The effect of perceived distance on induced movement*

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The magnitude of induced movement was measured as a function of the perceived depth between the test object and the plane of the induction object, with this perceived depth produced by stereoscopic cues. Three experiments were conducted. In each experiment, the induction object (a frame of constant physical size) was positioned at one of three distances with the test object (a point of light) placed successively at each of the three distances. Predictions of the magnitude of induction as a function of the depth separation of the test and induction object were made from the subject-relative and object-relative hypotheses of induced motion. It was expected, however, that neither of these hypotheses would predict the results independently of a factor described in the adjacency principle. This principle states that the effectiveness of whatever cues or processes determine the induced movement will decrease with increased depth between the test and induction object. The data indicate that the adjacency principle must be considered in explaining the results. The subject-relative rather than object-relative hypothesis as modified by the adjacency principle was most successful in predicting the results. Control conditions in which the frame was stationary and the point of light was physically moving were also used. Despite the fact that the relative displacement of the objects on the eye in the experimental and control conditions were the same, the results indicate that O could distinguish between these two kinds of conditions. Although the apparent movement was greater in the control conditions than in the experimental conditions, the reverse is true if the total perceived movement of the test and induction object are considered together.

If a small stationary object and a frame are presented under reduced conditions of observation, a right and left movement of the frame in a frontoparallel plane will result in an apparent left and right movement of the small object. This is an instance of induced movement (Duncker, 1939). Two types of physical motion are involved in induced movement. One type, called object-relative displacement, is the relative displacement between the two objects. The other type, called subject-relative (or angular) displacement, is the directional movement of an object (the frame) with respect to the O (Wallach, 1959, 1965; Wallach & Schaffer, 1966). The consequences of these two types of movement are not the same in that the movements have different perceptual thresholds (Wallach & Schaffer, 1966). Wallach has suggested that induced movement is a result of a misperception associated with object-relative displacements. Although the relative movement is correctly perceived, the motion is attributed to the wrong object. According to this explanation, the problem of induced movement is to determine the rules by which the perceived movement is apportioned among the several objects. This

hypothesis will be called the object-relative hypothesis.

A different explanation, to be called the subject-relative hypothesis, ascribes induced motion to a misperception of perceived direction. For example, it has been asserted (Broscole, 1966; Broscole, Cristal, & Carpenter, 1968) that the perceived straight-ahead tends to be at the center of the frame despite the displacement of the frame (Roelofs, 1935). As a result of this tendency, the small object apparently displaced to the right or left of the perceived straight-ahead seems to move back and forth. The problem of induced movement from this point of view is to determine the stimulus conditions controlling the apparent displacement of egocentric direction. More generally, the distinction between the object-relative and subject-relative hypothesis for the purposes of this study concerns the presence or absence of an egocentric perception. If the occurrence of an egocentric perception is necessary in order to explain the induced motion, the data will be considered to support the subject-relative rather than the object-relative hypothesis.

In studies of induced motion, it has been customary for the small stationary object (the test object) and the moving frame (the induction object) to be located at the same physical (and perceived) distance. A situation in which the different

implications of the object- and subject-relative hypotheses can be examined is one in which the test object is displaced in depth from the plane of the induction object, with O instructed to report the magnitude of the apparent linear movement of the test object. Under these conditions, it would be expected from the subject-relative hypothesis that the reported movement would increase when the test object was more distant than the induction object and would decrease when the test object was less distant than the induction object. This expectation results because a linear extent subtending a constant apparent visual angle (an induced displacement of perceived direction) should increase with the perceived distance of this extent from O. The prediction from the object-relative hypothesis for this case might seem less clear. But, if any reference to an egocentric perception is to be avoided, the object-relative displacement must not be defined in terms of apparent direction or apparent visual angle, since each of these terms requires the specification of apparent egocentric position. It follows that the extent of induced movement from the object-relative hypothesis should be independent of changes in apparent distance between the induction and test object. The predictions from these two hypotheses are illustrated in Fig. 1. In Fig. 1, the predicted linear extent of the induced motion is given by the length of the solid line, and the position of the moving frame is indicated by the arrow. The dashed lines are construction lines to permit the reader to compare readily the magnitudes of predicted movement at the different

Fig. 1. Predicted magnitude of induced movement from the object-relative and subject-relative hypothesis for a near (N), middle (M), and far (F) distance position of a stationary point of light with the moving frame at the middle position.

