Oculomotor adjustments in darkness and the specific distance tendency

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Two experiments were performed to investigate the relationship between the oculomotor adjustments assumed in total darkness and perceived distance under reduced visual conditions. Experiment I compared the dark focus of accommodation with the perceived distance of a monocular light point presented in a dark environment. Experiment II compared the convergence angle assumed in darkness (dark convergence) with the perceived distance of the light point. Both accommodation and convergence were found to assume intermediate values in darkness. Perceived distance of the monocular light point was significantly correlated with dark convergence and unrelated to the dark focus of accommodation. It was suggested that ocular vergence is a major determinant of perceived distance under reduced visual conditions, and thus provides a possible mechanism for the specific distance tendency.

The oculomotor responses are of primary importance to virtually every visual function. A clearly focused retinal image and, in the case of binocular viewing, accurate registration of the two images, are prerequisite for optimal sensitivity and acuity. Additionally, the oculomotor adjustments influence the perception of size and distance at near distances, particularly in the absence of contextual distance information (Gogel & Sturm, 1972; Grant, 1942; Harvey & Leibowitz, 1967; Heineman, Tulving, & Nachmias, 1959; Leibowitz & Moore, 1966; Leibowitz, Shiina, & Hennessy, 1972; Swenson, 1932). Hence, control or assessment of oculomotor adjustments is essential when measuring these psychophysical and perceptual functions.

The generally accepted theories of the oculomotor system assume that relaxation of the eyes is accompanied by adjustment for far distances (see Toates, 1972 and 1974, for reviews). Although this position is supported by observations of accommodation (Westheimer & Blair, 1973) and vergence (Toates, 1974) in deep anesthesia and death, a growing body of evidence suggests that the behavioral resting state, i.e., that assumed by an alert subject in the absence of adequate visual stimulation, is conjugate to an intermediate rather than a far distance. Early research on the etiology of night myopia (Campbell & Primrose, 1953; Otero, 1951; Palacios, 1943; Schober, 1954; Wald & Griffin, 1947) found that accommodation assumes an intermediate focal length of 1 to 2 diopters (D, meters⁻¹) under conditions of very low illumination. More recently, experiments utilizing the laser optometer have shown

that as luminance is lowered accommodation gradually shifts from a focus appropriate for the stimulus to an individually determined intermediate, resting or dark focus (Johnson, 1976; Leibowitz & Owens, 1975a). Shifts toward the intermediate dark focus also occur when observing a bright scene through small artificial pupils (Hennessy, 1975; Hennessy, Iida, Shiina, & Leibowitz, 1976; Leibowitz & Owens, 1975b), a bright interference pattern on the retina (Leibowitz & Owens, 1975a), and a bright field containing no contours or texture, a *Ganzfeld* (Leibowitz & Owens, 1975b). These data imply that whenever the visual stimulus is degraded by the reduction of luminance or contrast, or is not affected by changes in accommodation, the accommodative response will shift toward the individual's dark focus. Data from over 100 college students showed individual dark focus values to vary from 0 to 4 D (optical infinity to 25 cm), with a mean of 1.71 D (58 cm, Leibowitz & Owens, 1975b).

In a study of the effects of reduced luminance on binocular vergence, Ivanoff and Bourdy (1954; Ivanoff, 1955) describe an analogous phenomenon. As the luminance of binocular targets presented in the near periphery was lowered from 1 to 10⁻⁶ cd/m², convergence gradually shifted from an angle corresponding to the target distance to an intermediate angle that was independent of target distance and was attained in total darkness. Similar results were reported by Fincham (1962), who measured accommodation and vergence photographically "in the absence of retinal images." He found that both accommodation and convergence were adjusted to intermediate, but not equivalent, distances in total darkness. On the basis of these and related phenomena, several theories of accommodation (Morgan, 1946, 1957; Schober, 1954; Toates, 1972) and convergence (Toates, 1974) incorporate intermediate behavioral resting states.

