Vision Res. Vol. 16. pp. 193–198. Pergamon Press 1976. Printed in Great Britain.

THE ROLE OF CONVERGENCE IN VISUAL SPACE PERCEPTION[1]

CLAES VON HOFSTEN
Department of Psychology, University of Uppsala, Trädgårdsgatan 20, S-75220 Uppsala, Sweden

(*Received* 19 *November* 1974; *in revised form* 2 *April* 1975)

Abstract—Earlier experiments suggest that the perception of relative and absolute distance in binocular space is affected by the convergence angle to the stimulus. The question is how? A hypothesis was proposed in which the obtained effects are accounted for in terms of convergence differences. The hypothesis states that binocular stimuli are related to the rest convergence of the eyes which is assumed to be stable. Two experiments were conducted in which distance estimations were made to single binocular dots, viewed through a polarization stereoscope. The experimental results support the proposed hypothesis.

Ever since Berkeley (1709), the role of convergence in binocular space perception has been much discussed. Experimental results do not support the hypothesis that veridical perception of distances is based on convergence, but neither do they support the opposite hypothesis, i.e. that no relation exists between convergence and perceived distance. The present article is an attempt to explain the experimental results obtained and to determine the role of convergence in visual space perception. The notation which shall be used is illustrated in Fig. 1.

P_n, P_f:	points in the binocular field,
D_n, D_f:	egocentric distances of the points from the eyes ($D_f > D_n$) in cm,
d_{fn}:	the distance between P_n and P_f,
i:	interpupillary distance,
γ_n, γ_f:	convergence angles of the points in radians,
γ_a:	convergence angle of the eyes in the absence of visual stimuli (rest convergence) in radians,
Γ_{nf}:	horizontal disparity between P_f and P_n,
Γ_{fa}, Γ_{na}:	the retinal displacement of each dot at rest convergence,
D'_n, D'_f:	perceived egocentric distances of the points in cm,
d'_{fn}:	perceived distance between P_f and P_n.

Geometrically, the convergence angle varies in a systematic way with radial distance. If the convergence angle is small, this relation can be expressed as,

$$D_f = \frac{i}{\gamma_f}. \tag{1}$$

If the absolute convergence of the eyes determines perceived distance, then

$$D'_f = \frac{K}{\gamma_f} \tag{2}$$

where K is a constant.

Numerous attempts have been made to establish a relationship between convergence angle and perceived egocentric distance to a single binocular dot. Most of the relevant literature has been extensively reviewed by Woodworth (1938), Woodworth and Schlosberg (1954) and Linschoten (1956). The results of these experiments are not unambiguous, but on the whole they indicate that there is a relation between convergence angle and perceived egocentric distance at least on an ordinal level (see e.g. Grant, 1942; Gogel, 1961; Foley and Held, 1972). However, the perceived distance does not change as much with convergence angle as predicted by equation (2).

It is also possible to establish the role of convergence in visual space perception by measuring perceived relative distances in stereoscopic space. Relative depth distances in physical space are jointly specificed by disparity and convergence angle:

$$\frac{\Gamma_{nf}}{\gamma_n} = \frac{d_{fn}}{D_f}. \tag{3}$$

If both disparity and absolute convergence are effective determinants of perceived space, then

$$\frac{d'_{fn}}{D'_f} = \frac{K \cdot \Gamma_{nf}}{\gamma_n} \tag{4}$$

where K is a constant. Equation (4) states that perceived relative distance is determined by the ratio of disparity to convergence.

Increasing the convergence to each object in a binocular configuration by an equal amount would change the perceived relative distances within the configuration, if equation (4) is correct. A group of studies done to test the implications of Luneburg theory of binocular space perception (Hardy, Rand,

[1] The author is indebted to Professor Gunnar Johansson for valuable discussions. This investigation was made possible by grants to the author from the Swedish Council for Social Science Research.

