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SOME DIFFERENCES BETWEEN REAL AND APPARENT VISUAL MOVEMENT[1]

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Abstract—When a target stimulus is flashed in the path of an objectively moving line of light, threshold for the target increases with a decrease of the distance between the two forms. A parallel experiment was performed when the line of light was in apparent movement ("beta movement"); the target was flashed in its path. It was found that the "position" of the object in apparent movement did not affect the probability of detecting the target. The experiment was also performed of presenting supra-threshold objects in the path of apparent movement. These objects were found to affect the path, so that it curved into three dimensions. Thus an asymmetrical influence was revealed between the object in apparent movement and objects in its path. The results are taken to show that, the identity of appearance of the two perceptions notwithstanding, the mechanisms underlying real and apparent movement seem to be quite different. The asymmetrical influence between objects and the path of apparent movement is interpreted as evidence for sequential processing of visual information.

Résumé—Quand un test émet un éclair lumineux sur le trajet d'une ligne de lumière qui se déplace réellement, le seuil du test augmente quand la distance entre les deux objets diminue. Une expérience parallèle a été réalisée avec une ligne de lumière en mouvement apparent ("mouvement bêta"); le test émettait un éclair sur son trajet. On a constaté que la "position" de l'objet en mouvement apparent n'affectait pas la probabilité de détecter le test. On réalisa aussi l'expérience de présenter des objets supraliminaire dans le trajet d'un mouvement apparent. On trouva que ces objets agissaient sur le trajet qui se courbait à trois dimensions. On a ainsi révélé une influence asymétrique entre l'objet en mouvement apparent et les objets sur son trajet. Ces résultats montrait que, malgré l'identité d'apparence des deux perceptions, les mécanismes en cause pour les mouvements réels et apparents semblent tout à fait différents. L'influence asymétrique entre des objets et le trajet d'un mouvement apparent est interprété comme prouvant d'un processus séquentiel pour l'information visuelle.

Zusammenfassung—Wenn ein scheibenförmiger Reiz auf dem Wege einer sich objektiv bewegenden leuchtenden Linie als Blitz dargeboten wird, so steigt die Schwelle für dieses Scheibchen, wenn der Abstand zwischen den beiden Formen abnimmt. Ein paralleles Experiment wurde angestellt, in dem sich die leuchtende Linie in erkennbarer Bewegung befand ("Beta-Bewegung"); das Scheibchen wurde als Blitz auf ihrem Wege dargeboten. Das Experiment wurde auch angestellt mit überschwelligen Objekten auf dem Wege erkennbarer Bewegung. Es zeigte sich, dass diese Objekte die Bahn in der Weise beeinflussten, dass sie sich in drei Dimensionen krümmte. Auf diese Weise zeigte sich ein unsymmetrischer Einfluss zwischen dem Objekt mit erkennbarer Bewegung und seiner Bahn. Die Ergebnisse werden herangezogen um zu zeigen, dass, während die Identität des Auftretens der beiden Eindrücke keinen Widerspruch erwarten lässt, die Mechanismen, die der wahren und scheinbaren Bewegung zugrunde liegen, völlig verschieden zu sein scheinen. Der asymmetrische Einfluss zwischen den Objekten und der Bahn scheinbarer Bewegung wird für den zeitlichen Ablauf der visuellen Informationsaufnahme als beweiskräftig betrachtet.

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WHEN two neighboring visual stimulus objects are alternated in place at an appropriate rate, the observer sees a single object in movement between them. This apparent movement is a compelling illusion: several investigators have reported that, given equivalent rates of apparent displacement, the observer is usually unable to distinguish apparent from real movement (WERTHEIMER, 1912; DIMMICK and SCAHILL, 1925; DESILVA, 1929; KENNEDY, 1936; GIBSON, 1954). The phenomenon, however, has not been studied much by investigators interested in quantitative relations between stimuli and response, but mostly in qualitative terms, particularly by the Gestalt psychologists. It is the cornerstone of the Gestalt theory of brain fields (WERTHEIMER, 1912; KOFFKA, 1931), but in fact there is no satisfactory theory that accounts for it. We may note that the phenomenon was of great interest to the sensory physiologists of an earlier day: HELMHOLTZ (1924) developed an apparatus to generate apparent movement, and EXNER (1875), his student, used the phenomenon to argue that movement was a "sensation" in its own right, since he was able to demonstrate with it that an image moving across the retina was not a condition necessary for a perception of movement. KOFFKA (1931), BORING (1942) and GRAHAM (1951) have summarized much of the vast, mostly qualitative, literature that has accumulated on this subject.

Many of the writers who have discussed the phenomenon seem to imply, or state outright, that since the perceptions of real and apparent movement are indistinguishable one from the other, the underlying mechanisms must similarly be identical (WERTHEIMER, 1912; DIMMICK and SCAHILL, 1925; DESILVA, 1929; KOFFKA, 1931; KENNEDY, 1936; GIBSON, 1954). In its literal, and trivial, sense this hypothesis can be rejected out of hand since, the stimulus conditions producing real and apparent movement being different, the mechanisms must be also. But, read generously, what these writers seem to be implying is that the perception of movement is determined only by the points of onset and offset of stimulation and the temporal relations between them. When these are of a certain kind, it does not matter, the argument seems to go, whether the "information" is provided by moving or merely by stationary but alternated stimuli. In this argument, stimulation by a physically moving image of the retinal regions *between* the termini is regarded as irrelevant for a perception of movement. GIBSON has pushed the argument farthest, asserting at one time that it was "unfortunate" (1954, p. 310) that a distinction was made between the two kinds of perception of movement. In view of the recent discovery that movement is "coded" at post-retinal regions of the visual nervous system (LETTVIN *et al.*, 1959; HUBEL and WIESEL, 1962), some support can be produced in behalf of these arguments. However, the extent of the similarity in processing of the two perceptions seems never to have been tested directly; nor has it been shown that stimulation of the inter-space between the termini is in fact irrelevant for a perception of movement. In this paper, we are concerned with the first of these, the question of similarity in processing of the two perceptions, the test to be made by comparing the effects of an object seen to be moving upon the detection of a target in its path. The basis of the test is the masking effect.