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Since oculomotor adjustment serves as a distance cue, one would expect that, in the absence of contextual distance information, a reduction in stimulus effectiveness will result in a change in perceived distance corresponding to the shift in oculomotor adjustment toward the resting state. This result might be obtained, for example, by requiring the subject to observe a bright scene monocularly through a small artificial pupil, or by simply reducing the luminance of a binocularly viewed target. A number of studies have shown that when subjects judge the distance of an object in a situation which contains few contextual cues and minimal oculomotor stimulation, responses tend to correspond to an intermediate distance regardless of the true stimulus distance (Gogel, 1969, 1972; Grant, 1942; Mershon & Gogel, 1975). Gogel (1969, 1972) attributes such inappropriate distance perception to the "specific distance tendency," which he describes as a fundamental metric of the visual system. According to this view, if all conventional distance cues (including oculomotor adjustments) were eliminated, the specific distance tendency would be the sole determinant of perceived distance; to the extent that conventional cues remain, perceived distance represents an interaction between the available cues and the specific distance tendency.

Gogel and Tietz (1973) demonstrated the specific distance tendency by asking subjects to verbally estimate the distance of a single light point presented in a dark visual alley, and to also report any apparent motion of the light point when the subject moved his head from side to side. Earlier studies had indicated that when a single point of light is perceived to be nearer or farther than its actual physical distance, it appears to move in the same or opposite direction, respectively, with respect to head movements (Hay & Sawyer, 1969; Wallach, Yablick, & Smith, 1972). Hence, in addition to the verbal judgments, Gogel and Tietz were able to infer the perceived distance of the light point by determining the physical distance at which the apparent motion changed from "with" to "against" with respect to the subjects' lateral head movements. Both the verbal distance estimates and the motion judgments indicated that the distance to a far light point was underestimated and that to a near light point, overestimated. Qualitatively similar results were obtained with monocular and binocular observation. Since oculomotor adjustments were assumed to be accurate for all targets and since all other potential distance cues had been eliminated, they concluded that the specific distance tendency is a more effective determinant of perceived distance than accommodation and convergence.

Unfortunately, the subject's accommodation and convergence were not assessed in Gogel and Tietz's experimental situation. Neither, for that matter, were they assessed in any of the experiments in which specific distance tendency effects have been found. Thus, it is possible that the mistaken perception found under these conditions is related to a shift in oculomotor adjust-

ment toward the resting state, and is not based solely on the operation of higher-order perceptual processes.

The present experiments investigated whether the apparent distance of a single light point presented at various distances in the dark can be predicted by the resting or dark state of accommodation or convergence. Perceived distance was measured by an apparent motion technique similar to that used by Gogel and Tietz (1973). Hence, perceived distance was operationally defined as that distance at which the apparent motion of a stationary light point changed from "with" to "against," or vice versa, with respect to the subject's head movements. In Experiment I, perceived distance of the light point and the accommodative response to the light point, as measured by a laser optometer, were compared with the dark focus of accommodation. In Experiment II, perceived distance of the light point was compared to the vergence angle assumed in total darkness (i.e., dark convergence).

EXPERIMENT I

Method

Subjects. Eleven introductory psychology students, ages 17 to 21, served as subjects. All had a far visual acuity of at least 20/35 as measured by a Titmus Vision Tester (Model OV-7M).

Apparatus. Perceived distance was measured in a light-tight visual alley, 5.6 m in length and 1.5 m in width. The subject was seated in an observation cubicle at one end of the alley. A head-and-chinrest, which was mounted on ball bearings permitting smooth lateral head movements 6.5 cm in either direction from center, was provided. A mechanically operated metronome, set to 96 beats per minute, was used to time the subject's head movements, and a remotely controlled guillotine shutter prevented the subject from looking down the alley between trials. The stimulus consisted of a 1.2-mm circular aperture placed before a ground glass which was back-illuminated by a 7.5-V tungsten filament bulb. The stimulus produced a luminous intensity of 0.02 cd and subtended a visual angle which varied from 1 min of arc at 4 m (0.25 D) to 12.4 min of arc at .3 m (3.0 D). Neutral density filters were used to maintain a constant flux at the cornea.

