Experiments on the locus of induced motion

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Two experiments examined the locus of induced motion effects. The first used a subjective technique to test for the presence of retinal slippage due to systematic eye movements when an observer fixates a test spot in the center of a horizontally moving rectangle. The second experiment tested for "local" retinal effects by presenting test and inducing figures dichoptically. There was no evidence of retinal slippage under conditions where induced motion was not discriminable from real motion. Moreover, good induction was produced across eyes. Implications for the locus of induced motion effects are discussed.

A typical experimental paradigm for demonstrating the phenomenon of induced motion uses a rectangle moving slowly back and forth horizontally with a stationary spot in its center. Subjects in the dark, instructed to fixate the spot, report seeing it move back and forth within a stationary rectangle. One important implication of this effect is that perceived motion cannot always be explained in terms of local retinal displacements.

It is possible, however, that despite subjects' reports of maintained fixation, they may in fact track the motion of the surround, thus producing a retinal displacement of the spot in the opposite direction. This possibility has, of course, been recognized before. Duncker (1929) argued that the fact that induced motion occurs with stroboscopic presentation contradicts an eye-movement explanation. Wallach (1959) argued that the phenomenon of separation of systems—in which two separate frames produce simultaneous, but independent, induction effects—rules out a simple eye-movement explanation. Shaffer and Wallach (1966) found induction effects with stimulus presentations too brief to allow significant pursuit movements.

A more direct approach was adopted in the paper by Brosgole, Cristal, and Carpenter (1968). They measured eye position by monitoring discrete changes in the corneo-retinal potential. When a rectangular frame moved horizontally by 10.3° , an average of only $.09^\circ$ of eye movement was recorded. Unfortunately, it is difficult to determine how compellingly motion was induced in this experiment, since the index of target motion¹ revealed a perceived horizontal excursion of only 2.6° , as contrasted to the 10.3° of actual frame displacement. In other reports based on the same general apparatus and similar procedures, but without monitoring eye

movements, Brosgole (1967, 1968) reported consistently larger induction effects—on the order of 7° .

The issue of compellingness in induced motion deserves some attention, since parameters of velocity, displacement, and size have neither been standardized nor investigated systematically. For example, Gogel and Koslow (1971) report an experiment using a frame velocity of approximately $1.5^\circ/\text{sec}$, whereas Brosgole et al. (1968) used a velocity of $.33^\circ/\text{sec}$. Such differences make it difficult to ascertain if the conditions created in any given experiment are optimal to motion induction.

This is particularly relevant to the question of whether induced motion and real motion are perceptually distinguishable. Gogel and Koslow (1971) report, on the basis of differential verbal estimates of displacements in these two conditions, that actual and induced motion are indeed distinguishable.

As previously stated, the displacement velocity in the Gogel and Koslow experiment was $1.5^\circ/\text{sec}$. In our own pilot work, this velocity was found to be too rapid for effective induction. It is therefore possible that induced motion and real motion are not perceptually distinguishable when more effective conditions for induction are used.

Our first experiment is therefore motivated by two related issues. First, because of the lack of evidence for powerful induction in the Brosgole, Cristal, and Carpenter (1968) experiment, our study monitors eye movements under conditions that allow us to test for the discriminability of induced motion from real motion. Powerful evidence against an eye-movement explanation of induced motion would be afforded by a demonstration that no systematic eye movements occur under conditions where induced motion is *not* distinguished from real motion. Second, this would also suggest that the results reported by Gogel

and Koslow (1971), where the two types of motions were found to be distinguishable, may have been caused by the choice of parameters less than optimal for motion induction.

Our experiment used a simple subjective index of the presence of eye movements. The method is taken from Stoper (1973) and makes use of a pattern that falls on the blind spot when a target is foveally fixated.

