An indirect measure of perceived distance from oculomotor cues

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The sensitivity of an indirect method of measuring perceived distance was compared in two experiments with the direct procedure of eliciting verbal reports of distance. Perceived distance was varied by varying the oculomotor cues to object distance. The indirect method, called the "adjustable pivot method," uses an apparatus that physically moves the stimulus object laterally concomitantly with the lateral motion of the head. The magnitude and direction of this concomitant motion determines the distance of the point around which the direction of gaze to the object rotates (the pivot distance) as the head is moved. The pivot distance at which the object appears stationary with head movement measures the apparent distance of the object. Both types of measures were found to vary systematically with the oculomotor distance of the object for points of light (Experiment 1) and extended objects (Experiment 2). A previous study has shown that the adjustable pivot method avoids cognitive errors that can distort verbal reports of distance. The present study, by demonstrating the discriminative capability of this method under conditions in which differences in perceived distance were expected to occur, provides clear evidence that the adjustable pivot method is a sensitive and useful procedure for measuring perceived distance.

A previous article (Gogel & Newton, 1976) has described a method of measuring the perceived distance of an object which requires the observer to move his head laterally. This method, called the "adjustable pivot method," is free from the kind of cognitive effects that can distort other, more direct, procedures such as that of obtaining a verbal report of apparent distance. With the adjustable pivot method, the distance of the point around which the direction from the observer to the object pivots as the observer moves his head laterally is systematically varied. The principles upon which this method is based are shown in Figure 1.

The three drawings of Figure 1 represent situations in which a single object, a rectangle, is presented in an otherwise homogeneous surround. The physical and apparent positions of the rectangle (arbitrarily selected for the purpose of this discussion) are shown in Figure 1 by the solid and open rectangles, respectively. The notations n , m , and f represent a near, middle, and far distance, respectively, from the observer. The observer moves his head laterally between Positions 1 and 2 while gazing at the rectangle. The changes in direction (lines of sight) to the rectangle as the head is moved laterally are different in Figures 1A, 1B, and 1C. This is caused by physically moving the rectangle concomitantly with the head motion between n_1 and n_2

in Figure 1A, between m_1 and m_2 in Figure 1B, and between f_1 and f_2 in Figure 1C. The point around which the line of sight pivots is P_n , P_m , and P_f , in Figures 1A, 1B, and 1C, respectively. In Figure 1A and 1C, unlike 1B, this pivot distance differs from the apparent distance of the rectangle and therefore the rectangle appears to move as the head is moved right and left. Specifically, if the distance of the pivot, to be called D_p , is less than the apparent distance of the rectangle as shown in Figure 1A, the rectangle appears to move opposite to the motion of the head (between n'_1 and n'_2 as the head moves between Positions 1 and 2). If D_p is greater than the apparent distance of the rectangle, as is shown in Figure 1C, the rectangle appears to move in the same direction as the motion of the head (between f'_1 and f'_2). Only if D_p is the same as the apparent distance of the rectangle from the observer, as is shown in Figure 1B, will the rectangle appear stationary ($m'_1 = m'_2$) as the head is moved between Positions 1 and 2. Conversely, the pivot distance at which the stimulus *appears* stationary (the null position) as the head is moved between Positions 1 and 2 is a measure of the apparent distance (D') of the stimulus from the observer. The method of measuring D' by the adjustment of D_p to the null position is called the adjustable pivot method and the resulting measure of perceived distance is labeled D'_m .

The procedure illustrated in Figure 1 could be applied to the measurement of the apparent distance of the rectangle by mounting the rectangle (stimulus) on a rigid bar extending to the position of the observer's head with this bar capable of pivoting

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Figure 1. A top-view schematic diagram illustrating the principles involved in using the adjustable pivot method to measure perceived distance.

around different positions along its length as the head is moved laterally. To avoid the long bar that would be necessary for measuring apparent distances far from the observer, an apparatus described in detail by Gogel and Newton (1976) was used. This apparatus, consisting of a system of levers, provided a large range of pivot distances, even though the bar on which the stimulus was mounted was less than 2 m in length. The lever system was such that D_p was variable between 45 cm and infinity.

