is possible. In fact, one such *possible* explanation occurred to the writer upon reading the article in question.

Let us assume the truth of the doctrine generally accepted before Dodge advanced his extreme proposition, viz., that eye movements can mediate visual motion, but only for the greater magnitudes and velocities; that their limen of perceptibility is much greater than that of the factor of retinal displacement. The assumption is entirely probable, for surfaces differ in their sensitivity to movement. A stimulus of a definite magnitude and rapidity may be below the limen of perceptibility on one part of the skin, and still be distinctly perceived as movement on another area. The same is true for different parts of the retina. In fact this is the generally accepted view, which Dodge is trying to overthrow. As the pendulum approaches the end of its swing, the rate of movement gradually decreases to zero. Consequently, for some definite portion of the end of its swing, its rate would be below the eye movement limen, but still above the retinal limen of perceptibility. In other words, the retinally perceived light would be seen moving for an appreciable time after the fixated light had apparently stopped. Hence the gratuitous whiplash excursion is evident. Since the function of eye movement in the perception of motion is the point at issue, one has as much right to make a positive assumption as Dodge has to assume a lack of function. The theory further has the weight of historical opinion behind it.

A third *possible* theory developed during a repetition of the experiment. The fixated light when successfully followed has (during the last portion of its swing) no positive after-image. The peripherally perceived light, on the contrary, does leave a pronounced positive after-image streak. The eye moves in a direction opposite to this latter light and consequently the rapidity of its retinal displacement equals that of a light, perceived by a stationary eye, moving at a rate equal to the combined velocities of the two lights used in the pendulum test. Other things being equal, the length of the after-image streak varies directly with the rapidity of the retinal displacement. Thus a very pronounced length of the positive streak results in the test. This light, with its positive after-image, is viewed peripherally and hence is seen indistinctly and *en masse*; without conscious effort on the part of the observer, it appears as an elongated light with

no very decided contour, nor sharply discriminated parts; it appears as a conscious whole or unity. As the pendulum reaches the end of its swing, this elongated mass of light rapidly contracts in length at its rear end. This occurs for two reasons: (1) the velocity of the pendulum rapidly decreases toward zero, and the length of the positive after-image is a function of the rate of movement; (2) the light on its return swing back-tracks, as it were, and meets the receding end of the fading after-image, but now leaves another positive streak in its rear. If the positive streak is six inches long when the pendulum is one inch from the end of its swing, and this streak has time to disappear while the pendulum is moving and returning over this final inch of its arc, it is evident that the total mass of light will have contracted at its rear end from six inches to one inch in length. These values are of course merely illustrative. Movement, psychologically, is the consciousness of spatial changes, and these changes occur at the two ends of the elongated light, the shifting boundaries between the two discriminable visual contents. One of these cues of movement becomes abnormally exaggerated as the pendulum comes to a full stop, and still continues to be operative, without any contrary cue, while the pendulum is gathering headway on its return swing. Consequently, the whole mass of light will appear to be moving on, after the pendulum has really stopped. The observed extra movement is thus a purely illusory one. Such a conception involves no new doctrine, for the influence of the receding positive after-image streak in mediating the perception of motion is well known. At the very least, the theory possesses an *a priori* possibility.

We shall term these theories *A*, *B*, and *C* in the order of their exposition. It is to be noted that only *A* and *B* are mutually exclusive. The phenomenon may be due to the causes designated in *A*, or *B*, or *C*, or it may be the combined result of those mentioned in *A* and *C*, or *B* and *C*. We propose to recount some additional observations and tests throwing light upon the relative efficiency of these conceptions as explanatory principles.

Hereafter the fixated and the peripherally perceived lights

will be termed the upper and the lower lights respectively. Unless otherwise stated, the following conditions will obtain: The length of the upper arm of the pendulum is slightly shorter than that of the lower arm. The lower arm is 78 cm. in length, and swings through an arc of 100 cm. The pendulum moves at a velocity of two seconds for a complete swing, *i. e.*, for a forward and a return movement. The observer is stationed at a distance of 230 cm., and the eye moves through an angle of 23 degrees in following the upper light. The angular distance of the lower light from the fovea is approximately 30 degrees. Two miniature incandescent lights were used of such intensity that no other objects were visible. The tests were conducted at night in a dark room.

