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Prism distortion and accommodative change*

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The literature concerning oculomotor changes during adaptation to prism distortion has dealt mainly with the question of eye movements. The present study examined accommodation during exposure to distortion by ophthalmic prisms. Ss were asked to fixate four targets of equal visual angle at four distances. Accommodation was measured at each distance by means of a Laser-Badal optometer. Repeated measures for the same target distances were obtained prior to, during, and after exposure to binocular prisms. The results indicated that prisms induce underaccommodation at each of the target distances, although the total range of predistortion and distortion accommodation was restricted. Significant recovery from the effects of induced underaccommodation was observed at near target distances. No significant aftereffects of wearing the prisms was observed. In a second experiment, where target background contrast was increased, consistent underaccommodation was again observed and recovery was observed at the near target distance. The range of accommodative change was also considerably improved. It was concluded that the angular magnification of ophthalmic prisms induced underaccommodation. It was suggested that partial recovery from the prism effect may be related to alterations in vergence.

Perceptual adaptation has usually been studied by means of observing reactions to some optical device which alters normal vision in some known manner. Smith and Smith (1962) have criticized such studies, however, for not having considered the broad range of behavioral effects such devices may have; their criticism was addressed mainly to studies of inversion of the visual field. The vast number of studies of adaptation to prism distortion have also typically avoided examination of other than the principle distortion effects of the prism (e.g., shape, color, direction). The full range of conditions to which the eye must adapt and their relationship to other adaptive changes thus remains unclear.

Studies concerning the nature of oculomotor changes in perceptual adaptation have been somewhat limited to an examination of eye position (e.g., Kalil & Freedman, 1966; McLaughlin, Rifkin, & Webster, 1966). Indeed, one of the effects of ophthalmic prisms is a change of oculomotor balance. In effect, prisms alter vergence necessary for fusing the viewing target. The response to prism deviation may be used as an index of oculomotor imbalance (Ogle, 1964). Another effect of ophthalmic prisms is angular magnification of the image (Ogle, 1950). If magnification of the image occurs, one would expect changes in accommodation of the eye. Studies of oculomotor adaptation to base-left or base-right prisms have not examined the convergence-accommodation synkinesis.

The present study is an examination of the effects of prism distortion on accommodation, under two conditions of target/background contrast in a relatively "passive" viewing situation.

EXPERIMENT I

Method

Subjects

Three female and five male volunteers were selected from a group of undergraduates at The Pennsylvania State University on the basis of normal uncorrected 20/20 vision. Ss received one credit toward their final grades for their participation and were uninformed about the purpose of the experiment.

Apparatus

The experimental spectacles were ophthalmic prisms (13 prism diopters) mounted base-left in spectacle frames and surrounded by blackened foam such that the field of view was strictly limited to that provided by the prisms; the frames were held firmly to the head by means of "Glastraps"; the average distance of the tear surface of the prism to the eye was 10 mm.

The fixation targets consisted of four flat-white equilateral triangles, serially positioned at four distances from S's eye: 0.5, 1.0, 2.0, and 4.0 m. The targets subtended a constant visual angle of 1.0 deg in height and were mounted on flat-black stems subtending a constant visual angle of 0.5 deg. The target height was 1.2 m, at center, from the floor, and the targets were placed perpendicular to the midpoint of S's eyes. The luminance of the targets was 13.0 fL (source, overhead fluorescent fixtures) and that of the surround was 11.6 fL.

Accommodation measures were obtained by means of a laser optometer based on the "Badal principle" (cf. Cegalis, 1971; Hennessy & Leibowitz, 1972). The use and rationale for the laser optometer has been elaborated and extended to perceptual research (Hennessy & Leibowitz, 1970). In brief, the laser optometer is based upon a scintillation pattern (Knoll, 1966); the diverged beam of a laser reflected from a surface produces a granular speckle pattern. If S moves his head, the granularity will appear to move either with or against the head motion. The direction of the reported motion is directly related to the refractive state of the eye: if the speckled pattern moves "with" the motion of S's head, it indicates underaccommodation; "against" motion indicates overaccommodation. If the

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Table 1
Mean Accommodation (in Diopters) for All Ss at Four Target Distances, Measured at Four Time-Activity Intervals,* and Theoretical Values of Accommodation for White Light Conditions

