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STROBOSCOPIC MOVEMENT BASED ON CHANGE OF PHENOMENAL RATHER THAN RETINAL LOCATION

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Although stroboscopic movement has been the subject of countless investigations over a period of many years, it remains to this day an unexplained phenomenon. For the most part, work on this problem during the last several decades has been directed at adducing evidence for or against two types of theories. The Gestaltists have hypothesized that the experience of movement is based on some central physiological interaction which takes place in the cortex between the loci of excitation yielded by the two light-sources.[1] Support for this position has been seen in the finding that the effect is superior or occurs more readily within one hemisphere than between the two,[2] in the finding that satiation of the cortical region between the loci of excitation will subsequently effect *phi*,[3] and conversely, in the finding that after-effects of stroboscopic movement can be predicted for objects which stimulate that cortical region or 'field.'[4]

Others have sought to show that the interaction is either retinal[5] or sub-cortical[6] and support for this view has been seen in the fact that the effect is more readily obtained when both sources stimulate the same eye than when each is located in a different eye,[7] and in the finding that decorticated guinea pigs apparently achieve stroboscopic movement.[8] Both

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1 Max Wertheimer, Experimentelle Studien über das Sehen von Bewegung, *Z. Psychol.*, 61, 1912, 161-278.

2 A. Gengerelli, Apparent movement in relation to homonymous and heteronymous stimulation of the cerebral hemispheres, *J. exp. Psychol.*, 38, 1948, 592-599.

3 B. H. Deatherage and M. E. Bitterman, The effect of satiation on stroboscopic movement, this Journal, 65, 1952, 108-109.

4 N. H. Livson, After-effects of prolonged inspection of apparent movement, this Journal, 66, 1953, 365-376.

5 C. T. Morgan, *Physiological Psychology*, 1943, 203-206; Koiti Motokawa, Retinal traces and visual perception of movement, *J. exp. Psychol.*, 45, 1953, 369-377; The physiological mechanism of apparent movement, *idem*, 378-386.

6 K. U. Smith, The neural centers concerned in the mediation of apparent movement vision, *J. exp. Psychol.*, 26, 1940, 443-466; K. U. Smith and W. E. Kappauf, A neurological study of apparent movement, *J. gen. Psychol.*, 23, 1940, 315-327.

7 C. H. Ammons and Joseph Weitz, Central and peripheral factors in the phi phenomenon, *J. exp. Psychol.*, 42, 1951, 327-332.

8 Smith, *op. cit.*, 1940, 443-466; Smith and Kappauf, *op. cit.*, 315-327.

theories share the common assumption that the effect depends upon a neural interaction between the excitations and that it is such interaction which creates the experience of movement.

The usual statement of the minimal conditions required to produce stroboscopic motion is that disparate retinal points must be exposed to alternate stimulation. Given the proper rate of such stimulation, the experience of motion will occur. While there can be doubt that the above statement represents a sufficient condition, one can by no means conclude on the same basis that it is also a necessary condition. The sources of stimulation—corresponding to the disparate retinal points—are typically localized phenomenally at distinct places in space. There are, therefore, two possible ways of stating the necessary conditions for movement, one in terms of anatomical locus of stimulation and the other in terms of experienced location of the sources of stimulation. It is to be noted that in the traditional statement of the minimal conditions required to produce stroboscopic motion these two possible alternatives are not distinguished, undoubtedly because change of retinal location is generally a concomitant of change of phenomenal location.

The possibility which was explored in the following experiments was that stroboscopic motion is primarily a function of change in *phenomenal location* of the source of stimulation and not at all a function of change in the anatomical locus of stimulation (neural interaction theories, as noted above, are based upon the assumption of change of anatomical locus).[9]

Experiment I

Part 1. The purpose of this experiment was to create conditions such that a single anatomical locus of stimulation be experienced at two different spatial locations. This was accomplished by having *O* so move his eye back and forth as to view each stimulus foveally. Thus, while *O* localized the distal object on his left and again on his right, the locus of retinal (and cortical) stimulation remained identical in both cases.