Accommodation was measured with a laser optometer incorporating the Badal principle (Hennessy & Leibowitz, 1972; Leibowitz & Hennessy, 1975). With this technique, a "speckle" pattern, which is produced by reflecting the diverged beam of a low output laser from the surface of a slowly rotating drum, is superimposed on the visual field by means of a beam splitter. If the subject is overaccommodated with respect to the optical distance of the pattern, the speckles appear to move in the same direction as the drum's rotation; if underaccommodated, they appear to move in a direction opposite the drum's rotation. When the drum's axis is at an optical distance conjugate to the retina,¹ the speckles appear either stationary or "boiling." By inserting a positive lens in the light path of the laser pattern, one focal length from the entrance pupil of the eye, the optical distance of the drum can be conveniently varied from optical infinity to the diopter value of the lens without changing the brightness or size of the test pattern (Ogle, 1971, p. 226). Numerous studies have shown that measures of accommodation taken with the laser technique are in close agreement with those obtained with conventional methods of refraction (Baldwin & Stover, 1968; Hennessy & Leibowitz, 1970; Ingelstam & Ragnarsson, 1972; Knoll, 1966; Phillips, Sterling, & Dwyer, 1975).

A schematic diagram of the optometer is shown in Figure 1.

The beam from a 2.5-mV He-Ne laser (Metrologic ML920) was diverged by a -15 D ophthalmic lens and reflected by a series of first surface mirrors to the surface of a gold-painted, 10-cm-diam aluminum drum. The drum, which could be moved toward or away from the subject along an optical bench, was rotated at a rate of 1 rpm by a reversible motor. A +4 D ophthalmic lens served as the Badal lens. Neutral density filters, positioned between the laser and the drum, permitted adjustment of the luminance of the red (632.8 nm) test pattern. A Lafayette mechanical shutter limited exposure to 0.5 sec, and a flat 12 × 8 cm pane of glass reflected the pattern into the subject's right eye. The subject's head was held in position by a stationary head- and chinrest. Black curtains prevented the subject from seeing the size of the area being viewed during the accommodation measures, and eliminated all stray light. The accommodative response of the right eye could be measured in a totally dark field or with the light point stimulus at 4 m (.25 D) or 50 cm (2 D).

Procedure. The subject, seated at the laser optometer, was asked to simply report whether the speckles within the test pattern seemed to be moving upward, downward, or in no particular direction. After a few practice trials, a bracketing technique was used to determine the subject's accommodation. The drum was first set at extreme optical distances, thus "bracketing" the state of accommodation. Over succeeding presentations, the bracket interval, or difference between near and far test flashes, was reduced until the point of no apparent speckle motion was found. Three accommodation measures, the dark focus and the accommodative responses to the light point at 0.25 and 2.0 D, were taken in random order. The subjects were instructed to focus the light point as clearly as possible, and to relax their eyes for the dark focus measures.

Perceived distance measures were made with the subject seated in an observation cubicle adjacent to the visual alley. He was given several minutes to practice moving his head from side to side in the movable head/chinrest in time with the metronome. After he had become accustomed to the task, the subject was told that for each trial he should move his head back and forth for four complete cycles, starting and ending in the far left position. Before each trial, the cubicle lights were extinguished and the guillotine shutter was opened, exposing the dark visual alley. The experimenter then signaled the subject to begin the head movements by saying "one, two, ready, go" in time with the metronome. The light point was illuminated simultaneously with the word "ready" and was extinguished at the end of the fourth cycle of head motion. The subject's task was to indicate whether the light point appeared to move "with" or "against" his head movements; "no motion" responses were not accepted. The 12 stimulus distances (equivalent to .25 to 3.0 D, in .25 D steps) were presented in random order. Once the transition between "with" and "against" motion was found, the stimulus

Figure 1. Schematic diagram of laser optometer used to measure the accommodative response to a single light point and the dark-focus of accommodation.