Recent studies of visual masking show that when two stationary, concentric, temporally separated flashes of light are presented to the eye, threshold of the target flash varies with the luminance of the masking flash and with the temporal and spatial separation between them (KOLERS, 1962 a; RAAB, 1963). The higher the luminance of the masking flash and the closer in time and space the two flashes occur, the higher the threshold of the target. This masking influence occurs irrespective of the order of presentation of the two flashes, although the quantitative relations are different for the two orders.

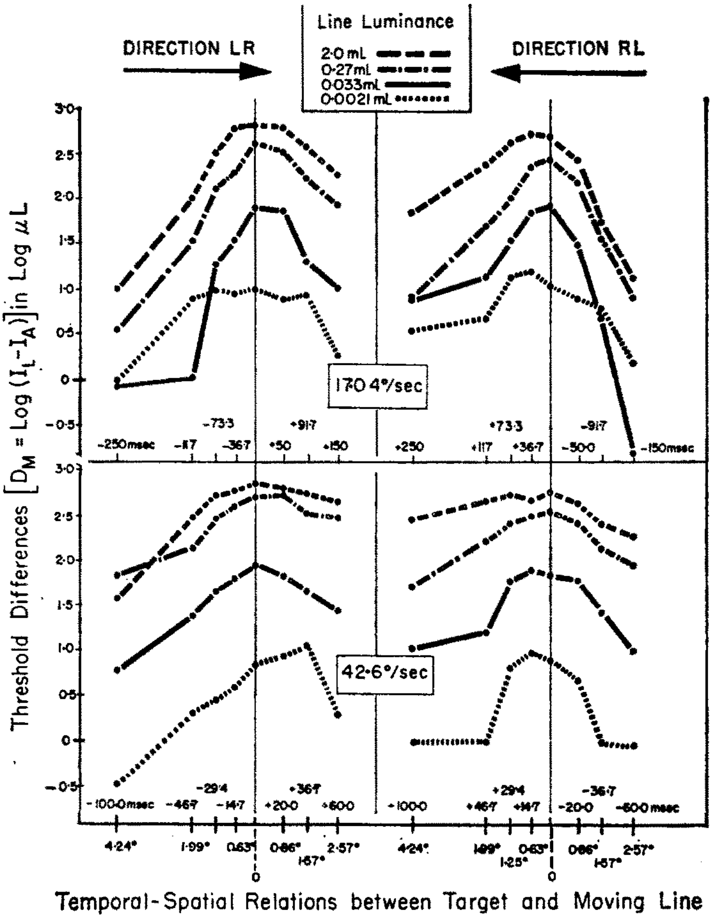

FIG. 1. Inhibitory influence of a line in real movement. A line moved in the direction and at the speeds and luminances shown in the legends. Once during each sweep of the line a fixed target was presented briefly. The target is represented by abscissa value 0, and the position reached by the moving line when the target was presented is shown by the other values on the abscissas. The difference in luminance threshold of the target when it was presented alone and when the moving line was also presented is shown on the ordinates. Maximum inhibition of the target occurs in the region of overlap of target and moving line. (From LURIA and KOLERS (1962).)

Several predictions can be made on the basis of these results for the case of a *moving* masking stimulus. Other things remaining equal, threshold for a brief fixed target should increase inversely with the spatio-temporal separations between the target and the moving stimulus, and directly with the luminance of the latter. If the target is a small luminous line flashed in the path of a larger, moving line, threshold of the target may be expected to be higher the brighter the moving line and the closer it is to the target. A preliminary report of results confirming these expectations has been presented (LURIA and KOLERS, 1962); a detailed account is still in preparation. For the sake of comparison with what is to follow, Fig. 1 has been taken from the preliminary report. It shows the difference between two measures of threshold luminance of a target positioned at abscissa value 0, one measure made when the target was presented, briefly, alone, and the second when the target was presented during a sweep of a physically moving line, the line having reached one of the other positions marked on the abscissa. Data are shown for four luminances of the moving line, two speeds, and two directions of movement. They show that the farther the moving line is from the target, temporally and spatially, when the target is presented, the less the effect the moving line has upon threshold of the target; and the brighter the moving line, the greater its influence.

In the data reported below, a similar test is made, but for the case of a line in *apparent* movement. The test examines the effect of the "position" of a line in apparent movement upon the detection of a target in its path.

