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Oculomotor adjustments and size-distance perception*

MELVIN K. KOMODA†
New School for Social Research, New York, New York 10011

and

HIROSHI ONO
York University, Toronto, Ontario, Canada

The relationship between perceived size and distance and oculomotor adjustments were assessed in two experiments. In both experiments, Ss were required to make scalar linear size, angular size, and distance judgments of stimuli subtending a constant retinal image size at different levels of convergence. The results of the first experiment indicate that the perceived linear size, angular size, and distance of the stimulus decreased with increased convergence, the decrease in perceived linear size being greater than that of perceived angular size. While again showing a decrease in perceived linear and angular size, the results of the second experiment also show that there was a smaller decrease in perceived distance with increased convergence when Ss continued to view the stimulus as convergence was changed than when they did not view the stimulus as convergence was changed. The implications these results have for size and distance perception are discussed.

Since Wheatstone's (1852) initial report, the change in the perceived size of stimuli with oculomotor adjustments has been well documented (e.g., Biersdorf, 1966; Gogel, 1962; Heinemann, Tulving, & Nachmias, 1959; Hermans, 1954; Leibowitz & Moore, 1966; Leibowitz, Shiina, & Hennessy, 1972). Following increased (decreased) accommodation and/or convergence to a stimulus whose retinal image size remains constant, Ss invariably report that the size of the stimulus has decreased (increased). However, while the size change has been reliably obtained, a discrepancy in the literature with respect to the quantitative relationship between perceived size and oculomotor adjustments has prevented a clear understanding of the phenomenon. In comparing the change in perceived size for identical changes in accommodation and/or convergence in a number of studies, Komoda (1970) noted that they could be divided into two groups, with one group reporting smaller changes in perceived size. It is unlikely that this discrepancy is due to any inherent instability in the phenomenon, since the reported results are consistent within each group.

The discrepancy in the literature may be due to the failure of investigators to provide a precise definition of the term "perceived size." As Ono (1970) points out, the term "size" does not refer to a unitary concept, but can refer to either the linear size or angular size of an object. While linear size has its conventional meaning of "ruler" or "objective" size, the angular size of an object is defined as the difference in the visual directions of its edges. For the veridical judgment of linear size, information concerning the retinal image size projected by the object and its distance from S (the object's egocentric distance) is sufficient. The theoretical sufficiency of these two pieces of information for veridical linear size judgments is generally accepted and is the basis of the size-distance invariance hypothesis (Kilpatrick & Ittelson, 1953; Schlosberg, 1950). For the veridical judgment of an object's angular size, information concerning its retinal image size and egocentric distance is also sufficient. In addition to retinal image size information, egocentric distance information is also required, since an object's angular size is not the same as the visual angle it subtends. As it has been defined as a difference in visual directions, the reference point for an object's angular size is the egocenter and not the entrance pupils of the eyes. The egocenter lies behind the entrance pupils of the eyes in the S's medial plane (cf. Funaishi, 1926; Roelofs, 1959), and accordingly, the angular size of an object which subtends a constant retinal image size decreases as the egocentric distance of the object decreases.

These points, in and of themselves, are not original. The notion that size is not a unitary concept has been suggested by other investigators (e.g., Jenkin & Hyman, 1959; Joynson, 1948; McCready, 1965; Rock & McDermott, 1964), while the sufficiency of retinal image size and egocentric distance information about an object for veridical linear size judgments has been subsumed under the size-distance invariance hypothesis. Also, McCready (1965) has suggested that the perceptually relevant angular attribute of an object is not the physical visual angle, but the "phenomenal visual angle," with his theoretical definition of phenomenal visual angle being identical to Ono's (1970) definition of angular size. Nevertheless, the above points have important implications for the relationship between perceived size and oculomotor adjustments. To the extent that oculomotor adjustments can provide egocentric distance information, a reduction in the

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†Requests for reprints should be sent to Melvin K. Komoda, Department of Psychology, New School for Social Research, 60 West 12th Street, New York, New York 10011.

perceived linear size *and* angular size of a stimulus should follow increased accommodation and/or convergence. Moreover, from the theoretical definitions of linear size and angular size, a given change in oculomotor adjustments should result in a greater change in linear size than in angular size.