Procedure. O's head was held rigidly in a fixed position by a head-rest. He viewed the scene monocularly (generally with the right eye) and alternately through one of two artificial pupils. The artificial pupils were about 0.014-in. in diameter, about ⅝-in. apart, punched in a circular piece of thin black paper surrounded by a shield which prevented *O* from seeing anything except through these openings. *O*

[9] Of course, phenomenal location depends upon certain underlying neural events, but not necessarily upon a particular location of the excitation in either the retina or in area 17 of the visual cortex. Throughout this paper "phenomenal location" (in contradistinction to "anatomical location") will be used in this sense.

could see through only one aperture at a time, in that light stimulated his retina only through the aperture his eye was facing at any moment.

The scene consisted of two vertical luminous lines on an otherwise dark homogeneous field. About 22 in. in front of the artificial pupils was the arrangement which produced the vertical lines. This consisted of a ground-glass screen upon which were mounted two pieces of black cardboard, each containing a vertical slit. (The slits were 3/16 in. in thickness and 3 in. in length.) The cardboard pieces, each containing a vertical slit, were mounted on a track over which they could be shifted horizontally behind the ground-glass screen so as to increase the distance between them when desired. Only one line was visible through each aperture and it was only visible when the eye was turned to fixate it through the aperture. Thus, when *O* viewed through the left aperture, only the left line was visible and when *O* viewed through the right aperture, only the right line was visible.

Extreme care was taken to insure that each line stimulated only the foveal portion of the retina. This was accomplished with each *O* in advance of the experiment by illuminating the aperture and the lines at the same time. *E* then moved the lines until their images were as close to the inner or nasal portion of each aperture as possible, while *O* fixated the lines. This insured that the lines would disappear from *O*'s view with the onset of the slightest lateral eye-movement in a nasal direction. With the eye so close to the aperture, any turning brings the pupillary opening out of alignment with the entire cone of light rays coming through the aperture from the line. It was not possible with the arrangement used here simultaneously to prevent *O* from seeing a given line peripherally through an aperture by turning his eye beyond the line. Under instructions to fixate, it is unlikely, however that this would occur. If it were to occur a theory based on neural interaction would have to predict movement in the opposite direction to that which was experienced based on an analysis of the proximal stimulus-situation. (See the discussion of this problem p. 203.) In other words, *O* could see each line by fixating it and nothing else was visible but the fixated line. As soon as the vertical lines were in place, the surrounding area was so darkened that the apertures were themselves no longer visible to *O,* but of course he could still see *through* them. By means of a dual projector and an episcotister, the two vertical lines were made to appear alternately, one through each aperture. *O* was then instructed to move his eyes from left to right, etc., so that the illuminated vertical lines would be in foveal view at each position of the eye. Fig. 1 illustrates the experimental arrangement. All *O*s, after a few trials, were able to synchronize their eye-movements to the alternating vertical lines.[10] *O* was then asked to report his spontaneous impression of the scene. The *O*s were students at the New School for Social Research; some of them probably had seen stroboscopic movement demonstrated in a class, but all of them were naïve about

[10] The main purpose of using the alternating projection of the vertical slits was to force *O* to achieve a particular speed of alternation of eye-movement. No doubt a stroboscopic effect would have been achieved even with both slits continuously illuminated because only one is visible at a time, but then there would be no control over rate of eye-movement and, hence, over rate of alternation. It is, however, possible that our arrangement did also contribute to a flashing on-and-off effect. Without it, *O* might have in some way sensed that it was his own eye-movement which 'turned off' a line and, if so, the lines may have been seen as permanently on but not always visible, which probably is not an ideal condition for producing a movement-effect.

the hypothesis. Care was taken not to mention that the experiment had to do with stroboscopic movement.

The precise conditions of rate of alternation and distance between lines varied somewhat for each *O*, depending upon the rate of eye-movement he was able to attain. For one *O* believed to be representative, the rate of alternation was approximately 0.3 sec. with the lines set 7 in. apart. Each line remained exposed for approximately 0.13 sec.