In describing these experiments, the following conventions will be used. "Real movement" refers to a perception of movement arising from a continuous physical displacement of a stimulus object. "Apparent movement" or "beta movement" (BORING, 1942; GRAHAM, 1951) refers to a perception of movement arising from the rapid alternation in place of two neighboring stimulus objects. "Optimal movement" (WERTHEIMER, 1912; KOFFKA, 1931; BORING, 1942) describes the appearance that a single object moves smoothly and continuously between the alternated forms.[2]

METHOD

Apparatus

A six-channel electronic device controlled the duration and intensity of mercury–argon gas-discharge lamps which illuminated the stimulus forms from either the front or the rear. The forms were placed in chambers of a multifield Dodge-type viewing apparatus. The circuitry, viewing apparatus and methods for controlling the lamps have been described in detail elsewhere (KOLERS, 1962 b). In brief, the apparatus can illuminate four different stimulus objects in sequence, each for its own predetermined duration and intensity. As many as two of the four can be re-illuminated in a single cycle of six presentations. Once begun, the device cycles automatically. A switch which disconnects a lamp permits timed intervals of darkness to be presented as readily as intervals of light. In addition, an ancillary circuit operates a warning bell 2 sec before the onset of a cycle.

Spectrophotometric measurements of the light output of a typical gas-discharge lamp were made prior to performing the experiments. Since such lamps have "lines" rather than "color temperature", the spectral composition of the light remained substantially unchanged through a tenfold change in current through the lamps (25–250 mA). In the experiment itself the lamps were operated well within that range (50–90 mA). The halide phosphor in the lamps produced a "snow white" or "blue white" light. Amplitude and waveform of the current through the lamp for the target stimulus were monitored by means of an oscilloscope placed across a 10-ohm resistor in series with the lamp. No variations were noted during the course of the experiments.

Materials

The stimulus materials for the experiments in Group I were transilluminated photographic negatives. That is, the negatives were between the light source and the observer's eye. The stimuli, therefore, appeared as lines of light on a dark background. The upper part

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[2] Although the distinction is not always preserved, "phi movement" is different from "optimal movement". In the latter, an object is seen to be traversing the space between the termini whose alternation produces the illusion. In phi movement, no object is seen; only a sense of movement is derived from the rapid alternation of the two termini. Phi movement thus may be compared with the blurred impression of real movement derived from a rapidly moved target (VAN DEN BRINK, 1957).

of Fig. 2 illustrates the appearance of one stimulus array used in the first group of experiments. The lines A and B were 0·9° long, the target stimulus or probe, P, 0·45°, and all were approximately 0·05° wide. The lines appeared in a visual field 4° wide by 5·5° high, of 0·002 ft-L luminance. The intensity of A and B was 3 ft-L each, while P was set for each subject at such a level that p(P), the probability of his seeing it in the absence of A and B, was 0·90+. This value was found for each S in separate viewing sessions before the main experiments and was checked regularly during their course. The brightness of the target stimulus making $p(\mathrm{P}) = 0{\cdot}90+$ ranged between 0·09 and 0·3 ft-L for the three Ss. In the second group of experiments, directly illuminated, high contrast photographs were presented to the light-adapted eye. The visual field was approximately the same size as for Group I, but of 4 ft-L brightness.

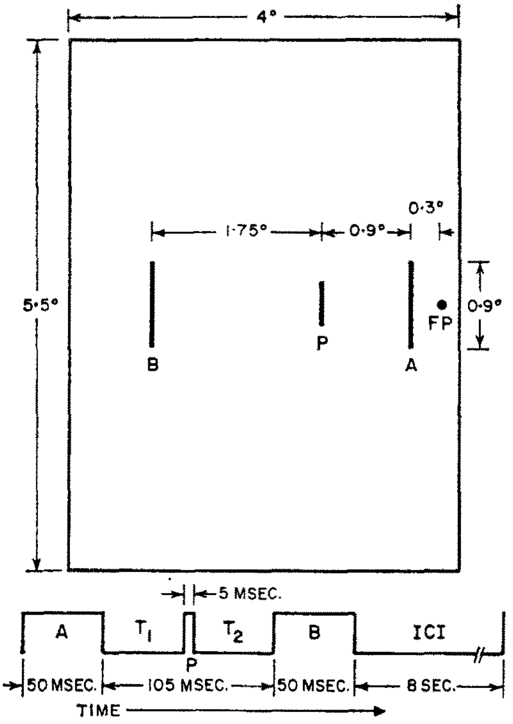

FIG. 2. The arrangement of the stimulus forms. A, B and P were lines of light presented on a dark field. The time diagram shows one sequence of presentations.

Subjects

The principal subjects were two Naval enlisted men aged nineteen and the writer. Other observers were called in from time to time.

Procedure. The essential requirement of the procedure was to specify the "position" of the line in apparent movement. This was accomplished by fractionating the temporal interval between the offset of A and the onset of B, and presenting the target, P, at a known time during it. In a typical experiment of Group I, the two lines A and B were presented alternately each for 50 msec, with fixed pauses between them. One fixed pause was the inter-stimulus interval (ISI), between the offset of A and the onset of B; this was usually 105 msec. The other fixed pause, the inter-cycle interval (ICI), between the offset of B and the recurrence of A, was 8 sec. The probe, or target, P, was presented for 5 msec at some varied time during the first pause (ISI). One such arrangement is shown in the lower part of Fig. 2. In that figure T_1 is the interval between the offset of A and the onset of P, and T_2 is the interval between P and B. During the experiment, T_1 and T_2 were varied together while their sum was kept constant. For example, when T_1 was 5 msec, T_2 was 95 msec; when T_1 was 25 msec, T_2 was 75 msec, and so on. By keeping the duration $(T_1+\mathrm{P}+T_2)$ constant, P was presented when the line had appeared to have moved through various portions of the distance between A and B. All three *S*s reported seeing a single line move smoothly and continuously between A and B (i.e. reported seeing "optimal movement") for the conditions used.