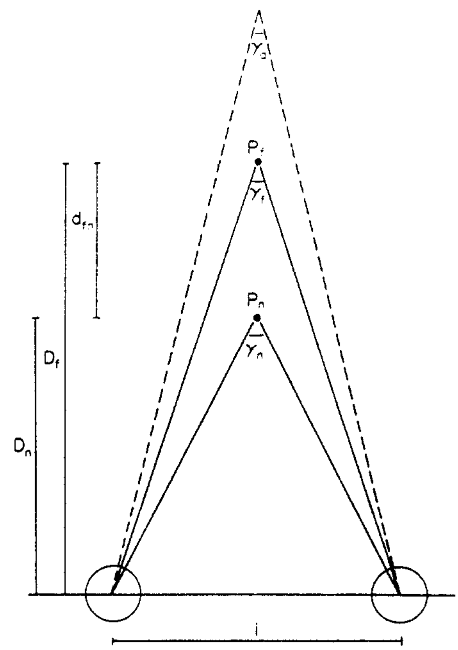

Fig. 1. Illustration of the notation used in the present article.

Rittler, Blank and Boeder, 1953; Blank, 1953, 1958) do suggest that this is not the case. In other words, perceived relative distance seems to be a function of disparity only and not of convergence. Experiments by Foley (1976b) indicate that this statement can only be approximately correct. He found that as the convergence angle to the configuration increases, more disparity is required to maintain a constant ratio. However, the increase in disparity with convergence angle was not as great as predicted by equation (4).

THE HYPOTHESIS

The statement by Blank (1953) that the visual system is sensitive only to convergence differences and not to absolute convergence seems to imply that the perceived relative distance between two points in space is determined only by the disparity between these two points. The statement also seems to imply that no relation exists between absolute convergence angle and perceived egocentric distance. These implications are, however, not necessarily true. It is quite possible to explain obtained effects of convergence angle on perceived relative distances in a binocular configuration, and on perceived egocentric distance to a single binocular point, in terms of convergence differences.

Woodworth (1938) has stated that convergence is in itself a reaction to visual stimuli, the most important of which is double images. Double images are defined as the difference in convergence between the binocular stimulus and the rest convergence of the eyes, i.e. the convergence of the eyes in the absence of visual stimuli. If the presence of double images is the effective determinant of the perceived egocentric distance to a binocular point or a binocular configuration, then it is necessary to postulate that the rest convergence is relatively stable. It is here suggested that in the absence of visual stimuli the convergence is always at the same rest value (γ_a). The double images which arise when presenting a single binocular point P_n would then be,

$$\Gamma_{na} = \gamma_n - \gamma_a. \tag{5}$$

The present hypothesis states that the perceptual system is insensitive to the absolute convergences γ_n and γ_a but sensitive to the convergence difference Γ_{na}. The perceived distance to the binocular point P_n is thus not determined by the absolute convergence angle (γ_n) but by the departure of the point from the rest convergence (Γ_{na}).

The hypothesis does not say anything about how the convergence difference in question is registered by the perceptual system. It could be visually and directly registered through the double images which arise when presenting the binocular stimulus, but it is also conceivable that it is indirectly registered through the kinesthetic sensations which arise when the eyes converge on the stimulus as a response to the double images.

The hypothesis implies that the stimulus scale is an interval scale where differences are correctly defined but not the absolute level. This implication is essentially the same as that of von Kries (von Kries, 1925, p. 384), although von Kries applied his hypothesis on the perception of binocular configurations. Von Kries stated that the relative parallax (i.e. convergence difference) between two points P_n and P_f is the same as the relative parallax between the perceived positions P'_n and P'_f of the points. If the absolute parallax of a point is expressed as i/D [see equation (1)], the rule is simply that

$$\frac{1}{D_n} - \frac{1}{D_f} = \frac{1}{D'_n} - \frac{1}{D'_f}. \tag{6}$$

The implication of the hypothesis regarding the perception of a single binocular point

It follows from equations (1) and (5) that egocentric distances in physical space can be expressed as,

$$D_f = \frac{i}{\gamma_a + \Gamma_{fa}}. \tag{7}$$

Since the visual system is assumed to be insensitive to absolute convergence, γ_a is replaced by a constant A. Perceived egocentric distance in binocular space can thus be expressed as

$$D'_f = \frac{K}{A + \Gamma_{fa}} \tag{8}$$

where K is a constant which depends both on the S and on the task. The choice of the numerical value of the rest convergence (γ_a) for the calculations of Γ_{fa} is not of critical importance for the predictions of perceived egocentric distances. As the rest convergence is a constant, the choice would only affect the numerical value of A. According to Alpern (1962, p. 97), the convergence angle in the absence of visual stimuli usually measures very close to zero. For reasons of simplicity Γ_{fa} is here always calculated as the departure of convergence from 0°.