EXPERIMENT 1

Method

Apparatus. A PDP-8/e computer was programmed to produce displays on an oscilloscope screen with phosphate type P4. The oscilloscope was viewed in the dark from a distance of 20 cm. A red filter was placed in front of the subject's eye to eliminate all glare from the face of the oscilloscope.

Procedure. The display for both experimental and control conditions involved a rectangle ($8^\circ \times 4^\circ$) and a central spot at the center of the visual field. A circular pattern, about 4° in diameter, was placed 14.5° to the left of the central spot and 3° below it (see Figure 1).

When the left eye fixated the central spot, the circular pattern was projected onto the blind spot. The exact position, shape, and size of this pattern was adjusted for each subject at the beginning of the experimental session to fall symmetrically on the blind spot. This was accomplished by the following procedure.

The rectangle and spot were replaced by a cross, centered where the spot had been, with hatch marks on the vertical and horizontal limbs. The subject was asked to fixate marks to left and right of center, and to report how much of the blind spot pattern he saw. The pattern was then displaced so that it was barely seen at equal displacement of the eye to the left and right. This procedure also revealed that parts of the blind spot pattern were seen when subjects fixated about 3.5 mm on either side of the center of the cross. Thus, the resolution of our apparatus was approximately 1° of visual angle on either side of the fixation target.

The program controlling the display was designed to generate two types of motion. In the experimental condition, the rectangle moved back and forth while the spot remained stationary. In the control condition, the rectangle was stationary while the spot moved with exactly the same parameters of distance and velocity, 5.6° of horizontal excursion at a rate of $.22^\circ/\text{sec}$.

Figure 1. The blind-spot pattern is shown to the left of the rectangle and central spot. The display was viewed monocularly with the left eye.

Subjects were presented both conditions in a within-subject design. A cycle always started with the spot in the center of the rectangle. During the experimental condition, the rectangle moved to the left, then all the way to the right and back to the center. The induced motion of the center spot would then be right, left, right. During a control cycle, the spot started to move to the right as soon as the rectangle reached the center position.

Subjects were instructed to fixate the center spot as carefully as possible, to report any perceived motion of the rectangle or spot, and to signal whenever they saw any part of the blind spot pattern. The response measures were collected from two switch boxes. In his right hand, the subject held a box containing four pushbutton switches arranged in a square pattern. The top pair served to report leftward or rightward motion of the rectangle, and the bottom pair served to report similar motions of the spot. In his left hand, the subject held a single switch which he held down when any part of the blind spot pattern was perceived. The output of the switches was recorded on a chart mover in an adjacent room.

Subjects. Seven volunteer subjects participated in this experiment.

Results and Discussion

Subjects reported the spot to be moving 92% of the time when the rectangle was moving, and 97% of the time it was in fact moving.

Scores on the report of the blind spot pattern were calculated for each subject by summing the length of time the pattern was reported over the five experimental and five control phases, respectively. The maximum possible mean duration that the blind spot pattern could be reported was 250 sec. The mean duration of "blind spot" reported in the experimental condition ($\bar{X} = 21.8$ sec) was significantly smaller than in the control condition where the spot actually moved ($\bar{X} = 107.1$ sec, $t = 3.59$, $df = 6$, $p < .01$, one-tailed). This indicates that the blind spot pattern was seen more often when the observer pursued the horizontally moving target spot than when he attempted to fixate a stationary target spot.

Two sources of error are likely to have attenuated this difference in means. First, some drift is expected when the eye fixates a stationary target, so that subjects' perception of the blind-spot pattern may have been due to eye movements that were not systematically related to induced motion. Second, the task of reporting the blind spot pattern while holding fixation and noticing the direction of motion of the spot or rectangle was quite demanding. It is likely that the division of attention required by the task led to some oversight in the report of the blind-spot pattern even when it did not fall on the blind spot.