The data for the first group of experiments were collected with a modified quantal method described previously (KOLERS and ROSNER, 1960). In this method, *S* makes a large number of observations to a fixed set of stimulus conditions, and the relative frequency of detections of the target is computed for each condition. In the modification of the quantal method used, *S* made his report to eight identical presentations; conditions were then changed without *S*'s knowledge and another eight presentations made, and so on. This procedure was followed until eight presentations were made at each of five pairs of T_1–T_2 values. Then a 1 min rest was given. This procedure was repeated four times in a single viewing session at each T_1–T_2 pair. *S*s reported detecting the probe by sounding a buzzer twice, and reported a failure to detect by sounding it once.

Of the eight presentations of each T_1–T_2 pair, the reports to the first two were discarded in order to lessen the effect of *S*'s response bias. A third presentation was made with the probe absent, in order to find the false alarm rate—the frequency of reporting the probe when it was in fact not present. This rate was always found to be less than 10 per cent with practiced *S*s, a rate small enough to warrant eliminating all the data based on blank trials. The remaining five observations of each T_1–T_2 pair are the data of interest. The curves below are based on the frequency of detecting P in 60–120 observations per plotted point, found in several viewing sessions in groups of five observations at each pair of T_1–T_2 values. These relative frequencies are plotted as p(P).

The experiments on real movement, the data for which are shown in Fig. 1, were collected using the method of limits. That method was used also in preliminary studies on apparent movement, but was found to be less sensitive than the modified quantal method. Note, however, that in Fig. 1 the ordinate plots luminous energy, so that higher values on the ordinate mean that detectability is poorer. For the data based on the quantal method (Figs. 3–7) *probabilities* are plotted, so that lower ordinate values are associated with poorer detectability.

All of the experiments of Group I were performed with transilluminated stimuli presented to *S*'s dark-adapted eye. In the experiments of Group II, illuminated forms were presented to the light-adapted eye. For the first procedure, *S* was dark-adapted for 15 min. Presentations were then made approximately once every 8·2 sec (i.e. ICI=8 sec), with the stimulus figures 75 cm from the eye. When the presentations were to the light-adapted eye (Group II), *S* was first dark-adapted for 3 min and then light-adapted for 1 min. Viewing distance was then 100 cm. In both cases *S* looked with his right eye only, through an artificial pupil 3 mm in diameter. A small ($<2'$ visual angle) red light provided a fixation point.

RESULTS

I. *Apparent movement of a line of light*

1. *Probe in the path of the moving line.*[3] The stimulus configuration for this experiment is shown in the inset of Fig. 3, the horizontal arrow indicating the direction of apparent movement of the alternated forms. The probability of seeing the probe, *p*(P), in this sequence is plotted on the ordinate of the figure, and T_1, the time between the offset of A and the onset of P, is plotted on the abscissa. The curves show the means for each of three *S*s based on 80 or 100 observations/plotted point. For all three *S*s a generalized inhibitory effect occurs in that *p*(P) is always less than 0·90, its minimum value in the absence of A and B. However, within that effect, for two of the *S*s *p*(P) increases slightly with an increase in T_1, then decreases; for the third, *p*(P) decreases only. For all *S*s the probability of detecting the probe seems to vary with the "position" of the apparently moving line, although the variation is not large.

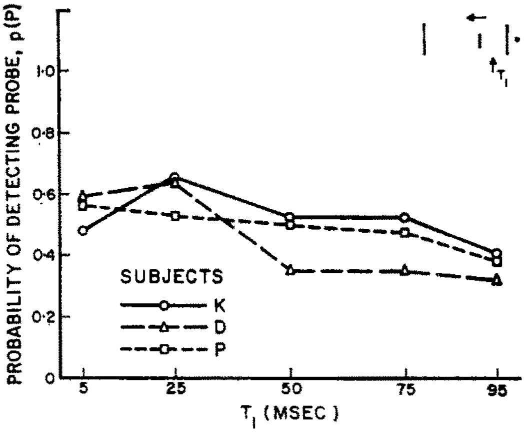

FIG. 3. The abscissa shows the time between the offset of A and the onset of P; the ordinate plots probability of detecting the probe presented at a fixed duration and intensity. Probability of detecting the probe in the absence of the apparently moving line is 0·90+ for all *S*s. The horizontal arrow in the inset shows the sequence of presentations, and thus the direction of apparent movement; the vertical arrow points to the temporal interval manipulated as T_1.

2. *Probe and line A only.* In this and the next experiment, *p*(P) was found when A and B were each presented without the other. First, *p*(P) was found at various times after the offset of A, with B absent. These probabilities are plotted on the ordinate in Fig. 4, with T_1, the time between A and P, on the abscissa. Each point in the curves is a mean based on 80, 100 and 120 observations for *S*s, P, K, and D, respectively. These means again describe a generalized inhibition (*p*(P) is almost always <0·90), but without much trend. Although not shown in the figure, this stimulus sequence yielded more variable data than any other. The basis for the individual differences is not known.

3. *Probe and line B only.* The results of the reverse experiment, finding *p*(P) at various times before the onset of B when A was absent, are shown in Fig. 5. In this experiment A was a timed interval of darkness. The values of *p*(P) are based on 60, 80 or 120 observations/point (K, P, D); the abscissa again shows the time after the "offset" of A. The means of Fig. 5 show the generalized inhibition, but in addition reveal trends similar to those in Fig. 3.

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[3] These results were previously reported in *Nature, Lond.*, **197**, 271–272, 1963.

