Oculomotor adjustments and size constancy*

H. W. LEIBOWITZ, KEN SHIINA, and ROBERT T. HENNESSY
The Pennsylvania State University, University Park, Pennsylvania 16802

The effect on matched size of the oculomotor adjustments was determined by stimulation and relaxation of accommodation and convergence by means of spherical lenses. The normal coupling between accommodation and convergence was maintained by introducing the amount of convergence appropriate to the lens power and each S's interpupillary distance. Data indicate that the oculomotor adjustments are adequate to account for size constancy up to approximately 1 m, beyond which their effect progressively decreases. The actual accommodation in force was assessed by means of the laser scintillation technique. It was determined that the magnitude of accommodation responds accurately to the spherical lens introduced up to about 1 m observation distance, beyond which underaccommodation was noted. Examination of the matched size as a function of the actual accommodation distance reveals a very close correspondence to the size constancy prediction up to about 1 m.

A number of studies have established that the oculomotor adjustments of accommodation and/or convergence influence perceived size. Stimulation of the oculomotor adjustments produces a diminution of perceived size, while relaxation has the opposite effect (for a historical summary, see Hochberg, 1971). Although there is no doubt that perceived size is related to the magnitude of the oculomotor adjustments, their quantitative relationship to size constancy is not clear. Under ordinary conditions of observation, Ss are able to correctly match the sizes of objects at varying distances in spite of changes in the size of the corresponding retinal image. The oculomotor adjustments could subserve size constancy by altering perceived size as a function of stimulus distance.

One of the reasons for the inability to determine quantitatively the role of the oculomotor adjustments as a mechanism for size constancy is the failure of most previous studies to maintain the normal relationship between accommodation and convergence. Although the effects of accommodation or convergence individually are of theoretical interest, their relationship to size constancy can be evaluated only when their relationship to each other preserves the normal coupling that occurs under conditions for which size constancy is normally observed. In a previous study (Leibowitz & Moore, 1966), accommodation was stimulated and relaxed by means of spherical lenses. In order to maintain the normal relationship between accommodation and convergence, the appropriate prism strength was computed on the basis of each S's interpupillary distance. In that study, it was determined that matched size for a fixed stimulus size was proportional to the distance to which the oculomotor adjustments normally corresponded within about 1 m. These data imply that the oculomotor adjustments are adequate to account for size constancy, within the 1-m range, beyond which their effect on matched size diminishes progressively. In the previous study, however, no independent measure of the amount of accommodation in force was available. The purpose of the present experiment was to replicate the previous study, utilizing the newly developed laser scintillation technique to assess accommodation (Hennessy & Leibowitz, 1970). This method does not require the introduction of distracting stimuli into the visual field, does not interfere with the state of accommodation, and is highly accurate.

*Supported by Grant MH 08061 from the National Institute of Mental Health. Presented to the Eastern Psychological Association, 1971, by Ken Shiina.

METHOD

The stimulus objects were white equilateral triangles constructed to subtend a constant visual angle (height) of 1 deg of arc at viewing distances of 15.3, 25, 50, 100, and 400 cm. The Ss, viewing these stimuli in complete darkness, adjusted the size of a similar triangle, located 90 deg to the right at a distance of 1 m, to match the size of the stimulus. For a given physical distance, matching data were obtained in the absence of prisms and lenses and for both stimulation and relaxation of accommodation in the amounts of ±3.0, ±2.0, ±1.0, ±0.5, and ±0.25 diopters by insertion of spherical ophthalmic lenses into the optical system. The appropriate convergence was maintained for each S by adjustment of Risely prisms based on computations derived from the interpupillary distance of the particular S and the spherical lens in use. Thus, for a given physical distance, size matches were obtained for that distance without prisms and lenses, and for accommodation and convergence combinations that corresponded to five shorter and five longer distances. The distance to which the accommodation and convergence in force would normally correspond is referred to throughout the study as the "equivalent distance."

The Ss were undergraduate volunteers who exhibited at least 20/25 near and far acuity in each eye and normal phorias as determined by a Titmus Professional Vision Tester. The S, seated inside a light-tight room, with his head in a chinrest, viewed the target triangle binocularly. Lens and

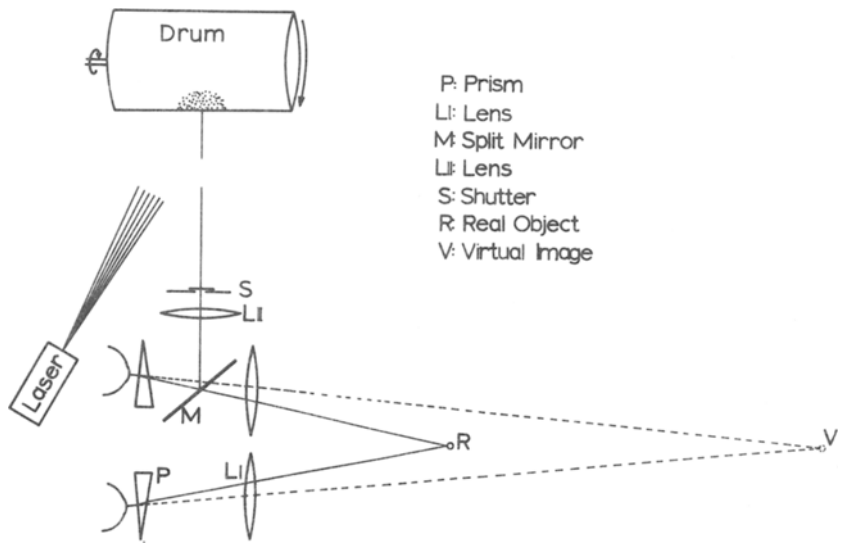

Fig. 1. Schematic diagram of the experimental arrangement.