II. Mr. Dodge alleges that the apparent length of the upper light's movement is judged to be much shorter than that of the lower one. In order to secure an equality of apparent length of movement, he found it necessary to make the upper arc of movement three times the length of the lower. He calls attention to the similarity between this ratio and that obtained by Exner, Von Fleischl, *et al.*, between the apparent rates of movement when judged with stationary eyes on the one hand, and with the eyes following the movement on the other. If the experienced velocity and duration of movement of the lower light are greater than that of the upper light, apparently it should seem to move for the greater distance.

My observers did not confirm these results as to the apparent lengths of movement. In fact, they gave judgments of equality of movement only when the two arcs were practically equal in length.<sup>1</sup> Moreover, the argument is not valid that the apparent movement of the lower light must be greater than that of the upper light because it has the greater apparent velocity and duration. In certain illusions, as the Pürkinje dizziness phe-

<sup>1</sup> Probably this discrepancy is due to a difference in the method of judging, for there are present several cues upon which the observer may base his judgments of length. It is practically impossible to make a judgment as to *pure length*, uninfluenced by other motives. The apparent rate of movement may have a determining influence, or the observer may mentally superimpose the two lengths to be compared. My observers invariably found themselves using the latter method.

nomenon and especially under some conditions of 'autokinetic sensations,' I have often observed that the customary mathematical relation between rate and magnitude of motion does not obtain. The light may appear to be moving at the rate of two feet a second, and yet after some time one would not judge the distance traversed to be over a few feet in length. The illusion is so striking to the writer under some circumstances, that the felt discrepancy between rate of movement and distance traversed forces itself upon the attention. The light appears to be *moving rapidly*, but yet does not appear to be getting anywhere, to be *traversing space*. One receives to some extent the anomalous feeling that the light is both moving and not moving at the same time. On the other hand, in a test to be described later, I received the impression occasionally that the amount of movement was too great for the velocity, that the object *got to positions without moving there*. As another illustration of the truth that axioms of ideal space do not necessarily hold true for experienced space, I may cite the fact that in cutaneous space two lengths equal to a third length do not always equal each other. In fact, many spatial illusions exist simply because the spatial relations of our experiences do not tally with the relationships of ideal space.

According to the theory *A*, the upper light appears motionless, when the pendulum has completed three fourths of its swing. The lower light is still perceived to be moving during the last quarter. Consequently, this extra movement of the lower light after the upper one has ceased moving ought to be equal in length to one fourth of the arc; with our conditions this would be 25 cm. Judgments as to its apparent length gave values of but 7-10 cm. Such judgments are of course unreliable so far as any nice accuracy is concerned, but the discrepancy between these values and 25 cm. appears too great to be explained in this manner.

If the upper light appears motionless when the pendulum completes but three fourths of its swing, and a screen is interposed so as to intercept the subject's vision of the lower light at this point, *i. e.*, cut off from view the last quarter (25 cm.) of its movement, it follows that the lower light should

disappear at the same time that the upper light ceases moving. This test was made as follows: The position of the screen was adjustable so that the subject's vision of the lower light was intercepted for any desired portion of the end of the swing. The amount of arc intercepted was varied in an irregular manner, nor was it known to the observer. The subject was asked to judge whether the lower light disappeared before, after, or coincidentally with the cessation of movement on the part of the upper light. As many trials were allowed as the subject desired before giving each judgment. For judgments of simultaneity, two observers gave an average result of 5 cm., with an average variation of 2 cm. Within these limits (3-7 cm.), hesitancy of judgment was the rule. For the greater values of 10-25 cm., the observers were never in doubt; the upper light was distinctly perceived in motion after the disappearance of the lower light, *i. e.*, during at least nine tenths of its swing.

This experiment was varied by so placing the screen as to wholly intercept the sight of the lower light. This screen contained a small opening, 2 cm. square. This opening could be placed at any position along the arc of movement. Consequently, the lower light would be momentarily visible only at a certain desired time during its swing. The observer was now asked to judge whether this light was seen before, after or coincidentally with the cessation of movement on the part of the upper light. An average value of 2 cm. was obtained for judgments of simultaneity. For larger values there was no hesitancy of judgment. For all points above 5 cm. from the end of the swing, the upper light was perceived in distinct motion after the lower one became visible. The theory demands that the upper light be seen moving *only* during 75 hundredths of its swing. These results show that it is *distinctly perceived in motion* throughout 90 to 95 hundredths of its arc.