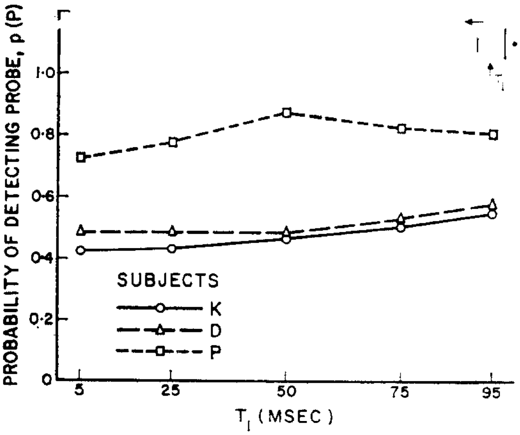

FIG. 4. Effect of origin of apparent movement on the detectability of the test probe. Co-ordinates are the same as in Fig. 3. B was a timed interval of darkness.

In Experiments 2 and 3 there was no apparent movement between A and B, as either the origin (A) or terminus (B) of movement was not shown. Occasionally, *S*s reported movement between P and A or B. More such reports occurred in Experiment 2 than in Experiment 3, so that these perceived movements may be the basis of the large amount of variability in Experiment 2.

4. *Reversal of sequence.* The sequence of stimulation was reversed with one subject, K, so that the line appeared to move from B to A. In Fig. 6 the abscissa shows the time, T_I, between the offset of the first line (now B) and the onset of P. Three curves are shown, for three experiments identical, except for direction of apparent movement, with those described in Figs. 3–5.

The relation between *p*(P) and T_I is shown in Fig. 6: (1) when an apparent movement appeared between the termini (circles, 80 observations/point); (2) when only the first line, B, and the probe appeared (triangles, 60 observations/point); and (3) when only the second line, A, and the probe appeared (squares, 60 observations/point). The data of Fig. 6 appear

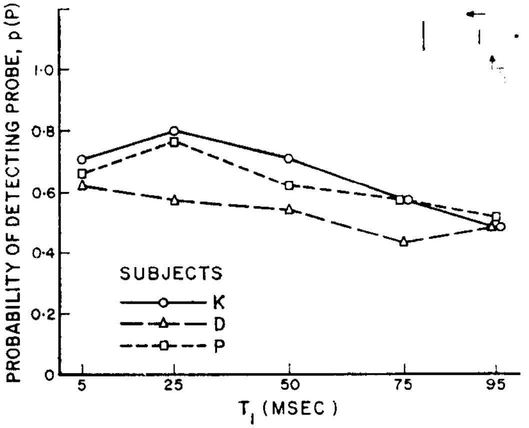

FIG. 5. Effect of terminus of apparent movement on detectability of the test probe. Co-ordinates are the same as in Fig. 3. A was a timed interval of darkness.

clearly to be related to those for subject K in Figs. 3–5. Thus, the effect shown in the earlier figures seems not to depend much on whether the apparent movement is toward the fovea or away from it, any more than it does with real movement (Fig. 1).

5. *Extension of ISI.* In another experiment the interval T_1 between A and P was fixed at 25 msec, and interval T_2 between P and B was varied from 50 to 150 msec in steps of 25 msec. The total ISI (T_1+P+T_2) now ranged from 80 to 180 msec. As in the first experiments reported above, A preceded B, so that apparent movement was towards the periphery. Figure 7 a shows the results of 80 observations/point for each of two *S*s, with p(P) on the ordinate and T_2, the interval between P and B, on the abscissa. Within the generalized inhibition, p(P) is greater in the region $T_2 = 100$ msec than at intervals longer or shorter than that. The data thus show two different masking effects bracketing the point of maximum detectability, while that point itself is less than 0·90, the value of p(P) in the absence of A and B.

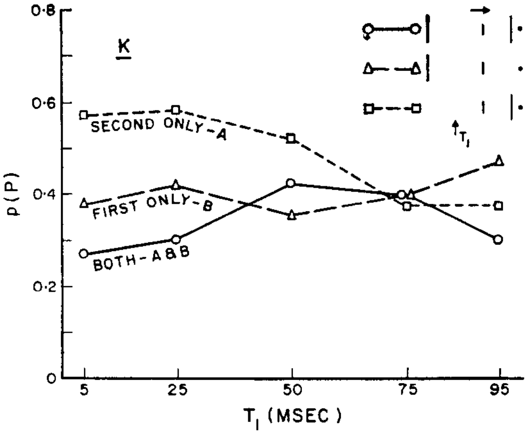

FIG. 6. Probability of detecting the probe when the direction of movement was reversed. The three curves describe the condition when an apparent movement appeared (Both—B and A); when only the origin and test probe appeared (first only—B); and when only the terminus and test probe appeared (second only—A). The vertical arrow shows the interval plotted as T_1.

The results of the converse experiment are shown in Fig. 7 b. For that experiment interval T_2, between P and B, was fixed at 25 msec while interval T_1, between A and P, was varied. Apparent movement was again from A to B. Fig. 7 b indicates that within the envelope of general inhibition p(P) tends to increase, but only slightly, with an increase in the temporal separation between A and the probe.

The results described in Fig. 7 reveal that p(P) is almost independent of the time between the probe and the stimulus that precedes it, but varies markedly with the time between the probe and the stimulus that follows it. These results tend to confirm those in Figs. 4 and 5, which also demonstrate that a stronger inhibitory effect is exerted upon the probe by the line following it temporally than by the line preceding it. Unrelated to this, but also of note, is the fact that *S*s reported that the velocity of the apparently moving form varied with changes in the total duration of ISI.