In a previous study, this apparatus had been applied to an examination of whether familiar size is a cue to perceived as distinct from cognitive distance (Gogel, in press). Although the cue of familiar size was found to modify the measurement of the perceived distance of the object as determined by the adjustable pivot method, this effect was much greater as determined by the method of verbal reports. Consistent with previous research (Gogel, 1969; Gogel & Newton, 1969), the familiar objects in this previous study were often perceived as non-normal in size. It was concluded that the difference between the results obtained with the adjustable pivot method and the method of verbal reports reflects the modification of the verbal reports of distance by a cognitive or inferential factor resulting from the perception of the familiar object as non-normal in size. Also, evidence was presented in this previous study that the differences from the two

methods could not be attributed to a lack of measurement sensitivity of the adjustable pivot method. The adjustable pivot method was shown to have a sensitivity comparable to that of the method of verbal report in an experiment in which the relative size cue, in addition to the familiar size cue, was available to produce changes in perceived distance.

The present study compares the verbal report and the adjustable pivot methods of measuring perceived distance in a situation in which the perceived distance of the object from the observer (the perception of egocentric distance) is varied by changing the oculomotor cues of distance (the accommodation and convergence of the eyes). Recent research has indicated clearly that the convergence of the eyes required to fixate an object provides an effective cue to distance, at least for distances within several meters from the observer (Foley, in press; Gogel & Tietz, 1973). It is expected that, unlike the study in which the familiar objects introduced cognitive distance effects, the function relating oculomotor cues and perceived distance will be similar for measures obtained from the verbal report and adjustable pivot methods. Two kinds of verbal reports will be compared with the data obtained from the adjustable pivot method. One of these (D_v) consists of the unmodified reports of apparent distance, and the other (D'_v) results from calibrating the unmodified verbal reports of distance by distance

judgments obtained from the same observer in a full-cue situation called the calibration alley. As in previous studies (Gogel, 1969; Gogel & Tietz, 1973), the calibration procedure is expected to remove observer idiosyncracies associated with the mental application of a foot ruler to the estimation of apparent distance.

EXPERIMENT 1

Method

Apparatus. Two situations, one an experimental and the other a calibration situation were produced, using separate visual alleys with different stimulus and lighting conditions in the two alleys. Each alley was viewed from its own observation position with the two observation positions enclosed in a single lightproof booth. The stimuli for the experimental alley were three clearly visible points of light, presented one at a time, at eye level and attached to the variable pivot bar at different distances along its length, with one end of this bar fastened to a movable head- and chinrest located at the observation position. The points were produced by pinhole apertures placed in front of incandescent grain-of-wheat bulbs. Each point of light subtended the same visual angle, with the far point 0.8 mm in diameter and the sizes of the other points reduced appropriately. In order to prevent the support (holder) for a nearer point of light from occluding the view of a more distant point, the near and middle points were displaced from the bar by mounting these points of light each on its own rigid metal attachment to the bar and were viewed by reflection from a partially transmitting mirror so that the direction to each of the points when illuminated was the same. The optical (oculomotor) distance of the points of light from the observer were 33.3 cm (near), 53.3 cm (middle), and 133.3 cm (far). The points of light were presented one at a time in an otherwise dark visual field and were equal in subjective brightness. The head- and chinrest in front of the experimental alley was movable left and right on ball-bearing rollers through a distance of 10.5 cm from one extreme to the other. With his left hand, the observer grasped a handle attached to the device and moved his head laterally from one extreme to the other at a rate of about one such movement per second.

As described in detail elsewhere (Gogel & Newton, 1976), the head- and chinrest was mechanically connected to the bar to which the points of light were attached, and by means of the lever system the point could be made to move physically concomitantly with the motion of the observer's head, in the same direction as the head motion or opposite to the direction of the head motion, by continuously variable amounts. Although the apparatus was limited to a near pivot distance of 45 cm (and thus to a near perceived distance of 45 cm), preliminary observations indicated that this pivot distance would permit the observer to adjust D_p until the point appeared to move in the direction opposite to motion of the head for any of the distances of the point of light, including the distance closest to the observer. In other words, it was expected that most observers would perceive the point of light at the near distance to be at a greater distance than 45 cm and, therefore, even for this near distance, they would be able to adjust the pivot distance to the condition of no apparent motion.