In summary, the major point of the above procedure was to insure (1) that the

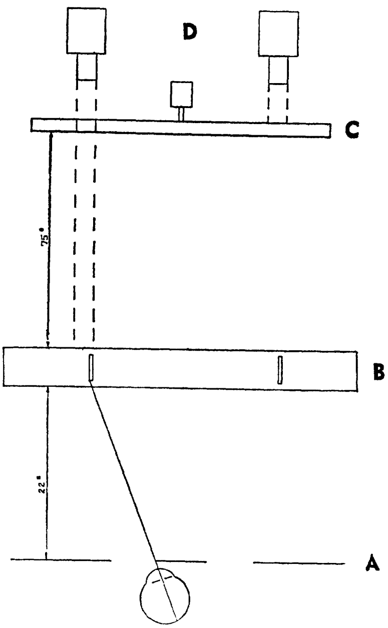

FIG. 1. SCHEMATIC DIAGRAM OF ARRANGEMENT USED IN EXPERIMENT I, PART 1
A, artificial pupils; B, ground-glass screen, with vertical slits in cardboard; C, episcotister in position of transmitting light from left projector; D, dual 300-w. projector.

proximal stimuli would fall in a single retinal region, and (2) that the corresponding distal stimuli would be experienced at different phenomenal locations, once to the left and once to the right. Such phenomenal localization is based on the change in eye-position.

Results. Of 10 *Os* who succeeded in properly coördinating their eye-movements to the alternating stimulus, 6 reported seeing a single object in motion almost immediately following the onset of stimulation. The remaining 4 *Os* reported seeing 2 objects, both of which were flashing on and off in their respective positions. These same 4 *Os* were, however, unable to perceive apparent movement under normal viewing conditions.[11] These cases do not, therefore, represent negative instances of the hypothesis in question. The results thus far indicate that stroboscopic motion can be experienced in the absence of disparate retinal-cortical stimulation.

Part 2. In Part 2 of this experiment, the attempt was made to create a situation in which different regions of retinal stimulation were phenomenally localized in the *same* region in space. In this situation, one eye-position allowed for foveal stimulation of the object whereas the other eye-position allowed for peripheral stimulation by the same object while fixating a small stationary spot. In both cases, however, the stimulus-object was experienced at the same locus in space. This was accomplished by requiring *O* to move his eye back and forth so as to view a single stationary flashing line alternately foveally and peripherally.

Procedure. As soon as Part 1 was completed, one of the vertical lines was removed and a hole ½-in. in diameter was substituted for it. This hole was continuously illuminated and served as a fixation-point. The two projectors behind the episcotister were now both trained on the same vertical slit from behind the ground-glass screen. This arrangement was thus one which illuminated the vertical opening at a rate exactly twice that of Part 1. (The reason for the increased rate was that every other exposure was intended to correspond to the exposure of a second line. Thus, the rate between exposures of the line equalled that between exposures of the two lines in Part 1.) The scene, therefore, consisted of a line flashing on and off and a continuously illuminated fixation-point. *O* was then asked to view the scene monocularly through a circular hole cut in black cloth (placed about 3 in. above the artificial pupils used in Part 1). The opening was fitted with two polarizing filters at such an angle with respect to each other as to maintain a black homogeneous surround for the flashing line and the fixation-point. *O* was instructed so to adjust his gaze between the line and the point that the line would stimulate alternately the foveal and peripheral regions of the eye with each flash. This was accomplished by the following succession of eye-movements: *O* fixates point on right (line flashes in peripheral vision on left); *O* fixates line on left (line stimulates fovea); *O* fixates point on right (line flashes in peripheral vision on left) etc. Thus, as far as the retina or cortex is concerned, there is alternate stimulation of disparate points exactly as occurs in a more typical demonstration of apparent movement. The major difference, however, is that here the flashing source will be localized at one and the same place in space. After several trials, all *O*s were asked to report their spontaneous impressions of the scene.

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[11] They were given the opportunity to view the alternating stimuli monocularly and without an artificial pupil. The rate of alternation was kept identical with the highest rate of eye-movement attained in the experiment proper. The reason these *O*s did not experience movement may be that their threshold for stroboscopic motion required a rate of alternation well above that at which they were capable of maintaining lateral eye-movements.

Results. The six *O*s used in this part were the same *O*s who experienced movement in Part 1. Of the six, none reported the perception of movement under these conditions.

These results indicate that in the absence of divergent spatial locations of the distal stimuli, stroboscopic motion will *not* occur, even though disparate retinal points are being stimulated. Apparently the fact that the line is experienced in one and the same place in space eliminates the possibility of seeing movement.