The data of Experiments 2–5 indicate that the influence of the line upon the probe shown in Fig. 3 is due principally to the effects of the alternated termini of apparent movement upon the probe, but not to any interaction between the object seen in movement and the probe:

that is to say, the effects of the physical stimuli—A, B and the probe—interact in the visual system so that the presence of each modifies the perception of the other; but no interaction appears to occur between the *real* form, P, and the *apparent* form, the line seen in transverse movement.

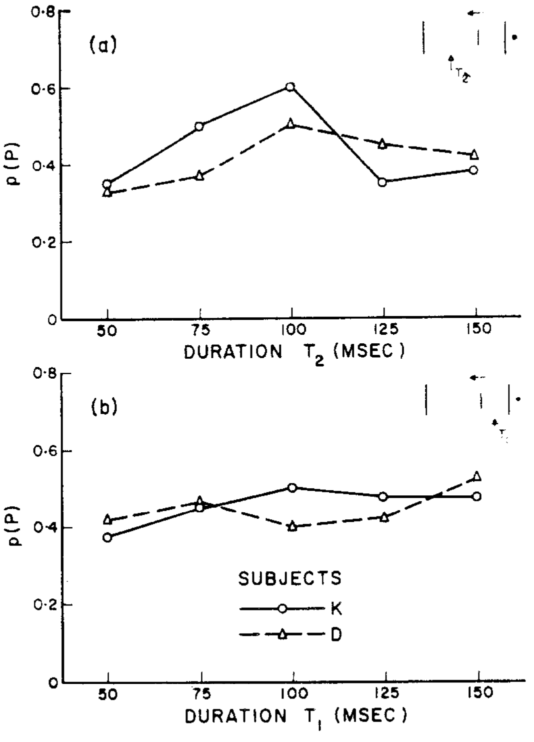

FIG. 7. Probability of detecting the probe at different inter-stimulus intervals. The insets show the direction of apparent movement (horizontal arrows) and the intervals represented on the abscissas (vertical arrows).

(a) Interval between the offset of A and the onset of the probe was fixed at 25 msec. Interval between the offset of the probe and the onset of B is given on the abscissa.

(b) Converse experiment. Interval between the offset of the probe and the onset of B was fixed at 25 msec and interval between the offset of A and the onset of the probe is given on the abscissa.

II. *Apparent movement of a black disk*

The detectability of a brief, normally supra-threshold form is lessened when the form is followed by a neighboring one (PIÉRON, 1934; ALPERN, 1958; KOLERS and ROSNER, 1960). In the extreme case, the normally supra-threshold target is made invisible by a subsequent stimulus exerting a "retroactive" masking effect. Thus, when a black disk is followed at a proper interval by a concentric black ring, only the ring may be seen. Utilizing this masking effect, the question can be asked whether the illusion of movement depends upon *perceiving* the stimulus object, particularly at the origin of movement. In answer it will be shown that it does not: the physical (not the perceived) presence of a form is sufficient for a perception of movement.

6. *Disk–disk sequence.* This sequence was used to establish conditions yielding "optimal movement". Two black disks, D_1 and D_2, each of 0·5° angular subtense, were arranged as in Fig. 8, but without the ring shown there. Each disk was presented for 30 msec, and optimal movement was reported when the intervals between them were each 100 msec. Observations were monocular and with a light-adapted eye. Under these conditions the ICI or re-cycling interval was very short, so that a continuous apparent oscillation of a single disk was perceived.

FIG. 8. Black disks alternated to produce apparent movement. A separation subtending 10′ visual angle was made between the border of D_1 and the inner border of R; the wall of R subtended 15′ visual angle. The distance from FP to the right edge of D is 2·95° (ref. Fig. 2).

7. *Disk–ring–disk sequence.* This procedure differed from the preceding only in that a ring, R, was presented for 50 msec during the ISI, immediately after the offset of D_1. The ring was so placed that it appeared concentric with D_1, though presented after it. The remaining duration of the ISI, T_1, was taken up by a blank field. The sequence thus made was D_1–R–T_1–D_2–ICI, a sequence in which D_1 was invisible. (The experiment was made also with R following T_1 without essential change in the results.) The *S* was instructed to report the occurrence of optimal movement of the disk as T_1 and ICI were increased in 10 msec steps. ICI, to begin with, was 50 msec. Table 1 outlines the results of five trials for each condition with one *S*. It shows, for each of the stimulus sequences given in the rows of the table, the ISI–ICI values at which optimal movement was first reported. Tests 3 and 4 in the table are the critical ones; they indicate, first, that with $R=50$ msec, T_1 had to be increased until the duration of $(R+T_1)$ or (T_1+R) equalled the previously found ISI of 100 msec for optimal movement. Since D_1 was made invisible by R in these tests, the results show that apparent movement depends upon the occurrence of a stimulus, not upon its being perceived.[4]

Secondly, the time between the offset of A and the onset of B has a unit quality. Rows 3 and 4 of Table 1 show that presenting another form during part of the ISI does not affect the total value of ISI required for optimal movement. Thus, presenting D_1 appears to start some timing mechanism in the visual system which is relatively insensitive to the occurrence of other stimulation within its "period", a process very different from that characterizing the formation time of simple figures (MCCONNELL, 1927; STROUD, 1956; BOYNTON, 1961; KOLERS, 1962 a). One may thus note the dependence of apparent movement upon transients in the visual nervous system since we have found in many experiments that no apparent movement is reported when one stimulus is continuous and the other is flickered. Both must be flickered for apparent movement to be seen.