A switch located near the observer's right knee permitted the observer to increase or decrease D_p continuously by holding the switch forward or back. The experimenter, using a similar switch, repositioned D_p at the beginning of each trial. A constant voltage source was applied across a potentiometer, the resistance and voltage output of which varied directly with D_p . This output was registered by a digital voltmeter that was visible only to the experimenter. The voltmeter reading could be converted to D_p in

centimeters by means of a previously established calibration function. In addition to the binocular observation of the points of light, control conditions were used in which the same three points were observed monocularly (right eye only). For the monocular observation, a positive spherical lens was located directly in front of the eye to place the point of light at a constant accommodation of 2 m regardless of its physical distance from the observer. This lens was 2.5, 1.37, or 0.25 D for the near, middle, and far points of light, respectively. It was mounted on the apparatus and moved with the observer's head so that the observer's line of sight to the point of light always passed through the center of the lens perpendicularly to the lens surface. A small shutter fixed to the headrest, when closed by the experimenter, occluded the left eye of the observer. For binocular observation, the small shutter was open and no lens was present. The monocular observation provided constant oculomotor cues, against which the results from the different values of oculomotor cues in the binocular conditions could be compared. During the experimental trials, the observer was in complete darkness except for the point of light. By closing a large shutter in front of the observation position, the experimenter could totally occlude the view of the experimental alley. Between trials, the large shutter was closed, the overhead lights in the observation booth were turned on, and the observer turned and looked at a large white surface in order to maintain a relatively constant light adaptation throughout the trials. The experimenter and observer communicated by means of speakers and microphones.

The observation position for the calibration situation consisted of a stationary head- and chinrest located in front of the calibration alley. The viewing of the calibration alley was always binocular. When a shutter in front of the calibration alley was opened by the experimenter, the observer saw a well-illuminated, multiple-cue alley with a raised floor, upon which six white squares were standing at 40, 100, 200, 350, 500, and 650 cm. The squares were 10 cm on a side, and each was marked with a large black number so that the experimenter could identify the stimulus square to the observer.

Observers. The observers were 8 men and 28 women, who partially satisfied a course requirement in introductory psychology by participating in the experiment. All had at least 20/20 uncorrected vision in both eyes and a stereoacuity of at least 25 sec of arc as measured on the Keystone orthoscope; all were naive as to the purpose of the experiment.

Procedure. Before entering the observation booth, the observer was given preliminary instructions regarding the experimental tasks. A small model was used to illustrate apparent motion in the same direction as (*with*) or opposite to (*against*) the motion of the head. Following this, in the observation booth, the observer was given practice moving his head in the head- and chinrest smoothly left and right and the function of the switch controlling the adjustable pivot distance was explained. To insure that the eyes were converged to the stimulus distance in the binocular conditions, the observer was asked to report whenever he saw more than one point of light. All of the observers used in the experiment achieved singleness of vision with each of the point distances.

The experimental situation was always presented before the calibration situation. In the experimental conditions, each observer indicated the perceived distance of the point of light at each of the three physical distances with monocular and with binocular observation, using the method of verbal reports of distance and the method of the adjustable pivot. Half the observers viewed the point of light consecutively at each of the three distances, first binocularly and then monocularly for the remaining observers, this order was reversed. The verbal report and the adjustable pivot methods were used to measure the perceived distance of a point of light at a particular distance before presenting a point of light at a different distance. For all observers, the verbal report of the apparent distance to a point

of light at a particular physical distance immediately preceded the use of the adjustable pivot for the point of light at that distance. The order of presentation of a point of light at the near, middle, and far distance was systematically varied between observers, with the same order used for an observer in the monocular and binocular conditions. In the monocular condition only, the experimenter entered the observation booth between trials to change the lens in the lens holder in order to maintain the point at the constant optical distance. Before beginning the experiment, each observer was given two practice trials with the adjustable pivot method. In the practice trials, the point of light was presented at the distance later used for the first experimental trial for that observer.