From this line of reasoning, the discrepancy in the literature on the relationship between perceived size and oculomotor adjustments may be due to Ss in one set of experiments responding to the linear size of the stimulus, while Ss in the other set of experiments respond to the angular size of the stimulus. The tenability of this hypothesis is supported by the fact that the reported results show agreement with the theoretically expected changes in either the perceived linear size or the perceived angular size of the stimulus following oculomotor adjustments (Komoda, 1970). Either angular size or linear size judgments may occur in a particular experiment because changes in the experimental setting via instructions, procedure, etc., while not necessarily changing the "perceived" size of the stimulus, may determine whether S responds to its linear or to its angular size.

Although the hypothesis that the perceived linear size and angular size of the stimulus changes with oculomotor adjustments can account for the discrepancy in the literature, there is a question concerning the underlying assumption that accommodation and convergence provide egocentric distance information. While there has been no systematic attempt to assess accommodation as a cue to distance, such an attempt has been made for convergence, with the results being equivocal (cf. Graham, 1965; Ogle, 1962; Osgood, 1953; Woodworth & Schlosberg, 1954). Also, in those studies which have measured both perceived size and distance following changes in oculomotor adjustments, some Ss judged the stimulus to be smaller and farther away upon increased accommodation and/or convergence (Biersdorf, 1966; Heinemann et al, 1959). The responses of these Ss have been labeled as instances of size-distance paradox, because according to the size-distance invariance hypothesis a stimulus that projects a constant retinal image size should appear smaller when it appears nearer (Epstein, Park, & Casey, 1961).

The equivocal results on convergence as a cue to distance and the occurrence of size-distance paradox may seem to undermine the hypothesis that oculomotor adjustments produce changes in the perceived linear size and angular size of stimuli. However, the hypothesis does not require accommodation and convergence to be the sole determiners of perceived distance, but only that they provide egocentric distance information. Again, while the relevant data for accommodation are lacking, there are data which imply that convergence does provide such information. For example, both Foley (1967) and Wallach and Zuckerman (1963) have shown that the perceived stereoscopic depth from a given retinal disparity changes as the amount of convergence is changed, implying that convergence provides egocentric distance information to the visual system for the evaluation of retinal disparities. Thus, it is likely that, although convergence provides the necessary distance information for size perception, such information is not necessarily used for distance perception.

The question which then arises is, what other sources of distance information, aside from accommodation or convergence, are available to S? A second source of distance information may be the change in the angular size of the stimulus serving as a relative size cue to relative distance. The rationale for considering relative size as a cue to relative distance is based on the fact that the same object produces a different difference in visual directions at various distances. Its effectiveness has been well documented (e.g., Epstein, 1961; Gogel, Hartman, & Harker, 1957; Hochberg & Hochberg, 1952; Hochberg & McAlister, 1955; Ono, 1966, 1969), although the relevant variable in those studies was thought to be different retinal image sizes. In other words, whenever S has information concerning, or assumes, stimulus identity (i.e., that the stimuli presented are the same stimulus or of constant linear size), variations in the perceived angular size of the stimulus may serve as a relative size cue to relative distance.

Following increased accommodation and/or convergence, then, Ss who assume stimulus identity may have conflicting information concerning the distance of the stimulus. While increased oculomotor adjustments may indicate that the egocentric distance of the stimulus has decreased, the reduction in the angular size of the stimulus may indicate that its relative distance, with respect to the previous stimulus or some assumed distance, has increased. As Schlosberg (1950) has pointed out, in situations where there are conflicting cues (or clues), Ss may resolve the conflict by discarding one of them. If the distance information provided by accommodation and convergence is discarded, the S should judge the linear size of the stimulus as having remained constant, its angular size as having decreased, and its distance as having increased. If, however, the information provided by relative angular size is discarded, the linear size, angular size, and distance of the stimulus should be judged as having decreased with increased accommodation and convergence. In this latter case, linear size should also change, as the discarding of the relative size information implies a rejection of the stimulus identity assumption.

The following two experiments were conducted in order to assess the present view regarding the relationship between oculomotor adjustments and perceived size and distance. Experiment I was designed to establish the occurrence of linear size and angular size changes with oculomotor adjustments, and Experiment II, to assess the basis of distance perception following oculomotor adjustments.