Equation (8) states that the perceived egocentric distance to a single binocular point is inversely related to the departure of the point from rest convergence. The relative properties of the perceived egocentric distance scale are the following.

(1) If D'_n and D'_f are the perceived egocentric distances to the points P_n and P_f in space, then the ratio of the two perceived egocentric distances can be expressed as

$$\frac{D'_n}{D'_f} = \frac{A + \Gamma_{fa}}{A + \Gamma_{na}}. \tag{9}$$

(2) If follows from equation (9) that the perceived relative distance between P'_n and P'_f, (d'_{fn}/D'_f), can be expressed as

$$\frac{d'_{fn}}{D'_f} = \frac{\Gamma_{na} - \Gamma_{fa}}{A + \Gamma_{na}}. \tag{10}$$

EXPERIMENT 1

The purpose of experiment 1 was to test the implications of the present hypothesis regarding the perception of a single binocular point.

The results of earlier attempts to establish a perceived egocentric distance scale to a single binocular object are rather unclear, as noted above. One of the reasons for the ambiguity might be that most of the earlier *E*s have used a binocular object extended in size. The visual angle of the object has thereby been held constant. If the perceived distance to such an object is varied the perceived size varies too: the shorter the perceived distance, the smaller the perceived size. The perceived change in size may have rather serious effects on the estimation of distance (see e.g. Bappert, 1923). In order to avoid any such complications a binocular dot of negligible size was used in experiment 1. This method was successfully used by Foley and Held (1972), who showed that subjects were able to order correctly the distances to a single binocular dot of neglible size at five different convergence angles, covering a range of approx 10°–20°.

Method

Apparatus. An oscilloscope (Tectronix 565) was used to generate the stimuli which consisted of two dots. The oscilloscope was connected to a device that could make each dot alternate between two positions on the screen in such a way that the dots were simultaneously displaced toward or away from the vertical diameter of the screen. The amount of displacement was controlled by the aid of a potentiometer. The outer positions of the dots were individually controlled by the aid of two other potentiometers. When the dots changed from one position to the other there was a pause with nothing appearing on the screen. The exposure times and the pause times were individually controlled by the aid of an electronic timer device with a precision of 1 msec. Four small lights on the instrument panel of the electronic timer device indicated continuously the phase of the presentation cycle. The subjects looked at the CRT screen through a 46-cm long tube covered on the inside with black velvet. Just in front of the screen two polarized filters (HN 22) were placed, one on each side of the vertical diameter of the screen. In the other end of the tube another pair of polarized filters were placed, so arranged that the left dot could only be seen by the left eye and the right dot only by the right eye. The optical device is diagrammed in Fig. 2. The subject looked into the tube through a rubber mask which prevented any light from the room to enter the tube.

Stimuli. The stimuli consisted of two dots positioned on the same horizontal line on the CRT screen. The dots were about 0·6 mm dia corresponding to a visual angle of approx 4·5′. The intensity of the dots was set individually for each subject just above threshold value. The dots were symmetrically positioned around the center of the screen and each dot alternated between two positions in a cyclic course as described above. Six stimuli were used in experiment 1. The distance between the two dots in their outer position was 16, 24, 32, 40, 48 or 56 mm, corresponding to convergence angles of approx 6°, 5°, 4°, 3°, 2° and 1°, respectively. The distance between the dots in their inner position was always 8 mm less than in their outer position corresponding to an increase in convergence angle of approx 1°. The dots were exposed 1 sec in each of their two positions. The pause time between each exposure was always 1·5 sec.

Procedure. The *S* had the following three tasks in experiment I:

(1) The *S* was asked to determine whether the binocular dot alternating between two angles of convergence was seen to alternate between two positions in depth or not. If the binocular dot was seen to alternate between two positions in depth, the *S* was further asked to determine when the dot was nearest to him and when it was farthest away from him.

(2) The *S* was asked to estimate on a meter scale the egocentric distance to the perceived farthest position of the dot.

(3) After the presentation a paper with a 25-cm long line on it was given to the *S*. He was told that the line symbolized the distance to the perceived farthest dot, and was asked to put a cross on the line where the nearest dot should be.