The procedural details of a trial were as follows. At the start of each trial, the head- and chinrest was stopped at the right extreme of motion, the observation shutter was opened, and the observer verbally reported the apparent distance of the point of light from his eyes, using feet or inches or some combination of feet and inches. The pivot had previously been set randomly by the experimenter at either the nearest or the farthest possible pivot distance. Following this, using the head- and chinrest, the observer made four head movements (left, right, left, right) and, following these, reported whether the point appeared to move laterally and, if so, whether the direction of the motion was with or against the head. Next, the observer was instructed to hold the switch momentarily in the direction for reducing the type of reported motion (with or against the head). This sequence of four head movements followed by the use of the switch was repeated until the observer reported that the no-motion (null) setting was reached. A bracketing procedure was used on each trial. In this procedure, the motion initially perceived in one direction relative to the head motion was modified by adjusting the pivot distance beyond the no-motion position until the point of light clearly appeared to reverse its motion relative to the head before returning to the no-motion setting. Upon completing this task, the observation shutter was closed, the booth lights were turned on, and the observer turned to look at the white card-board for 45 sec before beginning the next trial.

After completing the six experimental trials (the near, middle, and far stimuli with monocular and with binocular observation), the observer moved to the observation position at the calibration alley, the shutter in front of the calibration alley was opened, and the observer reported, in feet or inches or some

combination of both, the apparent distance to each of the six numbered squares on the alley floor, with the order in which the squares were reported varying systematically between observers. Assuming that the perception of distance was accurate in the calibration alley, the calibration data permitted a calibration equation to be calculated for each observer relating the verbal report (D_v) to perceived distance (D'_v) as measured by the calibrated verbal report. This calibration procedure, although correcting the verbal reports for differences in mentally applying a foot ruler to perceived distance, does not correct for other possible cognitive effects in the experimental situation. The presence of such additional cognitive effects in the verbal reports of distance is illustrated by the study in which the adjustable pivot method was used to measure the perceived distance from familiar size (Gogel, in press). Less cognitive effects are expected in the present study, particularly in the conditions with binocular observation, since convergence is expected to be a rather effective cue of distance.

Results

A summary of the results from Experiment 1 is shown in Table 1. Seven observers during the course of the experiment were unable to produce a change in direction of the apparent motion relative to the motion of the head for D_p greater or less than the value of D_p producing the no-motion perception. For five of these, this occurred with binocular observation, with three unable to obtain apparent motion against the head for the near distance of the point of light and two unable to obtain apparent motion with the head for the far distance of the point of light. These observers were replaced in the experiment. The uncalibrated verbal reports (D_v) in Table 1 are the verbal reports of the distance of the point of light converted to centimeters. The calibrated verbal reports (D'_v) were obtained by applying a calibration equation computed from the verbal reports obtained in the calibration situation to the

Table 1
Perceived Distance Data from All Presentations of Experiment 1

	Monocular Observation			Binocular Observation			F/N
	Near	Middle	Far	Near	Middle	Far	
Adjustable Pivot Method (D'_m)							
Mean	197	207	222	82	101	206	2.5
Geometric Mean	179	193	198	78	98	197	2.5
Median	170	196	176	76	99	199	2.6
SD	100	85	119	27	26	66	
Uncalibrated Verbal Report (D_v)							
Mean	240	304	228	168	116	114	0.7
Geometric Mean	99	103	116	32	44	78	2.4
Median	91	91	122	20	30	91	4.6
SD	386	389	244	553	324	122	
Calibrated Verbal Report (D'_v)							
Mean	307	358	328	224	164	169	0.8
Geometric Mean	157	161	192	57	77	129	2.3
Median	131	172	200	46	67	132	2.9
SD	417	572	325	719	413	142	

Note—Perceived distance data are as measured by the adjustable pivot method (D'_m) and by the method of verbal report (uncalibrated D_v and calibrated D'_v). All data are in centimeters.

verbal reports obtained from the same observer in the experimental situations. This procedure assumes that distance is correctly perceived in the calibration alley and describes the relation between perceived and verbal distance as a power function determined by applying a line of best fit to the calibration data. The calibration procedure is identical to that used in several previous studies (see Gogel & Tietz, 1973, 1974). D'_v data are larger than the corresponding D_v data because the calibration equation often consisted essentially of the multiplication of the D_v scores by a factor greater than one. The large geometric means and standard deviations found with the D'_v data of Table 1 for binocular observation are much reduced if the data from three observers are eliminated. In this case, the geometric means are 42, 62, and 113 cm for the near, middle, and far distances, respectively, with corresponding standard deviations of 23, 36, and 66 cm. Because of the tendency for the verbal reports obtained in the experimental conditions to be skewed, the experimental data were converted to logarithms before applying any statistical analysis.