The results therefore support those reported by Broscole et al. (1968) and suggest that retinal slippage due to eye movements is not responsible for the induced-motion phenomenon. This is particularly clear in view of an additional observation from our experiment. It has previously been stated that the shift from one condition to the other in the experiment was effected immediately; that is, if the induced motion of the spot was towards the right, the spot would actually move to the right as

soon as the rectangle reached the midpoint of its trajectory. This transition from induced to real motion and vice versa was never reported on the response measure. Moreover, when subjects were asked at the end of the experiment if they had noticed anything at the midpoint of the trajectories, none remembered noticing any shift. The experimenters themselves could not detect any discontinuity at transition points. It thus seems that real and induced motion are not distinguishable phenomenologically, although the behavior of the eye is clearly different in the two cases.

While retinal displacement of the target spot may not take place during motion induction, the phenomenon may still be due to a retinal mechanism. For example, local contrast effects could cause the motion of a large figure in the periphery of the retina to create an apparent opposite motion in a smaller foveated one. Such an effect may be related to Dichgans and Brandt's (1974) finding that motion in the periphery of the visual field is particularly effective in inducing an impression of self-motion. If any such local mechanism is responsible for induction, it should not be possible for a figure seen by one eye to induce motion in a figure seen by the other eye.

To test whether induction occurs across eyes, we first prepared a simple polarized display in which a spot was presented to the left eye, and the moving frame was presented to the right eye. In this condition, the moving rectangle did appear stationary, and the spot appeared to move, but the motion of the spot was quite unlike the smooth displacement which was seen with our previous, monocular display. The spot sometimes appeared stationary and sometimes moved in large jerky steps.

This occurred because the right eye followed the rectangle, while the left eye remained fixed on the spot. When some limit on difference in fixation direction was reached, the eyes suddenly moved to reestablish vergence. This was confirmed by allowing some light from the spot to reach the right eye. In this case, the observers reported seeing two spots moving away from each other.

To avoid this difficulty, it was necessary to present fixation targets to both eyes. This led to the following display. The left eye was presented with a large circle and a fixation point. The right eye viewed a smaller rectangle and another fixation point. Both fixation points remained stationary, but the circle moved vertically and the rectangle horizontally. This situation is a dichoptic version of a display originally described by Wallach (1959).

EXPERIMENT 2

Method

Procedure. A computer-generated display consisted of a left

and a right field which were viewed dichoptically with a haploscope. A rectangle ($11^\circ \times 5.5^\circ$) and a central spot appeared in the left field, while a large circle (27° in diameter) and a central spot appeared in the right field. The rectangle always moved horizontally and the circle vertically, $.9^\circ/\text{sec}$ in each case, while the spots in each field remained stationary.

The phase relations of the rectangle and circle were varied so that when the rectangle moved to the right, the circle could move either up or down. In one case, this would be expected to produce perceived motion of the rectangle along a diagonal of negative slope; in the other case, the rectangle should move along a diagonal with positive slope.

The program was prepared to generate five trials of each of these two types of motion, interspersed in a random order. Each trial began with all figures stationary for 2 sec, and during that time, the central spots were in the exact center of their respective figures. The rectangle then proceeded to move to the left, and the circle moved either up or down. When the right side of the rectangle approached its central spot, the two figures reversed directions and traveled to the other extreme of their trajectory (8.4° from one extreme to the other). Finally, the figures traveled back to their starting points.

A simple haploscope was built to view the display. It consisted of two lenses (150 mm focal length) separated in the middle by a black plate that extended to the oscilloscope screen. Red filters were again used to eliminate glare from the oscilloscope phosphor.

When looking through the haploscope, the two central spots could easily be made to fuse by adjusting their horizontal separation. Subjects then saw a spot at the center of a rectangle which was, in turn, surrounded by a circle (see Figure 2).

Figure 2. The binocular display is shown on top. When viewed with a haploscope, the center spots fused to yield the bottom percept.

A booklet was prepared for the collection of responses. It consisted of 10 identical pages, each depicting the spot, rectangle, and circle resting in their symmetrical position. The subjects were asked to draw arrows in the direction they perceived each figure to be moving. To the right of the figures were three rating scales on which subjects indicated the clarity of the impression of motion. A final question asked whether the central spot ever separated into two spots during the trial.