	Target Distance (in Meters)			
Time of Measure	0.5	1.0	2.0	4.0
Theoretical Value of Accommodation	+2.000	+1.000	+0.50	+0.25
Preexperimental	+2.004	+1.754	+1.534	+1.431
Experimental T_1	+1.536	+1.288	+1.208	+1.146
Experimental T_2	+1.773	+1.589	+1.180	+1.159
Postexperimental	+2.010	+1.759	+1.715	+1.630

**Preexperimental, normal vision; T_1, upon first exposure to prisms; T_2, after walking 5 min with prisms; postexperimental, immediately after removal of prisms.*

granularity does not move as a result of head motion, the image is in the ideal focal plane. Movement of the laser pattern can also be imparted conveniently by projecting the diverged beam on a slowly moving target drum. A measure of relative accommodation refers to the dioptric power needed to nullify movement in a speckle pattern. Previously reported measures of accommodation by means of a laser optometer have relied on variation of lens strength. The Badal principle allows fairly rapid mechanical changes of image distance without change in image size.

A rectangular beam splitter, 3 x 2 in. (reflectance, 53%; transmission, 47%), was placed 10 cm in front of the left eye. The right vertical edge of the beam splitter was centered and approximately parallel to the bridge of S's nose and was mounted at an angle such that an image of a gold-painted drum, revolving at approximately 8 rph, was reflected towards the left eye. S's head was stabilized by means of a head-/chinrest. The drum was mounted on an optical bench carrier at a height, at center, of 1.2 m from the floor. The carrier was mounted on a 50-cm "Zeiss" optical bench and could be moved through a distance of 45 cm at a right angle to the frontomedian plane of S's head. An "Alphax" shutter and iris diaphragm were mounted on a second optical bench carrier interposed between the beam splitter and the movable drum, at a distance of 11.5 cm from the center of the beam splitter; a +5.0 diopter field lens was mounted over the center of the iris diaphragm.

A first surface mirror was positioned above the drum on a rigid arm which moved with the drum as the drum was moved along the optical bench. The mirror reflected the image of a parallel laser beam (1.5 mW HeNe laser), diverged at the source by a +10.0 diopter lens, toward the center of the drum. The reflecting mirror was adjustable such that the image reflected from the drum could be optically aligned with the center of the iris diaphragm and field lens. S thus viewed the reflected circular image of a red laser beam superimposed on a white triangular target located straight ahead at one of four distances. Accommodation to the target distance was measured in terms of the laser image distance.

A scale affixed to the optical bench allowed E to determine the distance of the drum surface relative to the fixed field lens. Measures of S's accommodation were determined from the distance of the reflecting drum surface relative to the field lens, according to Ogle (1961); each centimeter of change from optical infinity was equivalent to 0.25 diopter of change of lens power. Because a red laser light was utilized in the present experiment, measures of accommodation were relative to the wavelength (632.8 nm) of the HeNe scintillation pattern.

The superimposition of the laser target was time-controlled by means of the shutter, which was set for 0.5-sec exposure. According to Hennessy and Leibowitz (1971), this time interval provides a reasonable safeguard against the possibility of a shift of accommodation during measurement. E adjusted the drum distance for greater or lesser dioptric power prior to activating the shutter.

Procedure

The S was seated with his head in the head-/chinrest, was asked to view a target placed 3.0 m from his eyes, and was then given training in discriminating the direction of the laser scintillation pattern. E informed S that at certain times he would see a red circle superimposed on the white triangular target. E opened the shutter a number of times until S saw the red pattern. E then directed S's attention to the grainy appearance of the red pattern and in particular to the direction of the movement (if any) of the "grains." S was instructed to tell E whether the "grains" were going "down," "up," or moving indeterminately, in which case S was instructed to respond "same." Experience with down, up, and same speckle patterns was given. S was then informed that E would announce, by the signal "ready," when the pattern would be visible. S was informed that he could ask E to repeat the procedure in the event that he blinked his eye or moved his attention away from the triangle. S was again reminded to view only the white triangle.