With monocular observation, the lens before the eye of the observer placed the point of light at the same accommodative distance (2 m) regardless of its physical distance. It was expected, therefore, that the perceived distance of the points with monocular observation would be the same. The partial tendency that seems to be present in Table 1 for the means of D'_m and D'_v from monocular observation to increase with physical distance is not statistically significant ($F < 1.0$), as determined by a simple analysis of variance of the log transformation of the data. In the case of binocular vision, both the convergence and accommodative cues were available to cause the perceived distance of the point of light to vary with its physical distance, with convergence probably the more effective cue (Foley & Held, 1972; Gogel & Tietz, 1973). The change in D'_m and D'_v as a function of physical distance was statistically significant, $F(2,70) = 107.0$ and 6.2 , respectively, as tested with a simple analysis of variance of the log transformation of the data. Both the D'_m and D'_v scores obtained with binocular observation clearly reflect the ability of oculomotor cues to modify perceived distance for objects at distances within several meters from the observer. For binocular observation, the geometric means from D'_m are larger than those from D'_v in Table 1. The ratios of the geometric means at the near and far distances (F/N in Table 1), however, are very similar for D'_m and D'_v . Both D'_m and D'_v seem to be sensitive measures of perceived egocentric distance.

The difference between the near (33.3 cm) and middle (53.3 cm) distance is 20 cm and, expressed as

an oculomotor difference, is .11 D. The difference between the middle and far (133.3 cm) distance is 80 cm, and expressed as an oculomotor difference again is .11 D. From the geometric means of Table 1, the corresponding differences are 20 and 100 cm from D'_m and 20 and 52 cm from D'_v . It is clear that, with binocular observation, equal dioptic differences do not result in equal perceived distance, but instead, the perception of depth from oculomotor cues approximates distance constancy, with D'_m and D'_v showing some amount of over- and underconstancy, respectively. The visual process of translating oculomotor differences to differences in perceived distance is such as to modify the perception in the direction of distance constancy; although this correction process would be expected to fail completely beyond perhaps 5 m from the observer, since the changes in oculomotor cues associated with changes in far distances are below the threshold for discrimination. Even within the discriminable range of oculomotor changes, however, it is not expected that perceived distance from oculomotor cues will be entirely veridical. The reason for this is that, according to the specific distance tendency, objects closer than about 2-3 m will be perceived at a distance greater than their physical distances (Foley & Held, 1972; Gogel & Tietz, 1973). This is consistent with the geometric means obtained with binocular observation from both D'_m and D'_v in Table 1.

A distinction can be made between oculomotor factors as a cue to the distance of an object from the observer (a cue of egocentric distance) and oculomotor changes as a cue to the perceived distance between objects on the successive presentations (a cue of exocentric distance). Since the time between presentations was about 1 min, it is likely that the oculomotor-perceived distance function shown in Table 1 is determined by egocentric, not exocentric, cues. This can be tested directly, however, by examining the results from first and successive presentations. If only egocentric, as distinct from exocentric, cues are involved, the results from first and successive presentations of the points of light should be essentially the same. Table 2 lists the geometric means obtained at the three distances for the observers who received these presentations first, second, or third. For either D'_m or D'_v , different groups of observers were used for the geometric means of a particular column. The similarity of the results from first and successive presentations is evident. It will also be noted that the geometric means obtained from D'_m were considerably less variable as a function of order of presentation than those from D'_v under both monocular and binocular conditions of measurement. According to these results, D'_m is a more reliable measure of perceived distance than is D'_v .

Table 2
Geometric Means in Centimeters of D'_m and D'_v as a Function of Whether the Point of Light at the Particular Distance was Presented to the Observer on the First, Second, or Third Trial in Experiment 1

	Monocular			Binocular		
	Near	Middle	Far	Near	Middle	Far
D'_m						
First	185	199	191	84	105	180
Second	168	195	215	74	95	197
Third	186	185	189	78	94	217
D'_v						
First	220	105	182	66	65	116
Second	101	206	266	48	60	163
Third	176	194	146	59	117	113

EXPERIMENT 2

Objects extended in the frontoparallel plane may provide oculomotor cues that are more adequate than those provided by points of light (Owens & Leibowitz, 1976). Thus, it is possible that the relation found in Experiment 1 between perceived distance and oculomotor cues will not be the same if extended objects, rather than points of light, are used as stimuli. Experiment 2 uses the adjustable pivot and verbal report methods of measuring apparent distance, with extended objects presented in a frontoparallel orientation at the near and far distances of Experiment 1. In addition to the measures of apparent distance, apparent size (width) was measured in Experiment 2 in order to provide a test of the size-distance invariance hypothesis, using the two methods of measuring apparent distance.