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positions of the test object. Figure 1 illustrates the case in which the induction object (the frame) is at the middle distance (M) with the test object at a near (N), middle (M), or far (F) distance. Although in Fig. 1 the frame is shown as located at the middle position, the same predictions from the subject-relative and object-relative hypotheses would be made for a displacement in apparent depth of the test object from the frame for any position of the frame. For any constant position of the frame, the subject-relative hypothesis would predict that increasing the distance of the test object from O would result in increasing the magnitude of the induced movement. On the other hand, under these conditions the object-relative hypothesis would predict that the magnitude of induced movement would be unaffected by the apparent displacement of the test object from the induction object.

There is reason, however, to expect that, as a result of a principle of visual organization termed the adjacency principle, neither of the above set of predictions would be obtained. The adjacency principle states that the strength or effectiveness of cues between objects is inversely related to the separation of the objects (Gogel, 1965). It follows that, whatever the process or cues responsible for the induced motion, the effectiveness of this process would be expected to decrease with the increased separation in depth of the test and induction object. An application of the adjacency principle that provides a parallel to the case of induced motion occurs in brightness perception. It has been demonstrated (Gogel & Mershon, 1969; Mershon & Gogel, 1970) that increasing the apparent depth separation between the test and induction surface results in a decrease in the whiteness contrast between these two objects. With increasing depth separation from the induction surface, the perceived whiteness of the test object approaches the perceived whiteness that would be expected if the induction object were absent. Similarly, for the case of induced movement, according to the adjacency principle, as the depth separation between the test and induction object is increased the perceived linear movement of the test object should approach the perceived movement expected in the absence of the induction object. That is, increasing the depth displacement of the test object from the induction object should result in O's perceiving the test object as more stationary (less moving) or as having a movement uncorrelated with the movement of the induction

object (autokinesis). It will be noted that the adjacency principle makes no statement concerning the causes of the induced movement. Instead, it asserts that whatever the cues or factors involved, the relative effectiveness of these factors will decrease with increasing separation of the test and induction objects.

A stationary test object and a moving frame can produce the same object-relative movement as a moving test object and a stationary frame. If these two kinds of situations are distinguishable perceptually, this discrimination must result from the ability to respond to subject-relative movement. The difference in the perception of movement occurring in these two kinds of situations would indicate that subject-relative motion contributes to perceived movement when both subject-relative and object-relative motion are simultaneously present. To test this possibility in the present study, a control was used in which the test object was physically moved with the frame stationary. The movement in this control condition was such as to duplicate the object-relative movement in the induced movement (experimental) condition. To the extent that O can discriminate between subject-relative and object-relative movement, the results from these two conditions should differ.

METHOD

Apparatus

A device capable of moving either a point of light or a luminous frame right or left at any one of three distance positions was constructed using motors and a chain drive. In all cases, the movement was perpendicular to the line-of-sight of O, with instantaneous reversal at the right and left extents of the movement. The near, middle, and far distance positions were 39.3, 61.3, and 87.3 in., respectively, from O. The total physical extent of the movement of either the point of light or the frame at the near, middle, and far distances was 6.5, 10.2, and 14.4 in., respectively. The total angular extent of movement was 9 deg 27 min at each of the three distances, with an angular speed (from O's position) of 1 deg 27 min per second at all three distances. This angular speed was found from preliminary observations with the moving frame to produce clear amounts of induced movement and also to traverse the full extent of movement with sufficient rapidity to insure reliable judgments of the magnitude of the induced movement. A frame of constant physical dimensions (1½ ft wide x 2 ft high,

with a 1½-in. border) was used at all three distances and was painted with white luminous paint. The point of light was constructed from a grain of wheat light bulb located behind a diffusing surface, with a pin hole aperture located on the diffusing surface. The point of light was adjusted to be the same apparent brightness at each of the three distances. Both the point of light and the vertical center of the frame were always at the level of O's eyes. In the experimental situations, the frame moved symmetrically to the right and left of the direction to the physically stationary point of light. In the control situations, the frame was stationary and the point of light moved symmetrically to the right and left of the center of the frame with a magnitude and rate of movement identical to that of the frame in the experimental situations.

Nothing was visible during the study except the frame and the point of light, with the remainder of the room totally dark. The observation position, containing an adjustable chinrest and a 25.4 x 96.6 mm binocular aperture (with a 50% neutral density filter and a shutter), was also totally dark when the stimuli were being observed. Throughout the experiment, both the frame and the point of light were viewed binocularly.