Table 1
The Dark Focus of Accommodation, Accommodative Responses for Near and Far Light Points, and Perceived Distance for Each Subject

Subject	Dark Focus	Near (2D) Stimulus	Far (.25D) Stimulus	Perceived Distance
1	1.94	1.57	.69	.40
2	1.97	1.82	1.37	.30
3	.66	.94	.56	.39
4	2.56	2.61	2.04	1.05
5	3.12	3.10	2.04	.35
6	2.61	3.20	2.84	.65
7	1.52	1.82	1.12	.47
8	2.20	1.85	1.69	1.11
9	3.12	3.04	2.56	1.11
10	1.02	1.62	.81	.77
11	1.05	1.24	.77	1.00
$\bar{X}$	1.98	2.07	1.53	.69
SD	.84	.78	.82	.33

Note—All values are given in diopters.

distances within .75 D of this point were presented a second time in random order. The subject's perceived distance was defined as the mean distance of the transition points for the first and second series of trials. Finally, the subject was taken back to the laser optometer, and the three accommodation measures were repeated in random order. Throughout the experiment, all subjects wore their normal refractive corrections and a patch over the left eye.

RESULTS

The mean dark focus of accommodation, mean accommodative responses for the near and far light points, and the mean perceived distance of the light point as defined by the apparent-motion technique for each subject are presented in Table 1. All data are given in diopters to facilitate comparisons. Since the laser pattern was monochromatic (632.8 nm), a correction factor of +.33 D, based on the data of Bedford and Wyzecki (1957), has been added to each accommodation measure to compensate for axial chromatic aberration. Dark focus values range from 0.66 to 3.12 D, with a mean of 1.98 D (equivalent to .5 m); perceived distance values range from 0.30 to 1.11 D, with a mean of 0.69 D (equivalent to 1.45 m).

As illustrated in Figures 2 and 3, Pearson product-moment correlations were used to compare the dark focus with (1) accommodative responses to the near and far light points, and (2) the perceived distance of the light point. Each data value represents two types of observations for a single subject. In Figure 2, the abscissa designates the subject's mean dark focus and the ordinate, the mean accommodative response of the same subject to the near and to the far light point. If the subjects accommodated accurately, the data would fall along the horizontal lines which define the optical distance to the stimuli. On the other hand, if accommodation for the light point were unchanged from that assumed in total darkness, the data would fall along the diagonals which depict a perfect correlation with the

Figure 2. The accommodative responses to near (.5 m) and far (4 m) light points as a function of individual dark-focus values. Horizontal lines specify stimulus distance; diagonal lines correspond to no difference between response to the fixation point and the dark-focus.

Figure 3. Scatter diagram illustrating the relationship between the dark-focus of accommodation and the perceived distance as measured by the absolute motion parallax technique.

dark focus. Although greater accommodation was consistently obtained for the nearer light point ($\bar{X} = 2.07$ D for near vs. 1.53 D for far), the data are clearly better described by the diagonal than by the horizontal functions. The correlations between dark focus and the accommodative responses for near and far light points were .92 ($p < .001$) and .90 ($p < .001$), respectively.²

The mean dark focus and perceived distance data are compared in Figure 3. The subjects' dark focus values are on the axis of abscissas; perceived distance values are on the axis of ordinates. Although both the mean of the dark focus values and the mean of the perceived distances corresponded to an intermediate distance, no significant correlation was found between these variables ($r = .19$, $p > .05$).

Discussion

Consistent with earlier research, all subjects in the present experiment accommodated to an intermediate distance in total darkness. In addition, the data presented in Figure 2 demonstrate that a single light point is not an adequate stimulus for accommodation.

For both the near and far light point, accommodation is better predicted by the dark focus than by the optical distance of the stimulus. Past experiments suggest that whenever stimulus effectiveness is reduced by lowering luminance of contrast (Johnson, 1976; Leibowitz & Owens, 1975a, b) or by increasing the eye's depth of field (Hennessy, 1975; Hennessy et al., 1976) accommodation shifts toward the dark focus. Thus, the accommodative response has been characterized as a compromise between the stimulus and the dark focus: as the stimulus is degraded, the dark focus, or resting state, exerts progressively greater influence.