EXPERIMENT I

The determination of the relationships between oculomotor adjustments and perceived size and distance requires an assessment of the changes in the perceived linear size, angular size, and distance of the stimulus. Accordingly, Ss were required to make, within one stimulus presentation, scalar judgments of the three attributes of the stimulus. Scalar judgments are judgments of the actual extent or magnitude of a stimulus attribute (Gogel, 1968). Since such responses are behavioral responses, they can show variation between Ss whose perceptions are similar and, therefore, should be calibrated under full-cue conditions (Gogel, 1968). However, rather than establishing calibration equations, training under full-cue conditions was employed to remove as much of that source of variation as possible. Moreover, two different training procedures were employed in an attempt to manipulate whether or not Ss assumed stimulus identity in the experimental situation.

Method

Subjects. The Ss were members of the university community and were paid for their participation in the experiment. All 24 Ss had 20/25 vision or better in each eye and were between 19 and 26 years of age.

Apparatus. For experimental trials, a Clement-Clark synoptiscope was used to present stimuli at different convergence distances under a reduced cue condition. The synoptiscope presents S with dichoptic stimuli and forces him to change his level of convergence to maintain proper binocular fusion. Artificial pupils, 1.2 mm in diam, were affixed to each eyepiece in place of the usual lenses, to prevent blurring of the stimuli due to the accompanying changes in accommodation. Chin- and foreheadrests held the S's head steady.

The stimuli presented with the synoptiscope were pieces of rear-illuminated, white translucent plastic located 15 cm from the artificial pupil. The shape and size of the stimuli were determined by black paper masks from which circular cutouts were removed. To ascertain whether proper fusion of the stimuli occurred, a square notch was cut out on the top of one monocular stimulus and the bottom of the other; upon proper fusion of the stimuli, S saw a single luminous disk with a "tab" on the top and bottom. To control for the artificial-pupil-accommodation effect (cf. Biersdorf & Baird, 1966), the horizontal diameters of the circular cutouts were 28.3, 27.3, 27.1, and 27.0 mm for the convergence distances of 20, 50, 80, and 120 cm, respectively. Thus, the fused bincoular stimulus subtended a visual angle of 10 deg at each convergence distance.

The training apparatus consisted of a box-like frame, 200 x 120 x 80 cm, with black and white checkered cloth covering the floor and sides, and back cloth covering both ends with the exception of a viewing aperture at the near end. A curtain of black cloth covered the viewing aperture whenever S was not viewing the stimuli. The top of the frame was left open in order to utilize the existing room illumination. The training stimuli were made from white cardboard in the same shape as the fused stimulus in the experimental trials. The stimuli were presented at different distances, at approximately eye level. They were attached to a black rod which moved along an optic bench located on the checkered cloth in the S's medial plane. Chin- and foreheadrests held S's head steady.

For linear size judgments, the apparatus consisted of a tube which moved over a fixed rod parallel to the S's frontal plane. The amount S separated the edge of the tube from a marker affixed to the stationary rod was directly read by E from an adjacent scale. A pointer which rotated in the horizontal plane, with its center of rotation in the S's medial plane, was used for angular size judgments. Suitable gears transmitted the rotation to the rear of the apparatus, where the amount of rotation was read directly from a protractor. The apparatus for distance judgments consisted of a long length of rope, which moved horizontally and parallel to the S's frontal plane. A marker attached to the rope moved along a scale, from which E directly read the amount of rope pulled. These pieces of apparatus, duplicated for both experimental and training apparatus, were located above the S's lap and were not visible when he was positioned in the apparatus.

Experimental Design. The 24 Ss were randomly assigned to one of two conditions with different training procedures. One training procedure was designed to create a bias against assuming stimulus identity (nonidentity condition), while the second procedure, a bias for assuming stimulus identity (identity condition). The relationships between perceived size and distance and oculomotor adjustments were assessed by requiring Ss in both conditions to make linear size, angular size, and distance judgments of a stimulus at each of four randomly presented convergence distances (20, 50, 80, and 120 cm). The order of the judgments was counterbalanced, with each S being randomly assigned to one of the six orders, which he followed for both experimental and training trials.