Experiment II

Part 1. As in Experiment I, Part 1, the over-all intent of Experiment II was to create the conditions under which an object would stimulate a given (constant) portion of the retina, but be phenomenally localized at two different places in space. The two experiments differ, however, in the way in which the disparate object-localization was achieved. In Experiment I, change in eye-position may be assumed to have been the major determinant of change in phenomenal location. In Experiment II, it was decided to utilize as the determinant the change in relative position of one object with respect to another.

Procedure. The conditions employed are quite similar to those of Duncker's demonstration of induced motion.[12] In Duncker's demonstration, motion was attributed to an object that had no moving counterpart in the retinal pattern. He attributed this effect to what he termed object-relative displacement. In the case where one object may be said to surround another or to act as a frame of reference, when the latter (the frame of reference) is set in motion, the enclosed, surrounded object is characteristically perceived as moving in a direction opposite to its frame.

The present conditions differ from those of Duncker with respect to the fact that the object expected to be seen as moving is not continuously present but instead flashes on and off in the same physical locus. A luminous line was moved back and forth (frame of reference), while a shorter luminous line flashed on and off in a fixed position in space. The short line thus appeared now to the left of the larger moving line, now to the right.

O was at a distance of about 4 ft. from a display which moved in a plane perpendicular to his line of sight. He viewed binocularly, in a completely darkened room, from a fixed head-position. The display consisted of the following: In the center of a black cardboard was a vertical luminous line of ½-in. width and 8-in. length. In symmetrical positions, to the left and right of this line, were two slits, ⅛ by 2 in. long. The slits were exactly 2⅝ in. apart at their extreme edges.

The entire display was mounted on a wooden frame which moved in a track laterally, for a total distance of 2⅝ in. Upon reaching the point of maximal displacement in any one direction, the display immediately changed its course and pro-

[12] Karl Duncker, Über induzierte Bewegung, *Psychol. Forsch.*, 12, 1929, 180-259.

ceeded in the opposite direction. The speed of alternation could be varied by means of variable rheostat. The movement was accomplished by means of a reduction motor which drove a circular metal disk in a horizontal plane. A shaft mounted at a point on the perimeter of the disk was attached to the wooden frame. As the metal disk revolved, a force was applied to the frame via the shaft and the ensuing direction of movement was determined by the horizontal track. The total displacement of the display ($2\frac{5}{8}$ in.) was determined by the diameter of the metal disk (and angle of disk to track).

At a fixed point on a wall directly behind the display was a single luminous line of dimensions identical with one of the slits in the display. This line was so situated as to coincide with each slit at the two points of maximal displacement of the display. Thus, as the display reached its left terminal point, the right slit became coincident with the luminous line; as the display reached its right terminal point, the left slit coincided with the same luminous line. This situation provided, therefore, for the alternate illumination of the left and right slits, although the source of illumination was at a fixed point in space.

O was instructed to fixate a luminous spot fastened to a clear glass plate at a distance of about 2 in. in front of the display and placed directly in *O's* line of sight. Under these conditions, the stimulation (coming alternately from each slit and provided by the fixed luminous line behind the display) consistently fell on the same portion of the retina. Thus as in Experiment I, Part 1, the classical conditions for phi (viz. the alternate stimulation of disparate retinal points) were not present. The question was whether the possible shift in phenomenal location of the flashing line induced by the actual change in position of the larger line would yield the impression of movement.

When the apparatus was set in motion, *O* was required to report what appeared to be taking place in his field of view. Different *O*s participated in this variation.

Results. All of the *O*s (10) who took part reported viewing a single short luminous line describing a semicircular path about a taller luminous line in the third dimension. The center line was also seen to move back and forth. About as many *O*s reported the motion of the short line taking place behind the tall center line as did those reporting motion in front of the line. The results clearly support the hypothesis that change in phenomenal location without change of retinal location will yield the perception of stroboscopic motion.