The general procedure was as follows. Before each presentation the room was darkened. The *S* was then asked to look into the stereoscope where the stimulus appeared in a random phase of its cyclic course. The inspection time was free. Before instructing the *S* of his three tasks, one test stimulus was given to him which he was asked to describe in general terms. After the instruction another three test trials were given to the *S* in order to see if the instruction had been correctly understood. After that, each stimulus was presented four times in randomized order, giving a total of 24 presentations.

Subjects. Twelve *S*s participated in experiment 1. The *S*s had a stereoscopic acuity of at least 83″ as measured by the Bausch–Lomb Ortho-Rater.

Results

All *S*s but one consistently perceived the dot to be farthest away in the position of the smallest convergence angle.

Of the remaining 11 *S*s, another two were excluded from the data treatment. The first one of these showed no relation whatsoever between perceived egocentric

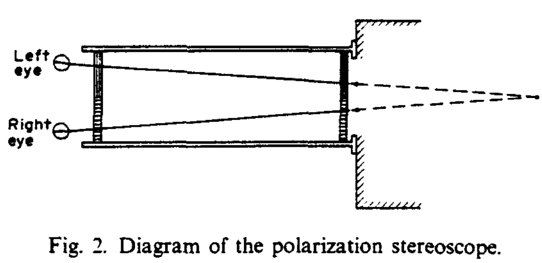

Fig. 2. Diagram of the polarization stereoscope.

distance and convergence angle, his estimations ranging in a random way from 1 to several hundred meters. The second one showed an increase in estimated distance with decreasing convergence angle but considerably less consistent than for the remaining nine *Ss*. The means of the estimations of egocentric distance for each of the remaining nine *Ss* are shown in Table 1.

The total means of estimated distance were used for the calculations of the constants A and K. A was calculated for each of the 15 possible stimulus pairs [equation (9)]. The mean of these calculations was 0·036 and was used as an estimation of A. K was then calculated for each of the six stimuli [equation (8)]. The mean of these calculations was 6·88 and was used as an estimation of K. It should be noted here that the obtained value of K is approximately the same as the interocular distance. The theoretical egocentric distance scale is shown in Fig. 3 together with the total means for each of the measured convergence angles.

Figure 3 shows that there is a very close correspondence between the predicted and the obtained increase in perceived egocentric distance with decreasing convergence angle. The theoretical curve intersects the distance axis at 191·3 cm, this value corresponding to the predicted perceived egocentric distance to a dot with a convergence angle of 0°.

The means of the estimations of relative distance for each of nine *Ss* are shown in Table 2. Table 2 shows that the estimations of relative distances are not as consistent as the estimations of egocentric distances although the total means do increase with decreasing convergence angle. The theoretical curve relating perceived relative distance (d'_f/D'_f) and departure from rest convergence for a constant difference in convergence of 1° between the two positions of the dot is shown in Fig. 4 together with the total means for each of the measured convergence angles. The correspondence between predicted and obtained values in Fig. 4 is not at all as clear as the correspondence between predicted and obtained values in Fig. 3. It should be noted here, however, that the predicted relation has been calculated from the absolute distance estimations and not from the relative distance estimations. In spite of this the absolute level of the

Table 1. The means of the estimations of egocentric distance in cm for each of nine *Ss* in experiment 1

Subject	Convergence angle 6°	5°	4°	3°	2°	1°
1	57.50	63.75	68.75	63.75	72.50	88.75
2	52.50	60.00	70.00	81.25	102.50	132.50
3	46.25	56.70	55.00	60.00	80.00	102.50
4	57.50	65.00	73.75	90.00	91.25	112.50
5	36.25	42.50	50.00	80.00	120.00	192.50
6	46.25	62.50	68.75	91.25	132.50	155.00
7	52.50	67.50	85.00	115.00	132.50	225.00
8	50.00	42.50	52.50	55.00	70.00	82.50
9	42.50	38.75	50.00	61.25	76.25	92.50
tot.mean	49.04	55.48	63.77	77.51	97.51	131.53