Training Procedure. Each S participated individually on 3 consecutive days, with the first day concerned solely with training. Prior to the start of training, S was shown a sample of the training stimuli and told that he would be required to make size, angle, and distance judgments of similarly shaped stimuli. Size was defined as the horizontal diameter of the stimulus, angle as the amount of head rotation required to point his nose horizontally from one end of the stimulus to the other, and distance as the extent from the bridge of his nose to the stimulus. The S made his linear size judgment by separating two markers, which initially were not separated, until their separation corresponded to the size of the stimulus. Angular size judgments were accomplished by rotating the pointer from an arbitrary position until the amount of rotation corresponded to the amount of the imagined head rotation required to match the angle of the stimulus. For distance judgments, the S pulled as much rope as necessary through his hands, such that the amount pulled corresponded to the distance of the stimulus.

The Ss in the nonidentity condition were trained on one judgment at a time following the assigned counterbalanced order. For the training on linear size judgments, a set of 12 stimuli of different linear sizes (1-23 cm in steps of 2 cm) was presented once in each of three blocks of 12 presentations. For each block of presentations, each stimulus was randomly paired with one of four distances (20, 50, 80, or 120 cm), with the constraint that the distances be equally represented. The 12 stimuli were then randomly presented, using a different randomized order for each block of presentations. The training procedure for angular size judgments was identical, except that the 12 stimuli represented different angular sizes (2.0-10.8 deg in steps of .8 deg). The training procedure for distance judgments employed a metal rod, which was presented as 12 distances (10-120 cm in steps of 10 cm). The metal rod was 1.2 cm in diam and 17.6 cm high; thus, its horizontal angular size varied from 3.44 deg at the nearest distance to .53 deg at the farthest distance. Each distance was presented in random order once in each block of presentations.

In the training procedure for the identity condition, one of five stimuli was presented at four successively larger distances. For each stimulus presentation, S completed linear size, angular size, and distance judgments in succession, following the assigned counterbalanced order. The linear sizes of the five stimuli ranged from 3 to 11 cm in steps of 2 cm, while the angular sizes of the

Table 1
Means and Standard Deviations for Linear Size, Angular Size, and Distance Judgments in Experiment I*

Condition	Convergence Distance 20	50	80	120
	Linear Size Judgments			
Nonidentity				
Mean	6.12	8.73	9.45	9.91
SD	3.45	3.25	3.83	3.67
Identity				
Mean	4.58	5.47	5.75	5.88
SD	1.20	1.26	1.50	1.52
	Angular Size Judgments			
Nonidentity				
Mean	6.44	8.16	8.34	8.52
SD	2.80	3.62	3.07	3.10
Identity				
Mean	5.96	7.04	6.91	6.92
SD	2.82	3.05	2.58	2.77
	Distance Judgments			
Nonidentity				
Mean	47.76	60.17	64.69	61.87
SD	16.70	12.75	15.28	15.73
Identity				
Mean	40.19	45.28	48.28	50.76
SD	17.92	10.00	12.61	15.20

**The units of measurement are: linear size and distance judgments in centimeters and angular size judgments in degrees.*

stimuli ranged from 1.32 deg for the smallest linear size at the farthest distance to 30.7 deg for the largest linear size at the closest distance. The training trials for the identity condition were also divided into three blocks of 12 presentations. The stimuli and distances used in each block were randomly determined, with the constraints that (a) a stimulus appeared once, but no more than twice, over the three blocks, and (b) all 12 distances (10-120 cm in steps of 10 cm) be equally represented in each block.

For both conditions, feedback concerning the accuracy of the S's judgment was given in the second and third blocks of training. The feedback was in the form of correcting the S's response to the appropriate stimulus value. For example, if S overestimated the size of the stimulus, E said, "You have overestimated the size of the disk by this much," while pushing the movable marker to the correct separation with S still viewing the stimulus and holding the markers.

Experimental Procedure. The experimental trials were completed over 2 days, with the procedure being identical for all Ss. On each day, however, Ss were briefly retrained on the three judgments prior to the start of the experimental trials. The retraining procedure for the nonidentity condition entailed the random presentation of six stimuli, which were randomly paired with six distances, while for the identity condition, the presentation of the same stimulus at six successively larger distances. The stimuli and distances used were subsets of those used in training and differed on each day. In both conditions, Ss made their judgments consecutively, with feedback given after each response.