This procedure on the surface is similar to one used by Duncker whereby stroboscopic motion can be used to illustrate induced movement. The relative position of an outer rectangle changes in two slides, alternately projected, while that of a central dot remains unchanged. The rectangle is seen to move but so is the dot, despite the fact that the dot's position is objectively unchanged. We would have cited this demonstration to support the proposition of the dependence of stroboscopic movement on change of phenomenal location rather than retinal location (instead of performing the above experiment) were it not for one flaw. The retinal position of the rectangle *does* change so that one might argue that the stroboscopic movement induced in the dot is transferred in some way from the stroboscopic movement of the rectangle and *that* movement *is* based on change of retinal location. In the present experiment, however, the central line is in *continuous* (real) movement and the short line merely flashes on and off in the same objective place. There is thus no stroboscopic motion to be transferred to the short line; nevertheless, a stroboscopic effect is achieved.

Part 2. The results of the previous experiment indicate that a discontinuous change in the relative position of the stimulus-object with respect to another object was sufficient to produce stroboscopic motion. This was the case despite the absence of disparate retinal stimulation.

If we consider this experiment from the perspective of Duncker's conceptual system, it is probable that the constantly illuminated center line served as a frame of reference, thereby 'inducing' stroboscopic motion in the alternately illuminated line. If Duncker's formulation can be applied to the present instance, then if the object, with respect to which a change in position takes place, were made relatively small as compared with the alternating stimuli, we should expect no induced movement because it would no longer have the character of frame of reference. The question remains, therefore, as to whether the experience of motion can be eliminated by changing the characteristic of the flashing stimulus to give *it* the property of frame of reference.

Procedure. The display of Experiment II, Part 1, was modified by making the slits 6 in. long. The luminous line, with respect to which the alternation occurred, was reduced to a tiny luminous spot (¼ in. square). The same apparatus and method of illumination was used as in the first part of Experiment II. Thus, the left and right slits were alternately illuminated from a fixed source behind the display.

Five naïve *O*s and five *O*s who were sophisticated about stroboscopic movement, but not the hypothesis under investigation, were used. They were given the instructions of Experiment II, Part 1.

Results. None of the 10 *O*s reported any motion of the vertical line. All indicated that the same line was going on and off at the same point in space. Of course, the small spot actually moving back and forth was seen to do so.

Part 3. In Part 3 an attempt was made to utilize Duncker's principles to interfere with stroboscopic movement under conditions where it might be expected to occur. It was required that the object, which now appeared in a constant position relative to another object, stimulate disparate portions of the retina. Thus, although the relative position of the stimulus-object remained constant, the corresponding retinal stimulation alternated between two points. Here, as in Experiment I, Part 2, we have represented, therefore, the classical conditions for stroboscopic motion.

Whereas in that experiment a change in retinal location was accompanied by a constant phenomenal location, in the present experiment it might be thought that the change in retinal location is accompanied by a change in phenomenal location. Insofar, however, as relative position is also a determinant of phenomenal location, and insofar as the latter does *not* change, this experiment is, in essence, putting in conflict two systems of cues to phenomenal location.

Procedure. In this part the apparatus remained the same as in Part 1 of Experiment II. The display, however, was modified in two ways. First, the left slit was covered over to block out any illumination from behind. Secondly, a second luminous strip of the same dimensions as the one used in Part 1 was mounted on the wall behind the display. This was positioned in such a manner as to correspond with the right slit at the extreme point of its left movement; and, as in Part 1, the right slit was illuminated at the extreme point of its right movement. Thus, the same slit was illuminated alternately at the two extreme points of its lateral displacement. The long center line remained continuously in view as it moved, as in Part 1. The outcome of this arrangement was that an 8-in. line moved back and forth and a 2-in. line flashed on 2⅝ in. to the right of the longer line at each of the terminal positions of the longer line. *O* was instructed to fixate a luminous point in front of the display as in Part 1 and to describe the visual scene.

Results. The *O*s of Part 1 were also used for Part 3. All *O*s found great difficulty in describing their experience. A typical report was as follows: "The small line seems to be moving and at the same time standing still." It will be recalled that in this condition, two systems of cues which normally act jointly to determine the spatial location of objects, are here opposed. That is, normally a change in retinal location with eye- and head-movement eliminated, will indicate a change in phenomenal location. On the other hand, the maintenance of a constant position relative to some external frame of reference serves to indicate a constant phenomenal location within that system. In light of this analysis the ambiguity expressed in the *O*'s reports is readily understandable.

On the whole, the results of this experiment seem to imply that to obtain the unequivocal experience of stroboscopic motion, change in phenomenal location must itself be unequivocally given. That is, when stimulus-conditions are such that phenomenal location is ambiguous, so too is the resultant stroboscopic movement experience.