The inability of a bright light point to stimulate accommodation is somewhat surprising. Inappropriate accommodation should produce a blurred image of the light point, and blur is considered to be an important stimulus for accommodation (e.g., Smithline, 1974). Perhaps the accommodative mechanism requires a more complex stimulus; e.g., one that includes contours or edges. Or possibly, with the low ambient luminance and concomitantly large pupils, the eye's dioptics are so poor as to produce a badly blurred image regardless of the accommodative state. In either case, one would expect the dark focus to exert greater influence than the stimulus. At present, it is important to recognize that not all stimuli are equally effective and, in particular, a single light point is strikingly ineffective as a stimulus for accommodation.

While the light point stimulus was perceived to be at an intermediate distance ($\bar{X} = .69$ D or 1.45 m) when presented in an otherwise dark environment, the data illustrated in Figure 3 imply that this distance cannot be predicted by the dark focus. Further, since the accommodative response for the light point is highly correlated with the dark focus (Figure 2), it would seem that the perceived distance of the light point is unrelated to the accommodative response in the presence of that stimulus, and that perceived distance in the present situation is therefore not determined by an accommodative cue. However, this does not rule out the possibility that perceived distance under these conditions may be related to convergence. Fincham (1962) reported that accommodation and convergence assume noncorresponding intermediate states in total darkness. This absence of the normal synergy between accommodation and convergence might also obtain under the impoverished conditions presently used to measure perceived distance. If so, perceived distance might be predictable from the convergence angle assumed in total darkness. Experiment II examined this possibility.

EXPERIMENT II

Method

Subjects. Twelve introductory psychology students, who had not participated in Experiment I, served as subjects. All had a far visual acuity of at least 20/35. Subjects were also screened for near and far lateral heterophoria; mean phorias ranged from 2 Δ

eso to 3.5 Δ exo. Each subject's interpupillary distance was measured by a Titmus P-D Scope.

Apparatus. Perceived distance was measured with the same apparatus described in Experiment I. Dark convergence was measured with an apparatus which presented two vertical lines dichoptically, one above the other. The lower, standard line could be seen only by the subject's left eye; the upper variable line, only by the right. As illustrated in Figure 4, these lines were produced by a He-Ne laser (Perkin-Elmer 75) in the following manner. The main beam was first diverged by a -12 D ophthalmic lens. A beam splitter divided the diverged beam into upper and lower beams which were reflected by a series of mirrors to a ground glass rear-projection screen 1 m from the subject. The reflecting surface of the final mirror in each light path was masked to produce a vertical line, approximately 7 min $\times$ 2 deg 52 min of arc, on the ground glass screen. The final mirror in the upper light path was mounted on a sliding carrier which permitted lateral displacement of the upper image 10.5 cm in either direction from the screen's center with no change in the apparent size or luminance of the image. The corresponding mirror in the lower light path was stationary. Two sheets of polarizing material with perpendicular transmission axes were fixed between the two pieces of ground glass which formed the screen. These, in conjunction with crossed-axis Polaroid filters at the subject's eyes, permitted light from the upper image to stimulate only the subject's right eye and that from the lower image, only the left eye. From the observation position, the luminance of the vertical lines was approximately 6.85 cd/m². An electric shutter held stimulus duration constant at 125 msec, rendering changes in vergence with stimulus onset improbable. The entire apparatus, which permitted vergence measurements ranging from 9 deg divergence to 9 deg convergence (assuming a 65-mm interpupillary distance), was surrounded by curtains.

Procedure. The procedure essentially duplicated that of Experiment I, except that dark convergence, rather than accommodation, was measured. Before and after the perceived distance measures, the subject was seated at the convergence apparatus, instructed to relax his eyes, and whenever the two vertical lines flashed in the otherwise dark field, to report the position of the top line relative to the bottom line. Stimuli were presented according to a bracketing procedure which involved setting the upper line to a position likely to elicit either a "right" or a "left" response, and then gradually converging the settings until the stimuli were judged to be aligned. The trials were separated by intervals of at least 10 sec, during which the subject sat in total darkness. After the first few trials, the subject was not warned when a trial would occur.

Figure 4. Schematic diagram of apparatus used to measure dark convergence.