Method

Apparatus. The stimuli in Experiment 2 were six positive transparencies transilluminated by electroluminescent panels. These were light in weight and were attached to the arm of the adjustable pivot apparatus in the same manner as the stimuli in Experiment 1. Six transparencies were used, with the height, width, and visual angular size of the width of each shown in Table 3. The cards were seven-of-spades playing cards, and the homogeneous rectangles, squares, and circles were uniform in luminance. The areas of all the large objects were equal, as were the areas of all the small objects. Only the 33.3- and 133.3-cm distances were used in Experiment 2. The small objects were always placed at 33.3 cm and the large objects at 133.3 cm, with the small and large object of the same kind subtending the same visual angle. The use of different kinds of objects provided a test of the generality of the oculomotor-perceived distance function. Binocular observation was used throughout Experiment 2, no lenses were present, and the luminance of each stimulus was .18 fL. As in Experiment 1, nothing was visible during the experimental conditions except the single stimulus object. The adjustable pivot apparatus used in Experiment 1 also was used in Experiment 2 to obtain D'_m . In Experiment 2, the observer indicated the apparent width of the stimuli by means of a device consisting of two vertical handles, each 13 cm in height, located 30 cm below the chinrest. The right handle was movable left and right and was adjusted by the observer until the separation

between the inner surfaces of the handles was judged kinesthetically to be equal to the apparent width of the visible stimulus. The left handle was stationary, and the observer was unable to see the handles while making the adjustment. A meter stick attached to the right handle extended outside the observation booth so that the separation of the handles could be recorded by the experimenter. The remainder of the experimental apparatus, including the adjustable pivot and movable head- and chinrest, was the same as in Experiment 1. The calibration situation also was used in Experiment 2 and was identical to that of Experiment 1.

Observers. The observers were 16 men and 32 women, who partially satisfied a course requirement in introductory psychology by participating in the experiment. All had at least 20/20 uncorrected vision in both eyes and a stereoacuity of at least 25 sec of arc as measured on the Keystone orthoscope. Seven of the observers had participated in Experiment 1.

Procedure. There were six experimental trials for each observer. Each trial consisted of the presentation of one stimulus at one distance. On each trial, the observer (1) verbally reported the apparent distance of the stimulus in feet or inches or some combination of both, (2) completed two adjustments of the handles of the size measurement apparatus to indicate the apparent width of the stimulus, with the average of these two adjustments taken as the measure of the apparent width (S'), and (3) adjusted the pivot distance in the manner described in Experiment 1 until the no-apparent-motion condition (the null adjustment) was achieved. The verbal reports of distance and the kinesthetic adjustments of width were always obtained before using the adjustable pivot with that stimulus. With half the observers, the verbal reports preceded the kinesthetic adjustment, and with the remaining observers, the order was reversed. The stimuli were not presented in a completely random order on the six trials. Instead, for the playing cards and the rectangles, a stimulus of one kind always preceded or followed the stimulus of the same kind presented at the other distance. Therefore, the stimuli can be divided into pairs on the basis of their similarity in shape or familiar characteristics on the successive presentations. One pair (A) consisted of successive presentations of the small (near) and large (far) playing cards. Another pair (B) consisted of successive presentations of the small (near) and large (far) rectangles. The third pair (C) consisted of the small (near) or large (far) circle or square followed by the large (far) or small (near) square or circle, respectively. The successive presentations in pair C were always between geometrical objects of different shape, i.e., (C₁) a large (far) square was preceded or followed by a small (near) circle or (C₂) a large (far) circle was preceded or followed by a small (near) square. The order of presenting A, B, and C was systematically counterbalanced among observers, as was the order of presenting the stimuli at the near and far

Table 3
Physical Height and Width in Centimeters and Visual Angle of Width in Radians of Stimuli Used in Experiment 2