After successful pretraining, S was instructed to fixate the series of four triangular targets, presented serially from near to far. Measures of accommodation were obtained at each target distance (pre). Following the initial series of measurement, S was immediately given the prism spectacles and was instructed to place them before his eyes. After the spectacles were comfortably adjusted, he was instructed to return his head to the headrest and a second series of accommodation measurements was obtained in the order near to far (T_1). After completion of the second series of measurements, S was instructed to walk with E through a series of corridors for a period of 5 min. S then returned to the testing room, where a third series of measurements was obtained (T_2). S was then asked to remove the spectacles, and a final series of measurements was obtained immediately after removal of the prisms (post). Accommodation measures were thus obtained during four time-activity intervals.

Results

Mean accommodation at four time-activity intervals is presented for four viewing distances in Table 1, and mean accommodation is also plotted as a function of target viewing distance for four time-activity intervals in Fig. 1. Preexperimental accommodation changes in the expected direction at the four target distances, that is greater lens strength is required for accommodation to near distances than for accommodation to far distances. The differences between preexperimental and T_1 measures show a consistent relaxation of accommodation attributable to the prism spectacles. Accommodation appears to change at T_2 after 5 min of walking with the spectacles; Ss are better able to accommodate to near targets. There appears to be little change in the observed relaxation at far distances at T_2 as compared to T_1, however. In the postexperimental condition, accommodation is nearly identical to that of the preexperimental testing period, excepting a slight increase in accommodation at farther distances. It is apparent from an inspection of the data in Table 1 that the range of accommodation, i.e., the total change of

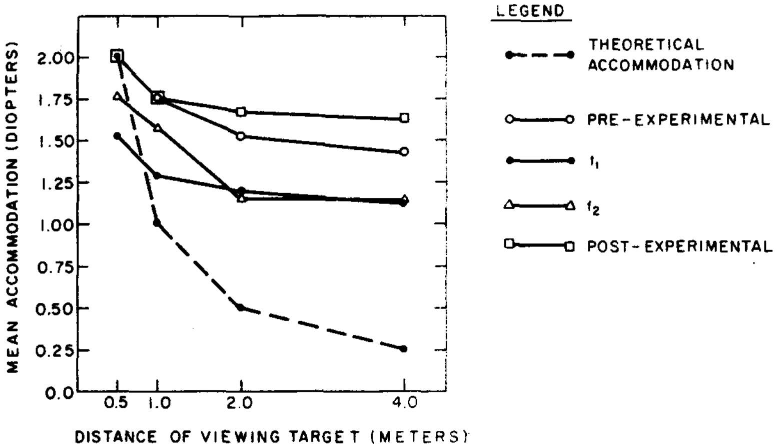

Fig. 1. Mean accommodation (in diopters) at four target distances during four successive time-activity intervals (preexperimental, normal vision; T_1, upon first exposure to prisms; T_2, after walking 5 min with prisms; post, immediately after removal of prisms) and the theoretical value of accommodation at each target distance.

accommodation from 0.5 to 4.0 m, is reduced compared to that expected for the same physical distances under white light.

A repeated measures analysis of variance indicated that there were significant differences in accommodation as a function of time-activitiy intervals ($F = 4.735$, $p < .01$). Furthermore, there were significant differences in accommodation as a function of target distances ($F = 19.521$, $p < .001$). The interaction of Time-Activity Interval by Target Distance was not significant ($F = 0.946$, $p > .050$). To determine if there were differences among separate intervals and separate target distances, the Newman-Keuls procedure was utilized. All comparisons of accommodation means for pre and T_1 measures at all four target distances were significantly different ($p < .05$), indicating that the prism spectacles induced an accommodative change, at all target distances, in the direction of relaxed accommodation. A comparison of means at T_1 and T_2 indicated that some change in the relaxation effect occurred, yet only at 0.5- and 1.0-m target distances; a comparison of pre and post measures indicated that no significant aftereffects of relaxed accommodation had occurred.

Discussion

The results of the present experiment indicated that the binocular ophthalmic prisms induced a change of accommodation in a "passive" viewing condition in the direction of relaxed accommodation. Optically induced relaxation was apparent at all the experimental target distances during initial exposure to prism distortion. Furthermore, after walking 5 min, some change in the effects of the prisms occurred at close distances (0.5 and 1.0 m) but not at farther distances (2.0 and 4.0 m). Slight aftereffects of overaccommodation observed at far distances were not significant.