This extra duration of movement, or the whiplash excursion, can be seen under conditions of observation other than those taken into account by theory *A*. It can be seen with *stationary* eyes where both movements are perceived *entirely by retinal criteria*. The subject fixates the point in space where the

upper light comes to a full stop and observes the two movements under these conditions. When the the two arms of the pendulum are equal in length, the whiplash effect is absent. However, if the lower arm of the pendulum is much the longer, the whiplash phenomenon is again in evidence. Obviously, this result can not be explained on the basis of theory *A*.

III. The results of the above test can be explained by theory *C*. This conception of the whiplash effect assumes that the lower light appears to move for a greater duration of time but not necessarily through a greater amount of space. This apparent greater duration of movement is due to the stimulation of the receding end of the positive after-image streak. The duration of this extra movement would thus depend upon the length of this streak, and this length would depend, other conditions being similar, upon the actual velocity of the light. When the two lights are viewed with stationary eyes, positive streaks follow both lights. When the two arms of the pendulum are equal in length, the linear velocities of the lights and the lengths of their streaks are equal. Both lights would thus appear to move *after* the pendulum actually stopped, but for an *equal* duration of time. When the lower arm is much the longer, the lower streak is also the longer. Both lights would appear to move *after* the pendulum stopped, but for *unequal* durations of time. The lower light would appear moving after the upper one came to a full stop. In other words, the whiplash effect would be absent in the first case, but present in the second, in accordance with my observations.

In the above judgments of simultaneity where the lower light disappeared behind the screen on the one hand, and appeared through the opening on the other, a larger value was obtained in the first case. Granted that this difference of value is a valid result under the two conditions, the fact can be explained by theory *C*. In the first case the positive streak is present, but is absent in the second case because the light is hid behind the screen. Simultaneity was secured at 5 and 2 cm. from the end of the swing respectively for the two conditions. When the positive streak is present, the lower light will be visible, in indirect vision, after its actual disappearance behind the



screen. In order to make its apparent disappearance coincident with the cessation of the upper light's movement, it would need to be intercepted earlier in its swing by an amount of time equal to the functional persistence of the positive streak. As a matter of fact when the positive streak was present, the light was intercepted 3 cm. earlier in its swing. According to the conception, the time taken for the pendulum to move these 3 cm. should equal the functional duration of the positive streak. Since the pendulum moves 100 cm. per second, this time would be .03 second, provided that the rate of movement were uniform. Since the pendular movement decreases in velocity at the end of the swing, the actual time must be greater than this value, probably at least .05 second.

The whiplash illusion is conditioned by the direction of the attention. If the positive streak be consciously neglected by focussing the peripheral attention upon the forward part of the moving light, the whiplash effect is practically eliminated. By voluntarily attending to the streak, *i. e.*, to the receding end of the elongated light, the illusion of extra movement at once becomes evident. It was this observation which led to the formulation of the after-image theory. A second observer who knew nothing at all of the theories involved, voluntarily offered the same explanation after some observation of the phenomenon.

A contrary illusion may sometimes be obtained by sharply discriminating the light from its positive streak. Instead of perceiving the lower light moving forward, it may be seen moving *backwards* a couple of centimeters on its return swing while the upper light still appears motionless.

Since the length of the positive streak varies directly with the pendular velocity, it would follow, according to theory C, that the illusory effect will vary in direct proportion to the pendular rate of movement. By a system of weights, the velocity was varied without any other alteration of conditions. The rates secured were 5, 3, and 2 seconds for a complete swing. Judgments of the illusory movement were then given in linear terms. Values of 1, 3, and 6 cm. respectively were obtained for the three rates in the order given above.