Discussion

One criticism that at an earlier time might have been made against Experiment I, Part 1 (undoubtedly our most important experiment) is that the cause of the experienced motion can be attributed to the eye-movements. By now, of course, it is clearly established that eye-movement is not a necessary condition for stroboscopic movement[13] and no one has ever demonstrated that it is a sufficient condition. We believe, therefore, that we are free to use change of eye-position as a technique for bringing about change of phenomenal location. In Experiment I, Part 2, the same eye-movements do not yield any experience of motion. Also it may be noted that Experiment II, Part 1 does not entail change of eye-position as an independent variable.

There are several facts about stroboscopic movement that support our over-all conclusions.

(1) A theory of stroboscopic motion based on neural interaction could never, in itself, be a complete theory for the following reason: Logically it is possible that the interaction could explain why an experience of movement occurs but it does not adequately deal with the problem of the experienced directions in space of the starting and ending positions of that movement or, in short, its path. If location were purely a matter of the locus of the proximal stimulus (as is no doubt the case in species whose eyes do not move), then the 'path' of the neural interaction would correspond with the path of the seen movement in space. Where, however, eye-position plays a central role in the location of objects with respect to the perceiver, certain logical difficulties arise. Suppose *O* does move his eyes somewhat while viewing the flashing points. Suppose, for example, he fixates one stimulus and fixates only slightly to the side of the other. If he sees movement, as we have every reason to assume he will, it will not merely be a slight movement, as might be predicted from the slight retinal shift involved in our example. Rather he will see the movement between the two points as veridically localized in phenomenal space, each on the basis of eye-position together with retinal position. Hence, the interaction between the anatomical loci of the stimuli *per se* does not tell us anything about the path of motion. That path corresponds with the

[13] Wertheimer, *op. cit.,* 161-278; J. P. Guilford and Harry Helson, Eye-movements and the phi-phenomenon, this Journal, 41, 1929, 595-606.

phenomenal location of the terminal positions and not necessarily with the retinal (or cortical) terminal positions. From this analysis, our experiments, in which no shift in the retinal stimulus occurs at all, represent the extreme case and show in addition that no interaction is necessary for the movement experience.

A related fact is that stroboscopic motion occurs in the third dimension of space under conditions where the source is phenomenally located at different distances from *O*. This illustrates the point made above; namely, the path of the movement does not correspond in any direct way with the path one would predict based on retinal stimulation—*i.e.* the 'path' of the alleged interaction between the anatomical loci of excitation.

(2) After these experiments were completed, a paper by Verhoeff which reports on certain clinical observations bearing on the present problem came to our attention.[14] Verhoeff demonstrated that stroboscopic movement can be elicited by alternate stimulation of the two foveas of squinters with anomalous projection. In such patients the image on one fovea is generally localized separately from that on the other. Thus, here, too, we see that the movement experience occurs so long as the light-sources are localized separately in space, despite the fact that only one retinal (and cortical) region is stimulated.

(3) The effect has been obtained with interocular stimulation, where the two excitations emanate from different eyes and end in different hemispheres of the brain.[15] This condition would seem to preclude peripheral interaction and to make unlikely central neural interaction. The effect has also been obtained across acquired scotomata of cerebral or retinal origin.[16]

(4) It has long been known, as one of Korte's Laws,[17] that as the distance between sources is increased, the time-interval between exposures must also be increased if an effect of movement is to continue to occur. The question arises, however, whether distance here is to be conceived of in retinal or in phenomenal terms. Corbin showed that Korte's effect occurs when the distance is so increased along a plane inclined to *O* as to hold constant the retinal distance.[18] If stroboscopic movement does depend on stimulus-conditions which yield change of phenomenal location as we have

[14] F. H. Verhoeff, Phi phenomenon and anomalous projection, *Arch. Opthal.*, 24, 1940, 247-251.

[15] K. R. Smith, Visual apparent movement in the absence of neural interaction, this JOURNAL, 51, 1948, 73-78.

[16] H. L. Teuber and M. B. Bender, Perception of apparent movement across acquired scotomata in the visual field, *Amer. Psychologist*, 5, 1950, 271 (abstract).