The restricted range of preexperimental accommodation somewhat limits the generality of the conclusions which might be drawn. Several factors may account for the restricted range of accommodation: (a) the flat white fixation target may have been a suboptimal stimulus to accommodation; (b) reduced contrast between the fixation target and the background may have reduced accommodative response; (c) repeated fixation of accommodation targets may have induced a general fatigue. A replication of the study appeared to be necessary.

EXPERIMENT II

A factor potentially contributing to the restriction of accommodation range in Experiment I may have been the reduced contrast between the target and the background. Heath (1962), for example, found variations in accommodation as a function of target/background contrast. The second experiment was then concerned with changes of accommodation as a function of prism distortion under high-contrast target/background conditions.

Method

Subjects

Two male and two female undergraduate volunteers were selected on the basis of normal uncorrected 20/20 vision. Ss were given one credit toward their final grades for their participation and were uninformed about the purpose of the experiment.

Apparatus

Both the experimental spectacles and accommodation targets were identical to those utilized in Experiment I. While the target background in Experiment I was a uniform gray wall, a large black drape positioned at the same location was substituted in the present experiment and the luminance of the black backdrop was 0.7 fL.

The apparatus used to measure accommodation was changed slightly from that of Experiment I. In the present experiment, the gold-painted drum was mounted on an optical bench at a distance of 1.90 m from the beam splitter; the drum was partially masked by a flat-black-painted box with a square aperture. The beam splitter was mounted on the optical bench at a distance of 10 cm from S's left eye. The optical bench was

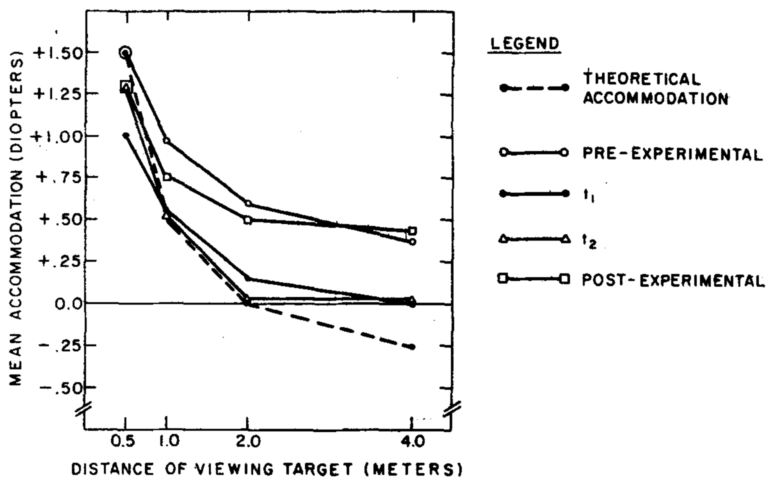

Fig. 2. Mean accommodation (in diopters) at four target distances during four successive time-activity intervals (preexperimental, normal vision; T_1, upon first exposure to prisms; T_2, after walking 5 min with prisms; post, immediately after removal of prisms) and the theoretical value of accommodation at each target distance.

placed at right angles to the front-median plane of S's head. The shutter was mounted on an optical carrier and was positioned on the optical bench at a distance of 11.5 cm from the beam splitter. A lens holder was mounted on the optical bench immediately behind the shutter. A series of trial lenses from +3.0 to −3.0 diopters was used to manipulate the direction of the scintillation pattern. This apparatus has been more fully described in Hennessy and Leibowitz (1971). Briefly, a measure of accommodation may be obtained by varying the strength of lenses interposed between S's eye and the laser scintillation pattern. Accommodation can be determined from the opposite power of the lens needed to neutralize movement in the laser scintillation pattern; therefore, the superimposition of the lenses of varying strengths served the same purpose as the physical movement of the drum in Experiment I.

Procedure

The procedure followed was identical to that reported in Experiment I.

Results

Mean relative accommodation[1] for targets at four distances are presented for four time-activity intervals in Table 2. Mean relative accommodation is plotted as a function of target distances for four time-activity intervals in Fig. 2. Accommodation changes in the expected direction over the four target distances during the preexperimental condition, that is, the lens strengths of S's eyes were greater for near targets than for far targets. Ss, however, showed slight overaccommodation during the preexperimental condition at all target distances. A consistent change of accommodation at all four target distances occurred during T_1, S's first exposure to the ophthalmic prisms—the prisms apparently relaxed accommodation. Relatively little change of accommodation occurred between T_1 and T_2 as a function of increased experience with the spectacles while walking. S's accommodation appeared to relax in the post condition as compared to slight overaccommodation observed in the preexperimental measures.