Thirdly, it is worth noting that a temporal disparity, wherein ISI is different from ICI, is resolved as a three-dimensional display. This seems to reflect a bias in the visual system, for

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[4] Since D_1 was invisible, its path of movement was reported to be from near the outside border of R to D_2 and back. If another ring were presented, to mask D_2, making the sequence D_1–R_1–D_2–R_2, with pauses added as needed, two distinct movement impressions might well occur, one of partly visible disks and the other of fully visible rings. Our apparatus could not readily be adapted to create this display.

the disparity could as readily be resolved as changes in rate, the form seen to be moving slower in one direction than in the other. Why a perception of depth is preferred to that of a change in rate is not clear.

TABLE 1. MINIMUM VALUE OF ISI REQUIRED FOR A REPORT OF OPTIMUM MOVEMENT IN VARIOUS SEQUENCES OF STIMULATION. (THE NUMBERS IN THE BODY OF THE TABLE REFER TO TIME IN MSEC. EACH ROW IS A SEPARATE SEQUENCE)

Test	A	ISI	B	ICI
1	$D_1 = 30$	100	$D_2 = 30$	100
2	$R = 30$	100	$D_2 = 30$	100
3	$D_1 = 30$	$R = 50$ $T_1 = 50$	$D_2 = 30$	100*
4	$D_1 = 30$	$T_1 = 50$ $R = 50$	$D_2 = 30$	100*

* If R is not presented, so that ISI = 50 and ICI = 100 msec, the temporal disparity is resolved as a three-dimensional display: the path of movement appears to be curved in depth during the ICI phase.

From the results of the preceding seven experiments, one might infer that apparent movement is perceived as the direct result of a given order and timing of stimulation; and, further, that it is coded at some level of the visual system at which no interaction occurs between nervous events reporting movement and those reporting other elements in the visual field. WERTHEIMER (1912), for example, in Section 16 of his great paper, reports that a segment of a line placed to be perpendicular to the arc made by another, apparently moving, line, did not summate with the latter to make it appear even momentarily longer. However, this inference of no interaction would be wrong, for complex interactions do occur, some of which are briefly described below.

8. *Other sequences.* Experiment 7 demonstrates also that a form placed in the inter-space, in this case the ring around the disk, does not prevent the occurrence of movement across that space. This apparent absence of an interaction between the object seen in movement and the space traversed by it was investigated more fully using two disks as the stimulus forms. The disks were presented for 30 msec each, and a variety of other forms were presented in the inter-space, singly, each for 50 msec. A blank field was presented for the remainder of the ISI. The forms used were solid and outline rectangles, grids, spikes, and the like. The maximum width of these forms was always less than the width of the inter-space. Under these conditions, apparent movement of a disk was always reported. The most common form of this movement, however, was an elliptical path or orbit in depth around the forms in the inter-space. A few subjects reported that the black disk in orbit appeared to be paler than when the forms were not present in the inter-space.

FIG. 9. A supra-threshold form presented between D_1 and D_2. The figure is drawn to the same scale as Fig. 8.

Finally, since the observer's attitude and past experience are known to affect the perception of apparent movement (WERTHEIMER, 1912; NEUHAUS, 1930; TOCH and ITTELSON, 1956; SCHURECK, 1960), various efforts were made to see a sinuous movement between the spikes shown in Fig. 9. The *S*s reported that they could not; only an elliptical path was ever seen.

DISCUSSION

Figure 2 shows that P, the probe, was positioned about one-third of the distance between A and B. If the line in apparent movement in Fig. 3 had constant velocity across the interspace, it would have been closest to P at the measured value $T_1=25$ msec. This would correspond to a separation from overlap no greater than 10 msec in time or 15′ visual angle of space. Overlap is shown for real movement in Fig. 1 as abscissa values of 0; and for two lines, one of which moved faster, the other slower than the calculated rate of the line in apparent movement. (The calculated rate is for a spatial separation of 2·65° between A and B, and a temporal one of 105 msec, or 25°/sec.) Inspection of Fig. 1 shows that at such spatio-temporal separations, a line in real movement exerts a very powerful inhibitory effect upon the detectability of the probe in its path. Therefore, if the effect of a line in apparent movement were similar to that of a line in real movement, the curves of Fig. 3 would all be U-shaped: the probe would be maximally detectable at the onset and offset of stimulation, and would be at a minimum in the region $T_1=25$ msec. Clearly the curves are not U-shaped. Clearly, then, the line in apparent movement has different effects from a line in real movement.

However, some inhibition in the detection of P does occur. This is of two kinds. First, *p*(P) is always less than 0·90, its "absolute threshold", when either A or B is also presented (Figs. 3–7). Secondly, there is a tendency for *p*(P) to be less at longer durations of T_1 (Fig. 3). No reason is readily apparent to account with certainty for the first of these, the overall decline in the probability of seeing P. The decline may be due to changes in sensitivity attributable to contrast with the line seen as moving, or equally to a change in adaptation induced by the physical presence of A and B. Further experiments are required to identify the basis of this effect. On the other hand, the change in the shape of the detection function of P found with changes in T_1 is easily explained as due to the "retroactive" masking effect one visual contour exerts upon another, neighboring, one (ALPERN, 1953; KOLERS and ROSNER, 1960). Presumably, the physical stimulus B exerts such a retroactive inhibitory effect upon P; while, consistent with the earlier findings just cited, very little "proactive" effect of A on P is found (Fig. 4). In no case is there any evidence, however, that the line in apparent movement itself exerts any influence upon the detection of the target in its path. Rather, the effects that are found seem to be attributable to the alternation of the physical stimuli, A and B, but not to the illusory line seen in apparent movement between A and B.