Table 2
The Interpupillary Distance (IP), Mean Lateral Heterophoria, Dark Convergence Angle, and Angle Corresponding to the Perceived Distance for Each Subject

Subject	IP (mm)	Lateral Heterophoria (prism diopters)	Dark Convergence (degrees)	Perceived Distance (degrees)
1	56	0	.74	2.62
2	66	exo 1	4.66	4.14
3	61	eso 2	2.27	1.49
4	63	exo 1	1.72	2.66
5	63.5	exo 3	3.10	1.56
6	71	exo 3.5	2.78	2.68
7	62	eso 1.5	1.32	2.16
8	65	exo 2	3.16	1.86
9	67	exo 3	3.10	3.24
10	60	exo 2.5	2.36	1.83
11	55	eso 1	4.28	3.55
12	60	exo 2.5	6.01	7.30
X			2.96	2.92
SD			1.48	1.60

Results

The dark convergence angle was calculated for each subject based on his interpupillary distance, the 1-m distance to the screen, and the direction and size of the separation between the dichoptically flashed lines when they were subjectively aligned. In order to avoid contamination of the convergence measures with inter-subject variability in lateral heterophoria, the vergence component attributable to heterophoria was subtracted from each subject's raw scores.³ Also, since the equivalent distance for a given convergence angle varies as a function of interpupillary distance, all data were normalized to a "standard" interpupillary distance of 65 mm. To facilitate comparisons, perceived distance measures were converted to equivalent convergence angles assuming the standard interpupillary distance.

Table 2 presents the interpupillary distance, mean lateral heterophoria, and mean normalized dark convergence and perceived distance angles for each subject. Dark convergence can be seen to vary from .74 to 6.01 deg, with a mean of 2.96 deg (equivalent to 1.7 m). Perceived distance angles vary from 1.49 to 7.30 deg, with a mean of 2.92 deg (equivalent to 1.5 m). The scatter diagram in Figure 5 illustrates the relationship between perceived distance and dark convergence. Each data point represents the mean results for a single subject: the ordinate indicates the angle defined by the perceived distance of the light point, and the abscissa, the dark convergence angle. One can see that subjects with larger dark convergence values tended to also have larger angles for their perceived distance measures (i.e., nearer perceived distances). A Pearson product-moment correlation showed a significant relationship between these variables ($r = .76, p < .01$).

Figure 5. Scatter diagram illustrating the relationship between dark convergence and perceived distance as measured by the absolute motion parallax technique.

Discussion

The results from Experiment II show that, in the absence of stimuli for accommodation or fusion, convergence assumes an angle which corresponds to an intermediate distance. In contrast to the dark focus of accommodation, dark convergence appears to be quantitatively related to the perceived distance of a light point presented in a dark environment.⁴ The study by Ivanoff and Bourdy (1954) suggests an heuristic interpretation of these data. They found that, similarly to accommodation, binocular convergence shifts toward a fixed intermediate angle with decreases in luminance. That is, as luminance was reduced, they found increasing overconvergence for a far stimulus and increasing underconvergence for a near stimulus. At the lowest stimulus levels, convergence assumed a fixed intermediate value for both stimuli. Although the present experiments did not assess the accuracy of convergence for binocular stimuli, it seems reasonable to assume that the fixed convergence found in near darkness by Ivanoff and Bourdy is the same state as that measured in total darkness in Experiment II, and that convergence will return to the dark position whenever there is no fusional or accommodative stimulus. The present measures of perceived distance utilized a monocular stimulus which was shown to be an inadequate accommodative stimulus. Hence, one would expect convergence to be adjusted to the dark or resting position. Since no distance cues other than accommodation and convergence were available, the positive correlation between dark convergence and perceived distance, which is impressively strong when one considers the differences in conditions for these two measures (e.g., a stationary, relaxed position vs. abrupt lateral head movements), suggests that perceived distance depended on convergence.