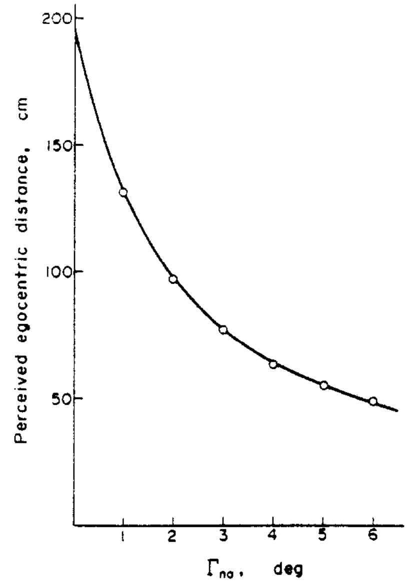

Fig. 3. The relation between perceived egocentric distance and departure from rest convergence (Γ_{na}). The rest convergence is assumed to be 0°.

Table 2. The means of the estimations of relative distance (d'_{fn}/D'_f) in per cent for each of nine *Ss* in experiment 1

Subject	Convergence angle at the far position 6°	5°	4°	3°	2°	1°
1	19.0	18.5	20.5	20.6	23.5	14.5
2	14.0	11.0	11.0	18.0	14.0	10.5
3	14.3	20.0	15.0	25.3	16.8	16.8
4	12.8	11.0	18.8	18.5	13.5	16.8
5	11.5	11.7	10.3	15.5	12.8	12.0
6	9.0	11.5	10.0	14.0	15.5	21.0
7	11.8	17.8	17.5	20.5	20.0	20.8
8	13.0	15.0	17.5	16.5	17.8	23.0
9	23.0	18.8	31.3	26.3	20.0	20.7
tot.mean	14.3	15.0	16.9	19.4	17.1	17.3

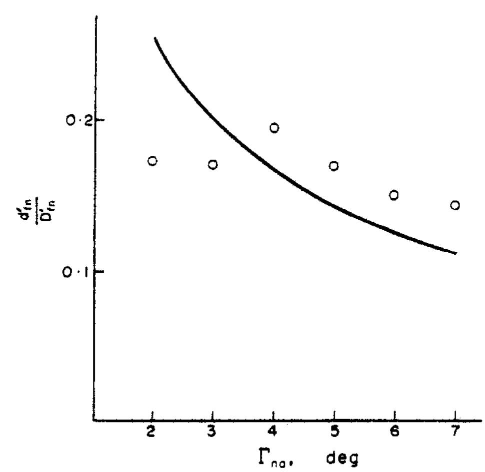

Fig. 4. Perceived relative distance (d'_{fn}/D'_f) as a function of the departure of the perceived nearest dot from rest convergence (Γ_{na}). The rest convergence is assumed to be 0°.

predicted relation corresponds to the absolute level of the obtained estimations.

Experiment 1 was repeated with the same *Ss* but five other stimuli. The convergence angle to the perceived farthest position of the dot was 1°, 2°, 3°, 4° and 5° and the difference in convergence angle between the two positions of the dot always was 2°. The result was essentially the same as that of experiment 1. The correspondence between the predicted and obtained values was remarkably good for the estimation of egocentric distance and somewhat poorer for the estimation of relative distance.

Conclusions

It is concluded from experiment 1 that the convergence angle of a single binocular dot is clearly related to perceived egocentric distance: the smaller the convergence angle the larger is the perceived egocentric distance to the dot. The egocentric distance judgements further support the hypothesis that it is the departure from rest convergence that determines perceived egocentric distance and not the absolute convergence.

EXPERIMENT 2

In experiment 1, a very short time occurred between the moment at which the subject was looking into the lightened room and the moment at which he was looking into the stereoscope. It is possible that the room served as a frame of reference for the estimations of egocentric distance and increased the precision of them. The purpose of experiment 2 was to further test the present hypothesis in a situation lacking any such frames of reference. This was achieved by letting the *S* close his eyes before and between the presentations of the stimuli throughout the experiment.

Method

The same apparatus used in experiment 1 was used in experiment 2.

Stimuli. The stimuli consisted of two dots positioned on the same horizontal line symmetrically around the center of the screen. The intensity of the dots was set individually for each subject just above threshold value. Six stimuli were used in experiment 2. The distance between the two dots was 16, 24, 32, 40, 48 or 56 mm, corresponding to convergences of approx 6°, 5°, 4°, 3°, 2° and 1°, respectively.