The experimental trials were conducted in a darkened room. One trial consisted of a linear size, angular size, and distance judgment of a stimulus at a given convergence distance. In the instructions for the experimental trials, E emphasized that similar stimuli would be presented and that, while no feedback would be given, S should make the three judgments in the same manner and in the same order as he had in training. The S was further instructed to make his judgments while viewing the stimulus, and only if he saw a single luminous disk with a tab on the top and bottom. The four convergence distances used (20, 50, 80, and 120 cm) occurred 12 times each over four blocks of 12 presentations. The order of occurrence of the distances was randomized within each block, with the distances being equally represented. The S completed two blocks of presentations on each of 2 days. The time interval between successive trials within each block was approximately 30 sec. During that time, S removed himself from the viewing position while E set the synoptiscope to a new convergence distance.

Results and Discussion

In addition to the experimental results, the results of training were also analyzed to determine whether the two training procedures introduced any systematic differences in the accuracy with which Ss made their judgments. Separate 2 by 3 (Training Procedure by Training Block) mixed-model analyses of variance on the constant and variable errors of linear size, angular size, and distance judgments revealed no significant training procedure main effects or Training Procedure by Training Block interactions.

The experimental results are presented in Table 1. In the computation of the results, the 12 responses made by each S were averaged to obtain a single score for linear size, angular size, and distance judgments at each convergence distance. Separate 2 by 4 (Training Procedure by Convergence Distance) mixed-model analyses of variance were performed on the scores for each type of judgment.[1]

Table 1 shows that closer convergence distances are associated with smaller judgments of linear size and angular size in both conditions. The analyses of variance revealed a significant convergence distance main effect for both types of judgments [$F(3,66) = 17.17$, $p < .001$, for linear size judgments and $F(3,66) = 13.50$, $p < .001$, for angular size judgments]. Over both conditions, then, increased convergence resulted in a decrease in the perceived linear size and angular size of the stimulus. These findings are consistent with the contention that there are two kinds of size changes with oculomotor adjustments. Also, the convergence distance main effect was found to be significant for distance judgments [$F(3,66) = 6.66$, $p < .001$], indicating that Ss, in general, perceived a decrease in the distance of the stimulus with increased convergence.

Table 1 also shows that the slopes of linear size and distance judgments on convergence distance are shallower (within the convergence distances of 20 and 80 cm, inclusive) in the identity condition than in the nonidentity condition. These results are consistent with the hypothesis concerning the occurrence of the size-distance paradox. That is, it can be argued that Ss in the identity condition tended to assume stimulus identity (i.e., the shallower slope in linear size judgments), which led to distance judgments in the direction of the size-distance paradox (i.e., a shallower slope or a slope closer to a negative slope). However, the pertinent statistics did not completely allow such a conclusion. Consistent with part of the hypothesis, both the training procedure main effect and the Training Procedure by Convergence Distance interaction were significant in the analysis on linear size judgments [$F(1,22) = 9.42$, $p < .01$, and $F(3,66) = 4.16$, $p < .025$, respectively] and nonsignificant in the analysis on angular size judgments [$F(1,22) = 0.89$ and $F(3,66) = 1.55$, respectively]. However, the Training Procedure by Convergence Distance interaction was not statistically significant [$F(3,66) = 0.76$] on distance judgments, although the training procedure main effect was significant [$F(1,22) = 6.51$, $p < .01$]. These results may be taken as evidence against the occurrence of a cue conflict in the situation where Ss assume stimulus identity. Although the results on the linear size judgments appear to indicate that the experimental manipulation was effective in creating stimulus identity assumptions, the predicted consequences of such assumptions on the distance judgments did not occur.

However, a possible alternative interpretation is that the significant interaction found in the analysis on linear size judgments is due to an artifact in the training procedures used. A possible source of the artifact is the use of a smaller range of linear sizes in the identity condition (3-11 cm as compared to 1-23 cm in the nonidentity condition). Perhaps, due to this factor, Ss in the identity condition restricted the range of their linear size judgments. Hence, the significant interaction may not be due to the successful manipulation of the stimulus identity assumption.