Stimulus Presented	Height	Width	Visual Angle
Stimuli Presented at 33.3 cm			
Small Playing Card	1.6	2.5	.048
Small Rectangle	1.6	2.5	.048
Small Square	2.0	2.0	.060
Small Circle	2.2	2.2	.067
Stimuli Presented at 133.3 cm			
Large Playing Card	6.4	9.8	.048
Large Rectangle	6.4	9.8	.048
Large Square	8.0	8.0	.060
Large Circle	9.0	9.0	.067

distance. For each observer, A, B, and C were completed using the same near-far order. One half of the observers received condition C₁, and the other half received C₂. Two practice trials on the stimulus to be presented first were completed before beginning the experiment. Between experimental trials, the shutter in front of the experimental alley was closed, the booth lights were turned on, and the observer turned and looked at the center portion of a large white surface for about 45 sec to maintain light adaptation. As in Experiment 1, the calibration situation always followed the completion of all of the experimental portions of the experiment.

Results

Six observers were unable to move the pivot distance sufficiently close to produce an apparent motion opposite to the head motion for at least one of the stimuli at the near distance. Three other observers were unable to move the pivot distance sufficiently far to produce an apparent motion in the same direction as the head motion for at least one of the far stimuli. These observers were replaced in the experiment. The overall results from the verbal reports (D_v or D'_v) and the adjustable pivot method (D'_m) are shown in Table 4. The similarity of the D'_m and D'_v results for the near (33.3 cm) and far (133.3 cm) distance in Tables 1 and 4 is obvious. It seems that the function relating oculomotor cues and perceived distance is the same for points of light (Table 1) and extended objects (Table 4). Using a *t* test, each of the near-far differences in the geometric means from the paired objects of Table 4 were significant at the .01 level for both the D'_m and D'_v data, with the eight values ranging from 3.25 to 14.3 with *dfs* of either 46 or 47. Also, in Table 4, as in Table 1, the ratio of the near to far obtained values of D'_m and D'_v are similar and for the same value of oculomotor cues D'_m is greater than D'_v .

It is also evident that the misleading cues of familiar size contained in the playing card stimuli did not modify the perception of distance associated with the convergence cue, since the results from the rectangles and playing cards were very similar.

The geometric means of the kinesthetic measure of perceived width were 3.0 and 5.8 cm for the near and far playing card stimulus, 2.8 and 5.4 cm for the near and far rectangle, and 3.5 and 6.3 cm for the near and far circle or square. It seems, from the similarity of the results from the playing card and rectangle, that the perceived size of the playing card was determined by the oculomotor cues of perceived distance and not by familiar size. This conclusion is consistent with the results from an analysis of variance of the measures of perceived size. Perceived size differed significantly as a function only of the distance of the stimulus, $F(1,47) = 9.94$, $p < .001$, and not as a function of the familiar size ($F < 1.00$). In the presence of effective oculomotor cues (probably convergence), familiar size seems to have little, if any, effect on either perceived size or perceived distance. This result is in agreement with the results obtained by Oyama (1974).

The values of perceived size, together with the D'_m or D'_v obtained in Experiment 2, can be applied to the size-distance invariance hypothesis. In simplest form, this hypothesis is that $K = S'/D'_0$, where *K*, an observer constant, should be independent of the distance of the object. Geometric means of distributions of *K* were obtained by computing a value of *K* for each presentation in the experimental situation for each observer. Table 5 gives the resulting *K* data at the near and far distances for each of the stimuli using D'_m , D'_v , and D_v . It is clear that *K* is some-

Table 4
Perceived Distance Data from Experiment 2

	Playing Card			Rectangle			Circle or Square		
	Near	Far	F/N	Near	Far	F/N	Near	Far	F/N
Adjustable Pivot Method (D'_m)									
Mean	90	190	2.1	85	187	2.2	90	200	2.2
Geometric Mean	83	177	2.1	80	174	2.2	83	179	2.2
Median	78	160	2.0	78	168	2.1	78	160	2.1
SD	38	82		29	82		52	123	
Uncalibrated Verbal Reports (D_v)									
Mean	67	99	1.4	45	93	2.1	36	89	2.5
Geometric Mean	39	85	2.2	34	78	2.3	30	75	2.5
Median	30	91	3.0	30	91	3.0	30	91	3.0
SD	102	52		50	54		27	52	
Calibrated Verbal Reports (D'_v)									
Mean	103	155	1.5	73	142	1.9	57	137	2.4
Geometric Mean	60	132	2.2	52	120	2.3	48	114	2.4
Median	47	144	3.1	46	131	2.8	44	126	2.9
SD	155	90		102	83		48	78	

Note—Perceived distance data are as measured by the adjustable pivot method (D'_m) and by the method of verbal report (uncalibrated D_v and calibrated D'_v). All data are in centimeters.