[17] Adolf Korte, Kinematoskopische Untersuchugen, *Z. Psychol.*, 72, 1915, 193-206.

[18] H. H. Corbin, The perception of grouping and apparent movement in visual depth, *Arch. Psychol.*, 38, 1942, (No. 273), 1-50.

argued, then, insofar as distance enters into the process, we would expect it to be phenomenal distance, which apparently is the case.

(5) There is considerable evidence that set, experience with the effect, and extent of training influence the perception of stroboscopic motion.[19] Such facts do not seem to follow from neural interaction theories which must necessarily regard the effect as autochthonously determined.

There are both negative and positive implications of our finding. On the negative side, it seems to follow that all theories which seek to explain the experience of stroboscopic movement in terms of some neural interaction between the loci of excitation are in error. A theory of interaction is only appropriate if it is correct that a necessary condition is stimulation of anatomically separate regions, and we have shown that this is not a necessary condition. In Gestalt thinking such a theory exemplified the postulate of isomorphism—viz. if motion is seen between two points in space, then some neural correlate of motion must exist between the cortical excitations representing those points in space. Without necessarily challenging isomorphism as such, our findings do challenge the way isomorphism has been applied in perception; namely, the seeking of correlates of various aspects of phenomenal space in terms of interactions within the cortical space. In other words, facts of space-perception cannot be accounted for purely in terms of a theory tailored to the *spatial* dimensions of the visual cortex. If, for example, only a single cortical region is excited, it can nevertheless represent various points in phenomenal space, depending on eye-position. In principle, all of space could be represented by a single retinal (and cortical) point, thus showing that perceived spatiality does not necessarily correspond with cortical spatiality in any simple or direct fashion.[20] This is not to deny, of course, that perceived

[19] C. I. Hovland, Apparent movement, *Psychol. Bull.,* 32, 1935, 755-778; W. S. Neff, A critical investigation of the visual apprehension of movement, this JOURNAL, 48, 1936, 1-42; E. E. Jones and J. S. Bruner, Expectancy in apparent visual movement, *Brit. J. Psychol.,* 45, 1954, 157-165; H. E. Toch and W. H. Ittelson, The role of past experience in apparent movement: re-evaluation, *ibid.,* 47, 1956, 195-207; William Epstein and Irvin Rock, Perceptual set as an artifact of recency, this JOURNAL, 73, 1960, 214-228.

[20] We do believe that the spatial dimensions of the cortex correspond with the experienced (two dimensional) topological relations of the momentary visual field. Perhaps all original experiences of extensity, shape, relative position, and the like depend upon the spatiality of the visual cortex. Nevertheless the stable visual world involving the location of things with respect to the observer is also very much a function of eye-position, *i.e.* of where the momentary field is 'aimed.' Thus objects stimulating, say, the fovea, although always located in the center of the momentary field, are located in space with respect to the self in whatever direction the eye is turned. (Cf. J. J. Gibson, *The perception of the visual world,* 1950, 26-43.) The integration of retinal position with eye-position in determining phenomenally perceived direction may be a matter of development and learning, at least in humans.

spatiality corresponds with some cortical events which represent space. In the long run, an appropriate neural explanation for the experience of stroboscopic movement will be found—which may or may not be compatible with the doctrine of isomorphism—but it will undoubtedly be quite different from present theories. We suspect, in line with the discussion below, that such an explanation will be similar to that which will be found to explain all perceived movement.

Somewhat similar reasoning applies to the peripheral theories of interaction. Only if it were the case that phenomenal space corresponds in a direct fashion with retinal 'space,' could such theories logically be considered tenable. Whatever, therefore, may be the evidence for neural interaction in the retina, our evidence shows that it cannot be considered a necessary condition for stroboscopic movement.

On the positive side, our finding that stroboscopic movement will only be experienced when change of phenomenal location is involved dovetails nicely with certain facts about the perception of movement in general. In the case of fixating a moving object, it is also clear that it will be perceived as moving, if its displacement is above threshold, despite the fact that here, too, there is no retinal (or cortical) displacement. (Cf. the analogous Experiment I, Part 1.) Of course, the converse, sweeping the eyes past a stationary object, does not yield an impression of movement despite the displacement of the image. (Cf. the analogous Experiment I, Part 2.)[21]

In the case of induced motion, the stationary object is seen as moving and, if below threshold, the moving object as stationary. Here, again, it would seem that change of phenomenal location occurs. The induced object is seen as changing its location with respect to the inducing one which acts as a frame of reference. (Cf. the analogous Experiment II, Part 1.)