Observers

Seventy-two university students were paid to participate in the study. All had a visual acuity (corrected if necessary) of at least 20/20 in both eyes and a stereoacuity of at least 36.12 sec of arc, as measured by a Keystone orthoscope. All Os were naive as to the purpose of the experiment.

Procedure

The study consisted essentially of three experiments. The experiments were run in successive blocks of three Os, with each O in a block used in a different experiment. In a particular experiment, the frame was at a constant distance from O (near, middle, or far position), and the point of light was successively placed at each of the three distances. Thus, each experiment included one condition in which the point of light was at the distance of the frame and two conditions in which the point of light was displaced in depth from the frame. The three experiments differed only in the position of the frame. In one experiment, the frame was in the physically near position; in another experiment, it was in the middle position, and in the third experiment, in the far position. Twenty-four Os participated in each experiment, with

Table 1
Results from the Experimental Conditions in Inches

	Position of Point of Light			Position of Point of Light			Position of Point of Light			Position of Point of Light		
	Near	Middle	Far	Near	Middle	Far	Near	Middle	Far	Near	Middle	Far
	Perceived Movement of Light			Perceived Movement of Frame			Perceived Distance of Light			Perceived Distance of Frame		
	Experiment 1: Near Frame Position											
Mean	7.8	32.2	157.4	9.8	8.4	8.2	44.5	203.7	665.5	40.2	30.3	26.5
Median	6.0	5.5	6.0	7.0	6.0	6.0	33.0	48.0	60.0	20.0	24.0	24.0
SD	6.4	118.5	717.8	9.4	6.6	6.3	35.0	709.1	2864.3	33.6	22.7	17.7
	Experiment 2: Middle Frame Position											
Mean	6.3	12.4	8.3	11.1	11.2	10.7	1232.8	955.8	515.8	61.7	54.3	43.2
Median	5.5	8.5	7.0	11.0	9.0	8.5	36.0	48.0	60.0	60.0	48.0	36.0
SD	5.5	12.2	5.7	7.8	11.0	7.4	5748.2	4304.7	2144.8	31.4	27.2	21.6
	Experiment 3: Far Frame Position											
Mean	6.3	10.2	17.4	22.1	22.1	23.2	34.0	57.6	81.8	88.0	90.3	81.8
Median	4.5	6.5	8.5	16.0	13.0	12.0	36.0	48.0	72.0	81.0	72.0	72.0
SD	8.3	11.9	25.5	20.3	23.6	34.9	10.2	31.8	44.3	45.6	55.6	45.1

each O viewing the three distance positions of the point of light in counterbalanced order. Each of the three experiments contained both experimental and control situations. In the experimental situations, the point of light was physically stationary with the frame moving. In the control situations, the frame was physically stationary with the point of light moving. For half the Os in each experiment, the three experimental conditions (one for each distance of the point of light) were presented first, followed by the three control conditions. For the remaining Os, the order of conditions was reversed.

The Os were instructed to fixate the point of light throughout the study. For each condition, after fixating the point of light for 30 sec, O was asked to indicate verbally in feet or inches, or in some combination of feet and inches, (1) the apparent left-right movement of the point of light, (2) the apparent left-right movement of the frame, (3) the apparent distance of the point of light from his eyes, and (4) the apparent distance of the frame from his eyes. Following this, the shutter was closed and the point of light was moved to a different distance. Tasks 1 and 2 were counterbalanced in their order of

presentation and were followed by the counterbalanced presentation of Tasks 3 and 4. At the end of the experiment, O was asked to report the perceived width of the frame.

Results

The mean and median results (omitting the perceived width of the frame) from the experimental and control situations are shown in Tables 1 and 2. The median reports of the width of the frame, determined from all 72 Os, are 24.0 and 25.5 in. from the experimental and control situations, respectively. The central results of the study are illustrated in Fig. 2 in diagrams similar to those of Fig. 1. In Fig. 2, the length of the vertical lines labeled N, M, F represent the median reports of the magnitude S' of the perceived linear movement of the point of light (induced movement) at the physically near (N), middle (M), and far (F) positions of the point of light. Medians, rather than means, are used in Fig. 2, since two Os, for some of the tasks, gave unusually large responses. The axis labeled D' represents the median reports of the distance of the point of light from O. The frame was at its physically near, middle, and far position for Experiments 1, 2, and 3, respectively.

Each of the pair of the experimental and control diagrams labeled Experiment 1, Experiment 2, and Experiment 3 in Fig. 2 represents the results from a different group of 24 Os.