By recording if subjects were successful in keeping the two dots fused, it is possible to infer if eye movements occurred during a trial. Since a horizontal frame motion is present in the left eye and a vertical one in the right eye, it follows that if each eye tries to track its respective frame, fusion would immediately be lost.

Subjects. Eight subjects participated in this experiment. Two additional subjects were unable to take part in the study because they could not maintain fusion, even with a stationary display.

Results and Discussion

The main measure of motion induction consisted of the diagonal slopes of the arrows drawn by subjects to represent the rectangle's motion. The slopes were coded as either positive or negative and were compared with the phase relationship of the rectangle and circle during a particular trial.

Since eight subjects viewed 10 trials each, a total of 80 trials was available for analysis. Of these, 4 were eliminated because fusion of the central spots was lost during the trial. The subjects reported the perceived direction of the rectangle motion in agreement with the objective resultant motions of the circle and rectangle in 74 of the 76 trials. This represents an agreement rate of 97%, where 50% would be expected by chance. It thus appears that motion was effectively induced in the rectangle. This is further supported by the fact that the circle was perceived as completely stationary in 67 of the 76 trials.

Although not directly relevant to the issue of induction across eyes, the results concerning the perceived direction of motion of the central spot are interesting. The spot was reported to move vertically in 52 cases, in more than one direction in 13 cases (e.g., diagonal and horizontal), and horizontally, diagonally, or as being stationary in about 4 cases. It is surprising that the spot was seen to move predominantly in the vertical dimension, since Wallach (1959) reports its perceived motion to be predominantly horizontal. On the basis of some preliminary testing with normal viewing, we believe that the difference in our results is not due to the dichoptic setup of our experiment, but to differences in size and velocity. In any event, the issue should be investigated further because of its relevance to the concept of separation of systems.

In the ratings of "clarity" of the perceived motion, the rectangle's motion was rated clearest ($\bar{X} = 8.3$ on a 9-point scale). There was no significant difference, however, in comparison to the ratings for the circle and spot ($\bar{X} = 7.5$, and 6.3, respectively, $F = 2.57$, $df = 2.14$, $p > .1$).

A final note on maintenance of fusion as an index of lack of eye movements is in order. It can be argued that subjects in our experiment moved their eyes vertically with the circle. This could produce the observed results because of a resultant diagonal translation on the retina for the rectangle and a vertical one for the spot. However, in view of the failure to coordinate both eyes when the spot alone was present in the left eye and the moving rectangle in the right eye, we think that this possibility is unlikely.

CONCLUSION

The experiments presented here rule out certain of the possible explanations of induced motion. The first experiment adds to the evidence against an eye-movement explanation. Moreover, the experiment demonstrates that under good conditions for induction, the induced motion of a target spot is not distinguishable from its real motion. The second experiment shows that, whatever the basis of the phenomenon, it is not due to a local retinal mechanism.

The problem of determining the locus of motion induction remains. Although a strictly retinal contrast mechanism is unlikely in view of dichoptic induction effects, some form of motion contrast is still possible, if it operates at a level receiving input from both eyes.

A second possibility is that the visual system processes the slow drift of the frame as information for rotation of the observer's eye. In such a case, the same mechanisms that are involved in producing an impression of motion when a moving object is pursued could be responsible for the induced perception of motion when the eye is, in fact, stationary (Stoper, 1973). Such a mechanism may be related to Broscole's (1968) suggestion that the motion of the frame causes a displacement of the perceiver's egocentric reference system.

In order to decide among these and other possibilities, careful examination of the stimulus conditions that produce induced motion is required.

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NOTE

1. A canceling procedure was used in which the observer adjusted the position of the target spot so as to keep it stationary. The resultant displacement of the spot was then taken as an index of motion induction.

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