Our findings also fit in with what is now known about phenomenal velocity, which is the quantitative aspect of phenomenal movement. Brown showed that perceived speed is a function not of the absolute rate at which an object's image traverses the retina but rather of the rate at which it displaces relative to its frame of reference.[22] In other words, we may say that phenomenal velocity is a function of rate of change of phenome-

[21] In the case of real movement, Gestalt psychologists, as for example Duncker or Koffka, have been well aware of these facts, but curiously they failed to see that they might equally be true of stroboscopic movement, and that, if so, it would contradict Wertheimer's type of theory.

[22] J. F. Brown, The visual perception of velocity, *Psychol. Forsch.*, 14, 1931, 199-232.

nal location, not of retinal location. The fact of speed-constancy also supports this conclusion.[23]

It therefore seems correct to generalize that the perception of movement depends on those stimulus-conditions which can yield an experience of change of an object's phenomenal location, providing, of course, that the change is above some threshold-value.[24] There is a certain logic to this, since, in reality, if an object changes its location, it does so by moving. (The focus of interest, therefore, shifts to the problem of uncovering the precise determinants of phenomenal location and to the problem of threshold.) Ultimately, an explanation in terms of brain-process will be one tailored to deal with this central fact.

From this point of view, there is only one remaining problem about stroboscopic movement that in any way makes it a special case. That is the fact of discontinuous rather than continuous stimulation. Some authors have tried to argue that this is not a crucial distinction, since the retina consists of cell which, even if adjacent, also are discontinuous. Hence, even real movement involves discontinuous stimulation, only less so. But as shown by the results reported in this paper, the discontinuity should not be thought of in retinal terms at all but rather in spatial terms. Even a flashing on and off in the *same* retinal location will, under the proper conditions, yield an impression of movement across space. In these terms, the problem *does* remain of why movement is perceived across a rather substantial stretch of space when there is no stimulation corresponding to continuous displacement.

Once it is realized, however, that stroboscopic movement can be subsumed under the general principle of change of phenomenal location, this phenomenon is perhaps no longer so puzzling. In line with the 'logic' that perception often manifests, if the identical thing is now 'here' and now 'there,' then it can only have changed position by moving. (The notion of identity has been stressed by many investigators of stroboscopic movement and the similarity of the two exposed objects is now known to be important.) Furthermore the stimulus-conditions are quite similar to those which obtain during real movement. The terminal positions of a really moving object perhaps form the more important component of the stimulus-conditions, particularly if the object moves rapidly, since the intervening positions are often blurred out or not noticeable as such. From this point of view, one might predict the phenomenon of stroboscopic

[23] Hans Wallach, On constancy of visual speed, *Psychol. Rev.*, 46, 1939, 541-552.

[24] Below threshold, a change in position will be noted but it will not be accompanied by the quality of movement, as for example the minute hand of a watch.

movement even if it were not known, based on similarity—a kind of stimulus-generalization.[25] It, therefore, becomes at least plausible that the effect is a function of past experience with real movement.

Summary

The question was raised whether stroboscopic movement depends upon successive stimulation of separate retinal (and therefore cortical) points or of points located separately in phenomenal space. Ordinarily the latter requires the former, but it is possible to create conditions where phenomenal separateness is experienced even when only one region of the retina is stimulated. With the use of two different techniques, it was shown that under such conditions stroboscopic movement is experienced. Conversely, it is possible to stimulate separate retinal points in such a manner that the source will not be experienced in two localities but, rather, in only one. It was shown that under such conditions movement will not be experienced. These findings were taken to imply that neural interaction between two loci of excitation (on any level) cannot be a general explanation of stroboscopic movement. It was pointed out that the findings are consistent with certain facts concerning movement-perception in general; namely, that motion is experienced whenever above-threshold change in the phenomenal location of the source occurs.

[25] Cf. R. S. Woodworth and Harold Schlosberg, *Experimental Psychology,* 1954, 515.