Since the distributions of scores sometimes were skewed, the S' data of Fig. 2 were analyzed, using the Friedman two-way analysis of variance by ranks, taking ties into consideration (Siegel, 1956). For the experimental conditions illustrated in Fig. 2, the differences between the induced motion S' for the three distance positions of the disk were not significant when the frame was located at the near position ($X^2_1 = 1.60$, $p > .05$) but were significant when the frame was located at the middle ($X^2_1 = 9.25$, $p < .01$) and the far ($X^2_1 = 10.33$, $p < .01$) distance positions. In all three control conditions, the differences in the perceived movement of the point of light for the three distance positions of the point of light were significant at the .01 level, with $X^2_1 = 13.58$, 28.00, and 35.89 for the physically near, far, and middle positions of the frame, respectively.

One interest of this study was to determine if the perceived movement of the point of light differed in the

Table 2
Results from the Control Conditions in Inches

	Position of Point of Light			Position of Point of Light			Position of Point of Light			Position of Point of Light		
	Near	Middle	Far	Near	Middle	Far	Near	Middle	Far	Near	Middle	Far
	Perceived Movement of Light			Perceived Movement of Frame			Perceived Distance of Light			Perceived Distance of Frame		
Experiment 1: Near Frame Position												
Mean	9.4	12.3	165.0	0.2	0.1	5.1	40.9	57.5	405.3	40.7	34.8	44.3
Median	7.5	9.0	10.0	0.0	0.0	0.0	36.0	51.0	60.0	30.0	24.0	27.0
SD	5.2	7.5	716.4	1.2	0.4	24.0	34.2	37.3	1435.3	36.4	33.3	54.2
Experiment 2: Middle Frame Position												
Mean	8.7	12.8	16.2	0.8	0.6	1.8	1230.7	799.2	644.2	60.2	54.0	41.6
Median	8.0	11.5	12.0	0.0	0.0	0.0	33.0	48.0	60.0	57.0	48.0	36.0
SD	4.7	6.6	11.2	1.8	2.4	5.0	5748.6	3586.7	2864.4	24.3	23.8	19.1
Experiment 3: Far Frame Position												
Mean	9.9	16.9	24.5	2.4	3.4	3.2	33.0	55.8	82.7	93.0	92.2	87.5
Median	7.5	12.0	18.0	0.0	0.0	0.0	36.0	48.0	72.0	72.0	72.0	69.0
SD	6.5	13.0	24.2	4.0	6.3	6.6	11.5	24.7	45.3	46.5	54.6	54.9

Fig. 2. Median magnitudes of induced movement, S' , and perceived distance, D' , of the point of light for the three distance positions of the light (N, M, F) in the control and experimental conditions.

experimental and control conditions. For this analysis, a logarithmic transformation of the perceived movement of the point of light was used, with 1 in. added to all the scores in order to avoid score values of zero. Two separate analyses were completed, using the analysis of variance. One analysis was concerned with the question of whether or not the position of the light (for a particular position of the frame) produced different results in the experimental as contrasted with the control conditions. As might be expected from Fig. 2, for each position of the frame, the perceived movement of the point of light was significantly greater in the control than in the experimental conditions ($F = 21.4, 25.7, 67.5, df = 1/46$, for the near, middle, and far positions of the frame, respectively). But it was found

that only in the case of the far position of the frame were the changes in the induced movement resulting from changes in the displacement of the point of light from the frame significantly different (at the .05 level) between the experimental and control conditions ($F = 1.01, 2.80, \text{ and } 8.13, df = 2/46$, for the near, middle, and far positions of the frame, respectively). The second analysis was concerned with the question of whether or not the effect of the frame position on the perceived movement of the point of light differed in the experimental and control conditions as a function of the distance position from O of the point of light. It was found that changes in the perceived movement of the light differed significantly between the experimental and control conditions (at the .05 level) as a function of changes in the frame position when

the light was at the middle and far positions but not at the near position ($F = 1.73, 3.89, 10.78, df = 2/69$, for the near, middle, and far positions of the point of light, respectively). It is clear that the perceived movement of the point of light was often different in the experimental and control conditions. The control conditions resulted in larger reported movement of the light, and changes in the position of the frame had a different effect upon changes in the perceived movement of the light for the experimental than for the control conditions. Differences in the perceived velocity of movement for similar control and experimental conditions have been reported by Cohen (1964).