Alternatively, the data from Experiment II might be interpreted as implying that, in the absence of effective

stimulation, the specific distance tendency or, more generally, perceived distance determines convergence. This interpretation is considered to be less persuasive, since it has never been convincingly shown that perceived distance can influence oculomotor adjustments (see, e.g., Hennessy, et al., 1976). To the contrary, Fincham (1962) found large errors in convergence when subjects were asked to fixate their own fingertips, which presumably had a relatively well-defined perceived distance, in total darkness.

Perhaps experiments with prism adaptation can help to clarify which of these interpretations has greater validity. Several investigations have shown that adaptation to base-out (Craske & Crawshaw, 1974; Wallach & Frey, 1972) or to base-in (Wallach, Frey, & Bode, 1972) prisms produces a change in perceived distance under conditions in which oculomotor adjustments provide only cues for egocentric distance. Typically, subjects who have adapted to base-out prisms, which force greater-than-normal convergence, overestimate distances after the prisms are removed; those who have adapted to base-in prisms, which force less-than-normal convergence, underestimate distances. These findings imply that adaptation results in some sort of recalibration of the relationship between convergence and perceived distance (see Craske & Crawshaw, 1975, for theoretical discussions; Ebenholtz & Wolfson, 1975; and Wallach, Frey & Bode, 1972).

If, under reduced stimulus conditions, perceived distance were determined solely by the specific distance tendency, then the changes in perceived distance following adaptation to opposite-base prisms would imply a change in the specific distance tendency. However, this sort of change would be inconsistent with the characterization of the specific distance tendency as a fundamental metric of the visual system. Rather, the effects of prism adaptation on perceived distance seem to support the view that, in the absence of other contextual distance information, ocular vergence is a major determinant of perceived distance.⁵

Finally, it should be emphasized that the present results have implications not only for theoretical studies of space perception, but also for any experimental or practical situation which involves impoverished visual conditions. It is generally assumed that if the subject does not complain of blurred vision or diplopia, his oculomotor adjustments are accurate. Evidence for systematic errors in accommodation and convergence from this and earlier studies implies that this assumption is often incorrect and that, in order to obtain precise adjustments under reduced conditions, it may be necessary to adjust stimulus parameters in accordance with the individual's dark focus and dark convergence.

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NOTES

1. Charman (1974) recently pointed out the plane of no apparent motion, or "stationarity," for the laser optometer used in Experiment I falls at varying positions between the axis and surface of the drum. Thus, assuming the axis as the reference point results in a small error of underestimation of the accommodative response, which increases with increased accommodation. This error would not, however, affect the magnitude of the correlations reported in Experiment I.

2. These data have been separately reported as a research note (Owens & Leibowitz, 1975).

3. Examination of the data before correcting for lateral heterophoria showed a similar relationship between dark convergence and perceived distance, with a somewhat weaker correlation ($r = .56$). The weaker correlation would be expected, since the phoria component of the vergence data would not be reflected in the perceived distance data.

4. In agreement with Fincham's (1962) report, a control experiment showed no significant correlation ($r = -.05$) between the dark convergence and dark focus of accommodation for seven subjects.

5. Prof. Walter Gogel has pointed out that the present results might be interpreted as reflecting the operation of both the specific distance tendency and a convergence cue to distance. If this were the case, perceived distance under reduced conditions would be positively correlated with both the specific distance tendency and the dark state of convergence, while these determining variables were unrelated. The less-than-perfect correlation between perceived distance and dark convergence

obtained in Experiment III is consistent with such an interpretation. Furthermore, in accord with this view, the suggested prism adaptation studies could not rule out the existence of a specific distance tendency. A change in perceived distance following prism adaptation could be said to result from a change in the convergence cue, while the influence of the specific distance tendency on perceived distance remained unchanged. However, if such adaptation effects were demonstrated, their magnitude should indicate the relative importance of these variables as cues to distance. If changes in perceived distance were appreciably smaller than concomitant changes in dark convergence, one might argue that the specific distance tendency is exerting a "stabilizing" influence on perceived distance and thus counteracting changes in the convergence cue. On the other hand, if changes in perceived distance were quantitatively similar to changes in dark convergence, one could argue that convergence is the more important determinant of perceived distance.

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