Procedure. Before the experiment the *S* was asked to close his eyes. After 1 min the room was darkened, the *S* was asked to put his head into position in the rubber mask and then to open his eyes and look at the stimulus. The *S* was then asked to estimate the egocentric distance to the dot on a meter-scale. When the *S* had given his report he was asked to close his eyes again. After 1 min the procedure was repeated with a new stimulus. Thus, the *S* had his eyes closed throughout the experiment except when looking at the stimuli. Each stimulus was presented four times in randomized order, giving 25 presentations including one test trial.

Subjects. Thirteen subjects participated in experiment 2. The *Ss* had a stereoscopic acuity of at least 83″ as measured by Bausch–Lomb Ortho-Rater.

Results

Three *Ss* showed no relation between perceived egocentric distance and convergence angle and were therefore excluded from the data treatment. The means of the estimations of egocentric distance for each of the remaining 10 *Ss* are shown in Table 3.

Table 3 shows that the estimations of egocentric distance are remarkably consistent in spite of the fact that no frame of reference was supplied before or after the presentations of the stimuli. The absolute level and the range of the perceived egocentric distance scale determined by the constants in equation (8) differ somewhat more between the *Ss* than in experiment 1, however. The constant A and the constant K were calculated in the same way as in experiment 1. The obtained value of A and K was 0·014 and 7·32, respectively. A is smaller while K has approximately the same value as in experiment 1. The theoretical egocentric distance scale is shown in Fig. 5 together with the total means for each of the measured convergence angles. Figure 5 shows that there

Table 3. The means of the estimations of egocentric distance in cm for each of the 10 *Ss* in experiment 2

	Convergence angle					
Subject	6°	5°	4°	3°	2°	1°
1	72.5	102.5	110.0	165.0	237.5	272.5
2	48.8	52.5	83.8	105.0	131.2	146.2
3	55.0	81.2	85.0	116.2	157.5	187.5
4	100.0	117.5	152.5	152.5	182.5	235.0
5	65.0	80.0	90.0	125.0	200.0	293.8
6	27.5	32.5	40.0	50.0	62.5	85.0
7	32.5	38.8	53.8	90.0	143.8	256.2
8	52.0	61.3	80.0	111.3	170.0	280.0
9	63.8	76.7	81.3	86.3	106.3	123.8
10	82.5	102.5	117.5	145.0	152.5	182.5
tot.mean	60.0	74.6	89.4	114.6	154.4	206.3

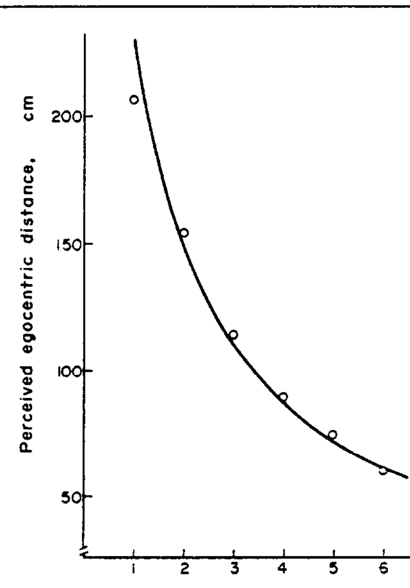

Fig. 5. The relation between perceived egocentric distance and departure from rest convergence (Γ_{na}). The rest convergence is assumed to be 0°.

is a close correspondence between the predicted and the obtained increase in perceived egocentric distance with decreasing departure from rest convergence. The theoretical curve intersects the distance axis at 518 cm, this value corresponding to the predicted perceived egocentric distance to a dot with a convergence angle of 0°.

DISCUSSION

The results of experiment 1 and 2 confirm the predictions of the present hypothesis, which states that perceived egocentric distances in binocular space are determined by convergence differences and not by absolute convergences. The convergence difference that can be utilized by the perceptual system in the perception of a single binocular point is the one between the stimulus and the rest convergence, i.e. the convergence of the eyes in the absence of visual stimuli. If the rest convergence is assumed to be stable, the predicted relation between perceived egocentric distance and departure from rest convergence will be in accordance with equation (8). There is a close correspondence between equation (8) and the empirical data in experiments 1 and 2.