DISCUSSION

In Fig. 2, for each of the experiments, an increase in the perceived distance (D') of the point of light resulted in an increase in the perceived extent of movement (S') of the point of light for the control conditions but not necessarily for the experimental conditions. In the control conditions, the physical movement of the point of light at the different distances subtended a constant visual angle (θ). It follows that the perceived movement of the point of light in the control conditions tended to satisfy the size-distance invariance hypothesis, i.e., for a constant θ , each increase in D' resulted in an increase in S' . The failure of the experimental conditions in Experiments 1 and 2 to show a monotonic relation between S' and D' indicates that a constant induced angle (constant subjective displacement in direction) did not occur under these conditions. By itself, the subject-relative hypothesis does not satisfy the data from the experimental conditions except in the case of Experiment 3. Also, the object-relative hypothesis does not satisfy the data from the experimental conditions except in the case of Experiment 1. In Experiments 2 and 3, in opposition to the object-relative hypothesis, the magnitude of induced movement, S' , for a constant position of the frame was not independent of the distance position of the point of light.

The results from the experimental situations, as shown in Fig. 2, are consistent with the joint application of the subject-relative hypothesis and the adjacency principle. With the frame in the near experimental position (Experiment 1), positioning of the point of light increasingly behind the frame should result in a decreased magnitude of linear induced movement from the adjacency

principle and an increased magnitude of induced movement from the subject-relative hypothesis. The constancy of the obtained value of induced movement in the experimental conditions of Experiment 1 is consistent with the effects of these two factors being in opposite directions. With the frame in the middle experimental position (Experiment 2), positioning the light in front of the frame should result in a decreased induced movement from both the adjacency principle and the subject-relative hypothesis. On the other hand, positioning the point of light behind the frame should place these two effects in opposition, with the result that the induced movement should be greater at F than at N. This was the result obtained. With the frame at the far experimental position (Experiment 3), positioning of the point of light increasingly in front of the frame should result in an increasing reduction in induced movement as a consequence of the joint operation of both factors. This also was the obtained result, although it might have been expected that the decrease in S' should have been more rapid as a function of displacement from the frame than was obtained. It can be concluded in general that the joint operation of the adjacency principle and the subject-relative hypothesis provides a good description of the results obtained in the experimental conditions. On the other hand, the combination of the adjacency principle and the object-relative hypothesis does not seem to provide as adequate a description of the results from Experiments 1 and 2. Thus, the data are best fitted by a modified form of the subject-relative hypothesis, i.e., modified by the action of the adjacency principle.

The results from the present study, although consistent with a misperception of direction being a cause of the induced motion, do not necessarily support this particular form of the subject-relative

hypothesis. The aspect of the subject-relative hypothesis supported by the data of this study is the postulation of a direct relation between induced motion and the perceived distance of the test object from the induction object. The perceived extent of the induced motion can be regarded as though it were a real extent defining a visual angle and thus requiring a perception of egocentric localization. It is suggested, for a constant position of the frame, that this hypothetical visual angle, were it not for the effect of the adjacency principle, would produce a consistently greater perceived size of motion for each increase in the perceived distance of the test object. Thus, the perceived extent of the induced motion, if the adjacency effects were not present, would satisfy the size-distance invariance hypothesis (Emmert's law). The need to postulate this underlying relation between the perceived size of the induced motion and Emmert's law in order to explain the data constitutes support for the subject-relative hypothesis.

It is interesting to note that a comparison of the results from the control and experimental situations in Tables 1 and 2 indicates that the total amount of movement perceived in the experimental situations (the perceived movement of the test object plus the perceived movement of the induction object) usually exceeded that in the control situations, even though the amount of physical movement in the two kinds of situations was the same. Consider, for example, the case in which both the point of light and the frame were physically in the near position. In the experimental situation, the *physical* movement was 6.5 in. for the frame and 0.0 for the point of light. The total (median) *perceived* movement from these objects was $6.0 + 7.0 = 13$ in. But in the corresponding control condition, in which the point of light moved 6.5 in. and the frame was stationary, the total perceived movement from these objects was 7.5 in. The greater

magnitude of the overall movement perceived in the experimental as compared with the control situations probably cannot be attributed to a general tendency to see extents as larger in the experimental than in the control situations, since, it will be recalled, estimates of the size of the frame in the experimental and in the control situations were approximately the same. It seems that the sum of the perceived extent of movement of the induction and test object usually was greater when the induction object rather than the test object was physically moving.

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