Table 5
Values of K in Size-Distance Invariance Hypothesis

	Playing Card		Rectangle		Circle or Square	
	Near	Far	Near	Far	Near	Far
			From D'_m			
Mean	1.08	.87	1.00	1.05	.87	.72
Geometric Mean	.75	.68	.69	.65	.66	.56
Median	.65	.66	.63	.56	.57	.56
SD	1.38	.82	1.55	1.75	.91	.64
			From D_v			
Mean	2.86	2.45	3.06	2.79	2.61	2.28
Geometric Mean	1.62	1.41	1.73	1.42	1.81	1.34
Median	1.52	1.22	1.44	1.21	1.58	1.10
SD	3.84	4.07	5.12	5.38	3.46	3.58
			From D'_v			
Mean	1.73	1.47	1.75	1.62	1.55	1.39
Geometric Mean	1.05	.91	1.10	.93	1.15	.87
Median	.98	.85	.96	.81	1.02	.74
SD	2.07	2.22	2.57	2.76	1.76	1.95

Note—Values of K ($S' = K \theta D'$) are as calculated from the angular size of the width (θ) of the stimulus, and the perceived width (S') and perceived distance (D'_m , D_v , or D'_v) obtained in Experiment 2.

what less at the far than at the near distance, suggesting that the increase in perceived size is not as rapid as is the increase in perceived distance with an increase in the physical distance of the objects from the observer. A K of unity indicates that the ratio of perceived size to perceived distance is equal to the visual angle of the stimulus expressed in radians. Values of K of this magnitude seem to be more characteristic of D'_v than of either D'_m or D_v . If it can be assumed that reported size and perceived size are proportional, the data of Table 5, although providing strong evidence that perceived size and perceived distance are monotonically related, also indicate that the simple form of the size-distance hypothesis given above is not adequate.

DISCUSSION

The present study provides clear evidence that oculomotor cues (probably convergence) are effective cues of distance for distances near the observer. Within a distance of 1.3 m, it is also clear that equal proximal changes expressed in diopters result in increasing changes in perceived distance as a function of increasing physical distance. This is the result expected if oculomotor cues are to contribute to distance constancy for distances near the observer. The results also indicate that the relation between oculomotor cues and perceived distance is the same for extended objects (geometrical or familiar objects) as for points of light and that oculomotor cues are considerably more effective than familiar size in determining perceived distance.

Of primary importance for the purpose of this study, the adjustable pivot method was found to be

a sensitive measure of perceived egocentric distance. Perceived distance was expected to vary with oculomotor cues, and in both experiments this variation was clearly indicated by the adjustable pivot method as well as by the method of verbal reports. Although the standard deviations were greater for D'_v than for D'_m in both experiments, the exclusion of the data from some observers because of their inability to demonstrate a near or a far null position with the head-motion procedure makes a comparison between the variability of the two methods somewhat unclear. It is of interest, however, to note that in Experiment 1 the variation in the results as a function of order of presentation was greater for D'_v than for D'_m . Since points of light were used in this experiment, no effect of order of presentation was expected, and this difference suggests that the adjustable pivot method provides a more reliable measure than the method of verbal report.

The ratios of perceived distance as a function of convergence were very similar as measured by either method. The values obtained with the adjustable pivot method, however, usually were larger than the corresponding values from the calibrated verbal reports. Clearly, a decision as to which method is more valid in the details of the results requires further investigation. But regardless of the final conclusion on this problem, it is clear that the adjustable pivot procedure for measuring apparent distance is very useful. It not only avoids the possible cognitive effects in distance judgments that can occur in some situations with direct measures such as verbal reports (Gogel, in press), but also is a sensitive method in which independent repeated measures can be obtained on the same perceived distance from the same

observer. As a "pure" measure of perceived distance, the adjustable pivot method is likely to be particularly useful, not only in testing hypotheses regarding spatial perceptions, but also in providing a criterion of apparent distance against which instructional and set variables can be evaluated.

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