Although the results are not consistent with the hypothesis concerning the occurrence of the size-distance paradox, they remain consistent with the hypothesis concerning the occurrence of two types of size changes with oculomotor adjustments. However, further support for the hypothesis would be obtained if the decrease in linear size judgments was greater than that of angular size judgments for a given decrease in convergence distance. But the results shown in Table 1 cannot be used for such an analysis, since linear size and angular size judgments have different metrics. Thus, for each S, the percentage change in his linear and angular size judgments from those made at the convergence distance of 120 cm were computed for the remaining three convergence distances. The hypothesis, then, predicts a greater percentage of reduction in linear size judgments than in angular size judgments at each convergence distance. In the assessment of this hypothesis, the data for all 24 Ss were combined inasmuch as the effects of the manipulation of the stimulus identity assumption are ambiguous.

The mean percentages for linear size judgments are −29%, −9%, and −4%, whereas those for angular size judgments are −19%, −2%, and −1% for the convergence distances of 20, 50, and 80 cm, respectively. (The negative percentages indicate a relative decrease in the judgments.) Although the differences are small, statistical analyses of the corresponding mean percentages revealed that the reduction in linear size judgments is greater than that of angular size judgments at the convergence distances of 20 and 50 cm [$t(23) = 3.3$, $p < .01$, and $t(23) = 2.1$, $p < .05$, respectively]. However, the percentage reduction in the two judgments did not differ significantly at the convergence distance of 80 cm [$t(23) = 1.4$]. Nevertheless, these results are consistent with the hypothesized occurrence of perceived linear size and angular size changes with oculomotor adjustments.

The results of Experiment I provide clear evidence that oculomotor adjustments to a stimulus whose retinal image size remains constant produce changes in both the perceived linear size and angular size of the stimulus. However, the results provide support neither for nor against the hypothesized basis of distance perception under such conditions. The difficulty in an adequate assessment of the hypothesis is probably due to the ineffectiveness of training to create assumptions of stimulus identity. This interpretation, that the use of training was not effective, is reasonable, as Epstein (1967) points out that the use of training has generally been unsuccessful in manipulating Ss' assumptions about the experimental situation. Thus, Experiment II was designed to create different assumptions of stimulus identity within the experimental situation.

EXPERIMENT II

The underlying idea behind Experiment II was to create different tendencies to assume stimulus identity by employing different viewing conditions in the experimental situation. One viewing condition involved changing the convergence angle while S was viewing the stimulus, and the second condition involved changing the convergence angle while S was *not* viewing the stimulus. The expectation was that Ss who continued to view the stimulus while convergence was being changed would more likely assume stimulus identity, and thus show an inverse relationship between distance judgments and convergence distance. Again, after training on such judgments, Ss were required to make scalar judgments of the linear size, angular size, and distance of the stimuli at different convergence distances.

Method

Subjects. The Ss, selected from the university community, were paid for their participation in the experiment. All 24 Ss had a visual acuity of at least 20/20 in each eye, and none of the Ss had participated in Experiment I. The Ss' ages varied from 16 to 30 years of age.

Apparatus. The apparatus were identical to those used in Experiment I, except for two modifications of the experimental apparatus. First, in order to effect a smooth, continuous change in convergence, a motor was attached to the synoptiscope to change the convergence angle at the rate of approximately 2 deg/sec. Second, since one group of Ss viewed the stimuli continuously, the horizontal diameters of the monocular stimuli in the synoptiscope could not be adjusted to nullify the

Table 2
Means and Standard Deviations for Linear Size, Angular Size, and Distance Judgments in Experiment II*

Condition		Convergence Distance 15	30	60
		Linear Size Judgments		
Discrete	Mean	5.16	7.24	9.00
	SD	1.65	1.66	3.51
Continuous	Mean	5.60	7.61	9.05
	SD	1.98	2.50	3.84
		Angular Size Judgments		
Discrete	Mean	7.31	8.55	8.89
	SD	2.35	2.17	2.49
Continuous	Mean	7.47	8.91	9.71
	SD	2.60	3.24	3.07
		Distance Judgments		
Discrete	Mean	23.16	30.62	38.88
	SD	9.79	9.45	15.10
Continuous	Mean	27.20	30.15	37.36
	SD	12.82	9.81	15.20

**The units of measurement are: linear size and distance judgments in centimeters and angular size judgments in degrees.*

artificial-pupil-accommodation effect. Each circular cutout from the black paper masks was 27.0 mm in diam and subtended a visual angle of 9.9 deg at the farthest convergence distance and 9.4 deg at the nearest distance. To ascertain whether or not proper fusion of the stimuli had occurred, a black dot was painted on the left side of one monocular stimulus and on the right side of the other. With proper fusion, S saw a single luminous disk with a dot on the right and on the left.