Foley's (1967) experiment regarding the perception of binocular configurations further support the present hypothesis. Foley found that there is an approximately linear increase in disparity with convergence for constant perceptual criteria. The absolute level of the relation was found to be determined by a constant dependent on the task and on the subject. If the present hypothesis is correct then equation (4) should be rewritten as,

$$\frac{d'_{fn}}{D'_f} = \frac{K \cdot \Gamma_{nf}}{A + \Gamma_{na}}. \tag{11}$$

The implication of equation (11) is in accordance with the results obtained by Foley.

The results of the present investigation do not say anything about how the convergence differences in question are registered by the perceptual system. They could be visually and directly registered through the double images which arise when presenting the binocular stimulus, but it is also conceivable that they are indirectly registered through the kinesthetic sensations which arise when the eyes converge on the stimulus as a response to the double images. The visual hypothesis is attractive for the reason that all binocular space perception would then be explained in terms of retinal disparities, where double images are regarded as a special form of disparity. On the other hand, experiments by Foley and Richards (1972) indicate that depth increases with disparity up to at most 4°, and over most of this range the increase is much less than the present data would require. It therefore seems necessary to assume at least some sort of interaction between vision and proprioception in this case.

Since the results of the present investigation imply that the perceptual system is only able to register convergence differences, the perceived egocentric distance scale has to be calibrated in some other way. In a full-cue situation the scale will probably be almost perfectly calibrated with the aid of monocular visual information. However, in most experiments on binocular depth perception, including these in the present article, all monocular information is eliminated. The calibration of the perceived egocentric distance scale in such a situation is probably determined by the Specific Distance Tendency (Gogel, 1969), i.e. the tendency to perceive objects in the absence of ordinary cues to depth at an intermediate value. When the eyes are at rest position the perceived distance most likely corresponds to this Specific Distance Tendency. If the rest convergence is 0° the Specific Distance Tendency would then be 191·3 cm in experiment 1 and 518 cm in experiment 2. These values are somewhat higher than those obtained by Gogel (*op. cit.*), which points to the possibility that the rest convergence may be greater than 0°. Evidence obtained by Schober (1954) and Leibowitz (1973) concerning the resting position of accommodation supports this conclusion. They found that the resting position of accommodation is not at infinity but rather in the vicinity of an arm's length.

REFERENCES

Alpern M. (1962) Movements of the eyes. In *The Eye* (Edited by Davson H.), Vol. 3. Academic Press, London.

Bappert J. (1923) Neue Untersuchungen zum Problem des Verhältnisses von Akkomodation und Konvergenz zur Wahrnehmung der Tiefe. *Z. Psychol.* **90**, 167–203.

Berkeley G. (1709) *An Essay Towards a New Theory of Vision*. Jeremy Pepyat, Dublin (Reprint 1922—Dutton, New York).

Blank A. A. (1953) The Luneberg theory of binocular space. *J. opt. Soc. Am.* **43**, 717–727.

Blank A. A. (1958) Analysis of experiments in binocular space perception. *J. opt. Soc. Am.* **48**, 911–925.

Foley J. M. (1967a) Binocular disparity and perceived relative distance: an examination of two hypotheses. *Vision Res.* **7**, 655–670.

Foley J. M. (1967b) Disparity increase with convergence for constant perceptual criteria. *Percept. Psychophys.* **2**, 605–608.

Foley J. M. and Held R. (1972) Visually directed pointing as a function of target distance, direction and available cues. *Percept. Psychophys.* **12**, 263–268.

Foley J. M. and Richards W. (1972) Effects of voluntary eye movement and convergence on the binocular appreciation of depth. *Percept. Psychophys.* **11**, 423–427.

Gogel W. C. (1961) Convergence as a cue to absolute distance. *J. Psychol.* **52**, 287–301.

Gogel J. M. (1969) The sensing of retinal size. *Vision Res.* **9**, 1079–1094.

Grant V. W. (1942) Accommodation and convergence in visual space perception. *J. exp. Psychol.* **31**, 89–104.

Hardy L. H., Rand G., Rittler M. C., Blank A. A. and Boeder P. (1953) The geometry of binocular space perception. Knapp Memorial Laboratories, Institute of Ophthalmology, Columbia University, New York.

Leibowitz H. W. (1973) The resting position of accommodation and its implications for space perception. Preliminary draft prepared for the U.S.–Japan cooperative science program symposium on space and motion perception, Honolulu.