Although the "position" of the line in apparent movement does not markedly affect the detectability of objects in its path, an effect in the opposite direction occurs. When suprathreshold objects are placed in the path of movement, the path curves into depth (Group II). Thus there is an asymmetry of effects: an object in apparent movement does not affect objects in its path, but the latter affect the path of movement. One difference distinguishes the stimulus conditions that produce real and apparent movement: no image moves across the retina in the latter case. An image moving across the retina thus seems to be a necessary condition for inhibition of the brightness threshold of objects in the path of movement. It would seem to follow, then, that brightness thresholds are coded principally at the retina, while depth and movement are coded beyond the retina. And since it has also been reported that curvature and three-dimensionality of the path of an object in apparent movement occurs when only strong after-effects of stimulation are present in the path (DETHERAGE and BITTERMAN, 1952; SHAPIRO, 1954), the question arises whether induced spatial displacement of contours is processed earlier or later than movement and depth.

The theories available to account for beta movement are unsatisfactory. The best-known is the Wertheimer–Köhler hypothesis that two neighboring regions of nervous excitation building up within the proper spatio-temporal bounds discharge into each other, and that this "short-circuit" is the correlate of the object seen as moving (WERTHEIMER, 1912; KOFFKA, 1931). This hypothesis assumes that perceptual experience (i.e. the "picture in the head") is unitary, and that in processing information the visual cortex acts as a homogeneous medium. Two facts, however, constitute objections to the hypothesis of a short circuit in a homogeneous visual cortex. The first is that beta movement "completes" across acquired scotomata, which is inconsistent with it (TEUBER *et al.*, 1960). A second objection is to the assumption that stimulation results in some sort of spatial spread of excitation. Experiment shows to the contrary that the principal influence a briefly stimulated region exerts upon its neighbors is inhibitory, not excitatory (FRY, 1934; ALPERN, 1953; RATLIFF and HARTLINE, 1959; KOLERS, 1962 a). Thus, two neighboring visual regions stimulated alternately would inhibit each other both "retroactively" and "proactively" in the temporal intervals studied. Since beta movement is perceived at ISIs equal to or greater than those at which such a spatial spread is stopped by inhibitory masking effects, it cannot be due to such a spread. Rather, the mechanism of apparent movement seems to be principally a temporal one, with only a limited spatial component to it. As Experiments 6 and 7 and Table 1 showed, stimulation by neighboring forms did not influence the occurrence of apparent movement determined by other stimuli. That is to say, the presence of other forms in interspace did not prevent *S* from seeing movement across that space, nor did those forms change the values of ISI required for the perception of movement. Such a temporal mechanism would seem to be sensitive to a "bucking" of on and off processes that would result from the rapid on and off alternation of neighboring stimuli (RATLIFF, 1961).

Therefore, if two visual experiences appear alike, but are produced by different stimulus conditions, we may speak of "a final common percept", but one produced by different "paths" in the nervous system. The fact that identical perceptions have different processes, according to which stimulus conditions produced them, argues that different interactions in the nervous system occur at different places. The question arises whether these different interactions—between contours, brightnesses, depths, and others—occur simultaneously or serially in the visual system. This may be answered by finding other perceptions whose component "parts" can be identified, for both the present results and recent electrophysiological evidence (LETTVIN *et al.*, 1959; HUBEL and WIESEL, 1962) imply that there is an order or sequence to the neural processing of a percept. Rather than in a "weighted average of influences" from nervous system, body tonus, experience and the like (ALLPORT, 1955), a percept may be processed in isolatable parts.

Another way to state the case is that stimulation from physically co-planar objects is not necessarily processed in co-planar regions of the nervous system. Therefore, the "unity" of a perceptual experience may itself be illusory; it may be but an end-product, organized from a series of separable operations, rather than an isomorphic representation of the physical field based on strict retino-topical projection.

SUMMARY

The perceptions of real and apparent movement are usually reported to be indistinguishable, suggesting to some writers that the underlying mechanisms for the two perceptions are identical. To test this hypothesis the question was asked whether an object seen in apparent movement affects the detection threshold for objects in its path, a known property of real movement.

1. The "position" of a line in apparent movement did not affect the threshold for a target line in its path. The variations in the latter that were found were attributable to masking effects produced by the alternated termini of movement upon the target, but not to an influence of the object in apparent movement upon the real test line.
2. Physical occurrence of the stimulus was found to be sufficient for a report of apparent movement; a form masked to the point of invisibility at the origin of movement was still reported to be seen in movement.
3. The pause needed between two stimuli of constant duration for a perception of movement to be reported was not affected by interposing other forms between them, spatially or temporally. The entire temporal sequence had a unit quality to it, apparently initiated by the onset of the first form.
4. While an object in apparent movement did not affect the detectability of objects in its path, supra-threshold objects affected the path, so that it curved in depth. This depth effect was in turn found to be insensitive to experimentally induced attitudes and wishes: sinuous movement of a form between spikes in its path could not be seen as a willed alternative to depth.

The results are taken to mean that different aspects of a percept are processed in different parts of the visual nervous system. Rather than representing a mélange of "influences", a percept may be thought to result from a series of separately encoded events. One task of the psychology of perception may be taken to be the plotting of the "flow chart" that describes the timing and loci of these processes.

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