Experimental Design. Two viewing conditions comprised the major experimental variable, with (a) the continuous condition designed to create a bias in favor of assuming stimulus identity, and (b) the discrete condition designed to create a bias against assuming stimulus identity. For both conditions, three convergence distances of 15, 30, and 60 cm were presented in sets of three trials, with each set representing one of the six possible permutations of the three distances. The order of presenting the six sets was randomly determined. All 24 Ss completed the two viewing conditions, but were randomly assigned to perform either the continuous or the discrete condition first. Each S was also assigned to one of the counterbalanced orders of linear size, angular size, and distance judgments, which he followed for both training and experimental trials.

Training Procedure. Each S was tested individually on 2 days, with the first day again solely concerned with training. All Ss followed the same training procedure, with the procedure being highly similar to that followed by the nonidentity condition in Experiment I. The Ss were shown a sample stimulus and told that they would be required to make size, angle, and distance judgments of similarly shaped stimuli, where the definitions of size, angle, and distance were identical to those given in Experiment I. The Ss were trained on one judgment at a time, receiving the same type of feedback concerning the accuracy of their responses from the first block of training. For training on linear size judgments, a set of 12 stimuli of different linear sizes (1-23 cm in steps of 2 cm) was presented twice in two blocks of 12 trials. In each block, each of the stimuli was randomly paired with one of four distances (10, 20, 40, or 80 cm), with the constraint that all distances be equally represented. The training procedure for angular size judgments was similar, except that 24 stimuli of different angular sizes (2.1-13.8 deg in approximately equal steps) were used. The training procedure for distance judgments employed a metal rod, which was randomly presented at eight different distances (10-80 cm in steps of 10 cm) three times over three blocks of eight presentations. In this case, the horizontal angular size of the rod varied from 3.44 to .76 deg. Each distance appeared once in each block of presentations.

Experimental Procedure. The experimental session followed 1 or 2 days after the training session. Prior to the start of the experimental trials, Ss received retraining on the three judgments. The retraining procedure involved the random presentation of eight stimuli of different linear sizes randomly paired with eight different distances. Each S made the three judgments consecutively, following his assigned counterbalanced order, with feedback given after each response.

The instructions for the experimental trials were the same as those given in Experiment I. One experimental trial consisted of a linear size, angular size, and distance judgment of the stimulus at a given convergence distance. For each set of three convergence distances, Ss in the continuous condition continued to view the fused stimulus as E gradually changed the convergence angle, whereas Ss in the discrete condition removed themselves from the viewing position after every trial. In the discrete condition, a curtain prevented S from seeing the change in the angle of the eyepieces. The trials were separated by an interval of approximately 20 sec, with a 5-min break after every nine trials. In each viewing condition, Ss completed 18 trials, with a different randomized order of the six sets of three convergence distances being used in each condition. During each break, S was reminded to report what he saw and not what he thought was there. The experiment was conducted in a darkened room.

Results and Discussion

The basic data from each S consisted of a single score, based on six replications, for linear size, angular size, and distance judgments of the stimulus at each convergence distance in the two viewing conditions. A 2 by 2 by 3 (Order by Condition by Convergence Distance) mixed-model analysis of variance was performed on the data for each type of judgment. Since, in all three analyses, the main effect of order and its interactions with the other variables were found to be nonsignificant, the scores were averaged over Ss in each viewing condition. The resulting means and standard deviations are presented in Table 2.

All of the analyses of variance also showed that the main effect of convergence distance was significant for the three judgments [$F(2,44) = 21.8$, $p < .001$, $F(2,44) = 24.5$, $p < .001$, and $F(2,44) = 31.5$, $p < .001$, for linear size, angular size, and distance judgments, respectively]. An examination of Table 2 reveals that all three judgments decreased with decreasing convergence distance. Thus, these results again indicate that increased convergence leads to a perceived decrease in the linear size, angular size, and distance of the stimulus.