A sufficient portion of the end of the swing for each of these

rates of movement was intercepted so as to obtain a judgment of equality in the duration of movement for the two lights. According to the theory the amount of arc intercepted should vary in proportion to the three rates. The values of 15, 30 and 45 mm. respectively were secured. These results correspond rather closely to the above values for the apparent lengths for this extra movement. The actual numerical values are in themselves unimportant; they bring out the fact, however, that the apparent extra movement does vary directly with the velocity of the pendulum.

A weak diffused light,  $10 \times 15$  cm. in dimensions, was so placed that the lower light would swing past and just emerge from it at the end of the movement. This background of diffused light was so varied in intensity that the positive streak could not be differentiated from it by direct observation. The experiment was then repeated as usual. At the end of the swing, the lower light would flash out sharply against its black background, while the positive streak could not be seen. The functional efficiency of the receding after-image was thus eliminated. Under these conditions the illusory movement was not apparent, while the lower light would flash out into distinct view practically at the same time that the upper light came to a full stop.

IV. But little positive evidence can be given in favor of theory *B*. The contrary illusion can be interpreted on this basis. The velocity of the pendulum is so small for the end and beginning of each swing that eye movements can not mediate a sense of motion. The upper light is thus not perceived in motion for a couple of centimeters at the end and beginning of its movement. Since the retina is more sensitive to movement than the eyes, the lower light is seen moving during this time; it not only moves *forward* a centimeter after the upper light stops, but also may be seen moving *backward* on its return swing before the upper light gathers a sufficient velocity to arouse a movement consciousness. The phenomenon might be explained legitimately in other terms, however.

In so far as the after-image theory does not entirely account for the illusory effect, it is legitimate to assume the influence of

factor *B*. In several of the tests, a slight illusory effect appeared to be present, although the after-image was eliminated. When the light appeared through the opening in the screen, the after-image was not present, yet the upper light was judged to be motionless when the pendulum lacked two centimeters of completing its swing. When the after-image was suppressed by the background of diffused light, a slight suggestion of the illusory movement was occasionally noticed. These cases are explicable in terms of theory *B*, though, of course, they may be explained by other means. No conclusive proof of this theory can be offered.

V. On the whole the evidence seems sufficient, to the writer, to warrant the conclusions that the phenomenon is not to be explained in any measure by theory *A*; that the upper light is perceived in motion during the major part of the last quarter of its swing; that the phenomenon is due mainly to the receding positive after-image; and that possibly factor *B* may have a small determining influence.

If Dodge's contention be true that ideal conditions obtain during the last quarter of the arc of movement, and if our tests prove that the upper light is seen in motion during the major portion of this time, it would logically follow that the experiment is proof positive against Dodge's theory as to the lack of function on the part of eye movements; that they, on the contrary, do function in the perception of movement. However, the writer does not presume to advance such a dogmatic conclusion on the basis of a single experiment, in view of the fact that the results of several other experiments advanced by Dodge and others remain to be controverted.

VI. A rather interesting phenomenon developed during a modification of the pendular experiment. Both lights were attached to the lower arm, but at different distances from the axis of rotation. If the upper light be followed by the eyes, the same results are obtained as formerly, though the whiplash effect is not so pronounced. The motion of the lower light is retinally perceived, because the eyes do not move to the same extent as does this light. When the lower light is followed, the eyes move faster than does the upper light, and consequently

retinal cues of movement are present. Moreover, the upper light is now *preceded* by a positive streak. Since the pendular velocity decreases at the end of the swing, the elongated light must now contract in length on its *forward* end. The forward end of the positive streak travels backward in relation to the light. Two opposing retinal criteria of movement are now present. The receding streak tends to *oppose*, or *neutralize*, instead of *emphasizing*, the upper light's motion. As a matter of fact, one's consciousness of this motion is strikingly peculiar and difficult of description. The movement seems weak and attenuated in character; it lacks body, force and vitality. It sometimes appears to be markedly shorter than its actual length, while at other times it appears to approximate its normal length, but in this case its length seems to be *too great* for its velocity; it strikes one at times as being in certain positions without having *moved* there. This illusory appearance becomes striking, if the observer suddenly stops the eyes and holds them stationary; the movement at once flashes out in vigor and vitality. Whatever the proper explanation may be, the illusion is certainly unique and seems worthy of further study.<sup>1</sup>

<sup>1</sup> The MS. of this article was received December 25, '06. — ED.