Table 2
Mean Relative[1] Accommodation (in Diopters) for All Ss at Four Target Distances, Measured at Four Time-Activity Intervals,* and the Theoretical Values of Accommodation for White Light Conditions

Time-Activity Interval	Target Distance (in Meters)			
	0.5	1.0	2.0	4.0
Theoretical Value of Accommodation	+1.500	+0.500	0.000	−0.250
Preexperimental	+2.031	+0.969	+0.584	+0.375
Experimental T_1	+1.063	+0.563	+0.156	−0.031
Experimental T_2	+1.281	+0.531	+0.188	+0.119
Postexperimental	+1.188	+0.750	+0.500	+0.438

**Preexperimental, normal vision; T_1, upon first exposure to prisms; T_2, after walking 5 min with prisms; postexperimental, immediately after removal of prisms.*

A repeated measures analysis of variance indicated that there were significant differences in accommodation at different measurement intervals ($F = 4.188, p < .041$) and at different target distances ($F = 27.783, p < .001$). The Interval by Distance interaction was not significant ($F = 1.593, p < .05$). Newman-Keuls comparisons of mean accommodation at the four target distances for pre and T_1 intervals indicated significant differences among all comparisons ($p < .05$). Comparisons between T_1 and T_2 indicated that a significant change in accommodation occurred only at 0.5 m after 5 min of walking. Pre and post comparisons gave no indication of significant differences.

Discussion

The results indicate again that the base-left ophthalmic prisms relaxed accommodation at near and far target distances. Furthermore, significant changes in prism-relaxed accommodation occurred only at the near viewing distance (0.5 m). No significant aftereffects in accommodation were observed.

GENERAL DISCUSSION

The data from two experiments indicate that ophthalmic prisms, mounted base-left, relaxed accommodation: Ss were consistently underaccommodated at each of four target distances from 0.5 to 4.0 m. The amount of underaccommodation was dependent upon target distance and perhaps target background contrast. Changes in accommodation occurred after 5 min of walking experience with the prisms, and the changes that did occur were at near target distances. No apparent aftereffects occurred during the time intervals tested. Of additional interest is the finding that increased target/background contrast appeared to have improved the range of preexperimental accommodative response: with low target/background contrast in Experiment I, the range of accommodative change from .5 to 4 m was 0.57 diopter; in Experiment II, where target/background contrast was high, the range of accommodative change was 1.66 diopter.

The observed relaxation of accommodation can be attributed in part to the angular and spherical magnification of the ophthalmic prisms in that the positive strength of the prisms induced relaxation in the lens of the eye. Moreover, the data from both experiments suggest that the relaxation effect is not uniform: while the lens of the eye relaxed more for distant than for near objects, the amount of relaxation induced by the prisms is less at far distances and more at near distances. The latter observation may be attributed to the fact that the accommodative response is likely, in part, a function of vergence changes. Greater convergence required at near distances may also require assymetric convergence as a function of the position of the eye relative to the base-apex meridians of the prisms. The change in accommodation after 5 min of walking is also complex. The lens of the eye, initially relaxed by the prisms, appears better able to accommodate after increased exposure to prism distortion. The recorded change in accommodation also parallels subjective reports of an improvement in the clarity of vision. Changes in accommodation may be related to improved convergence and acuity. Fatigue may also play a role in accommodation under prism distortion conditions, since the range of accommodative response was reduced over time even under the high target/background contrast conditions of Experiment II.

It is uncertain whether the improvement in accommodation is antecedent, consequent, or coincident to other forms of adaptation, to changes of eye movement, or to changes of oculomotor balance. At very least, changes of accommodative response to the effect of prisms suggest that the matter of oculomotor change in adaptation is much more complex than the change in eye position alone. Concern for the sources of information contributing to adaptation (e.g., Wallach, 1968) might be served, then, by examining the range of conditions induced by the device to which the eye adapts.

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NOTE

1. The laser target was 2.0 m from S's eye; hence, measures of accommodation to the distance of the viewing target were relative to the laser drum-eye distance.