However, the results of interest are any differences produced by the two viewing conditions, since they are pertinent to the hypothesis that whenever stimulus identity is assumed, Ss would show an inverse relationship between distance judgments and convergence distance. As expected, the two viewing conditions did not affect the Ss' judgments of angular size. Neither were the main effect of condition nor its interaction with convergence distance significant [$F(1,22) = 2.77$ and $F(2,44) = 2.00$, respectively]. With respect to distance judgments, the stringent prediction was that the slope of distance judgments on convergence distance would be negative in the continuous condition and positive in the discrete condition. A less stringent prediction was to obtain a steeper slope in the discrete condition. This latter expectation was confirmed by a significant Condition by Convergence Distance interaction in the analysis on distance judgments [$F(2,44) = 5.7$, $p < .05$]. As Table 2 shows, the significant interaction is due to the greater change in distance judgments with convergence distance in the discrete condition.

Although the results of distance judgments suggest that an inverse relationship between perceived distance and convergence distance is more likely to occur for a condition in which Ss are more apt to assume stimulus identity, such an argument is not supported by the results of linear size judgments. A stringent prediction was that the slope of linear size judgments on convergence distance would be zero in the continuous condition and positive in the discrete condition. However, even the less stringent prediction, based upon the results of distance judgments, that the slope would be steeper in the discrete condition, was not confirmed. The condition main effect and, more importantly, the Condition by Convergence Distance interaction were both nonsignificant in the analysis on linear size judgments [$F(1,22) = 0.98$ and $F(2,44) = 1.43$, respectively].

These results, then, place the hypothesis concerning the basis of distance judgment in an awkward position. The results seem to support the prediction concerning the outcome of a different relationship between distance judgments and convergence distance in the two viewing conditions, but the hypothesized reason for such a relationship finds no support. However, it might be argued that a predicted interaction based on a positive and on a negative slope is easier to confirm than a prediction based on a zero and a positive slope, given the sample size employed. This argument may be particularly cogent when the Condition by Convergence Distance interaction for distance judgments is not overwhelming. With this reasoning, the data of five Ss who showed an inverse relationship between distance judgments and convergence distance in the continuous condition, but a direct relationship in the discrete condition, were selected for examination. The means of their linear size judgments were obtained for each viewing condition and appear in Table 3.

No statistical analyses were conducted on the results shown in Table 3 because of the small number of Ss. An examination of the means in Table 3 does suggest, however, that the slope of linear size judgments on convergence distance is steeper in the discrete condition for these five Ss.[2] Such results imply that with a larger sample or with a different experimental procedure, the hypothesized relationship between perceived linear size and distance might possibly be confirmed.

Table 3
Means of Linear Size Judgments for Five Selected Subjects

Condition		Convergence Distance 15	30	60
Discrete	Mean	5.43	6.61	6.86
	SD	1.88	2.00	1.89
Continuous	Mean	5.99	6.87	6.46
	SD	1.71	1.48	1.07

Note—Means are in centimeters.

GENERAL DISCUSSION

The overall results of both experiments clearly indicate that increased convergence to a stimulus whose retinal image size remains constant results in the perceived decrease of its linear size, angular size, and distance. Also, the results of Experiment I show that the change in perceived linear size is greater than the change in perceived angular size for a given change in convergence distance, while those in Experiment II show that the relationship between convergence and perceived distance can vary as a function of the experimental situation. These results have several implications. First, the results imply that the concept of the angular size of a stimulus is a valid one and indicates the importance of distinguishing it from the linear size of the stimulus. The discrepancy in the literature with respect to the quantitative relationship between oculomotor adjustments and perceived size is probably due to the failure of previous investigators to make this distinction. Second, the results of distance judgments in Experiment II suggest that the equivocal results obtained in the assessment of convergence as a cue to distance is not surprising inasmuch as differing experimental situations yield different relationships between convergence and perceived distance. Nevertheless, the present results do show that convergence is a cue to perceived distance, albeit not a precise cue, and that the distance information provided by oculomotor adjustments is used in the perceptions of the linear size and angular size of the stimulus. Finally, although the results are not entirely clear, they do suggest that relative angular size can serve as a cue to distance in the present experimental situation.

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NOTES

1. For both Experiment I and Experiment II, the data were also analyzed using results based on the median rather than the mean. However, since the results based on the median data were essentially identical to that based on the mean data, only the latter are reported.

2. Similar results were found in Experiment I when Ss were divided into those who showed a direct relationship and those who showed an inverse relationship between convergence distance and distance judgments; Ss in the latter group showed very little change in linear size judgments with changes in convergence (see Komoda, 1970).

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