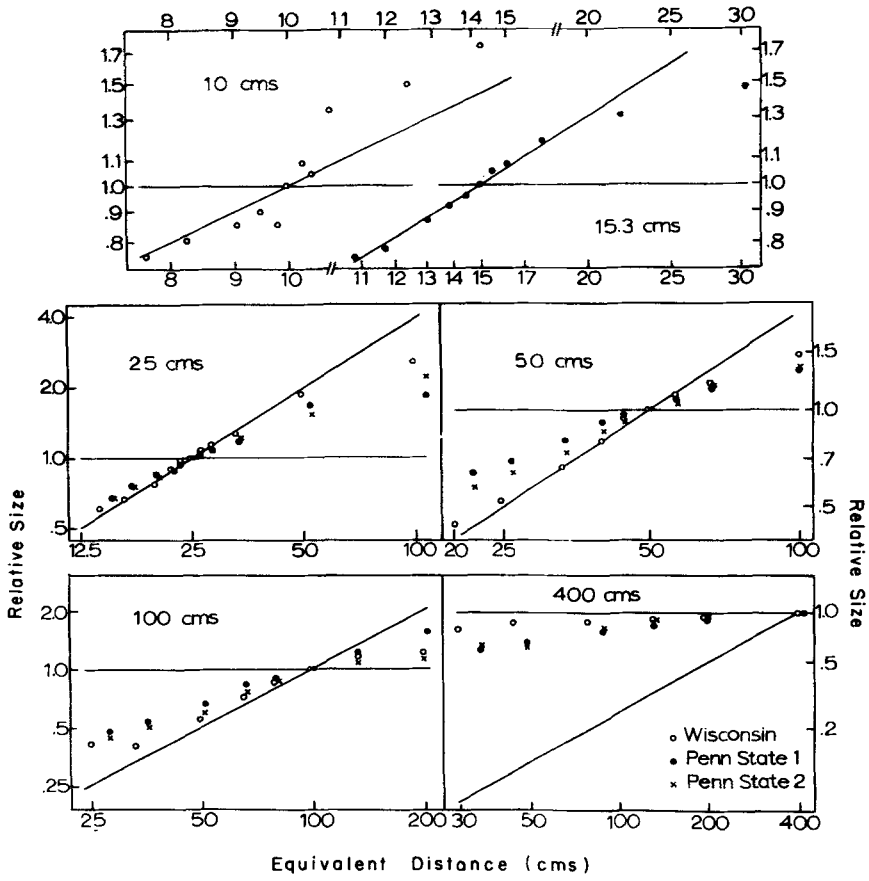

Fig. 2. Relative size as a function of "equivalent distance." Equivalent distance is defined as the distance at which the accommodation and convergence in force would normally correspond. Relative size represents the ratio between the size matches with the prisms and lenses to the matched size without prisms and lenses. Data are presented for the original experiment (Wisconsin) and for two replications (Penn State 1, 2). The parameter of each graph indicates the actual distance at which the test object was located.

prism combinations were tested successively in either increasing or decreasing amounts, the order being counterbalanced across Ss. The S viewed the test object and then turned to adjust the height of the comparison triangle, which was viewed directly. The comparison and test triangles each had a luminance of 13.1 fL. The S was allowed several views and adjustments for each lens and prism combination until he was satisfied with his match.

The experiment was run in two phases. In the first, different groups of seven Ss each served at each of the five viewing distances indicated above. Because the spherical lenses were located at a distance greater than normally used for ophthalmic lenses, a correction factor had to be applied to determine the effective spherical power. In order to be certain that these calculations did not influence the results, four additional groups of seven Ss each were tested at the four longer observation distances. The data from the two experiments were essentially the same.

In order to determine the amount of accommodative change induced by the prisms and lenses, the laser scintillation technique was employed to measure accommodative amplitude. The output of a low-energy helium-neon laser was diverged, reflected from a moving drum, and superimposed in the visual field through a half-silvered mirror in front of the left eye for 0.5 sec (Fig. 1). The appearance of this pattern is speckled due to the constructive and destructive interference of the coherent beam. The apparent movement of the beam depends in turn upon the accommodative state of the S. If the S's accommodation is nearer than the test object, the observed motion is the same as that imparted by the moving drum. Conversely, if accommodated beyond the test object, an "against" motion is observed. If the focal plane of the eye and the target are conjugate, no motion is observed. Appropriate lenses are inserted into the optical path which null or bracket the reversal of motion. The relative accommodation in force can then be precisely determined. Due to chromatic aberration, a correction must be introduced if absolute values are desired. For details of the technique, see Hennessy and Leibowitz (1970, 1972). For a mathematical analysis, see Ingelstam and Ragnarson (1972).

RESULTS

The data from the two phases of the present study, along with those from the previous experiment conducted at the University of Wisconsin (Leibowitz & Moore, 1966), are presented in Fig. 2. This plot presents the data for each of six observation distances, five from this study plus the data obtained at 10 cm in the previous study.[1] Taking the matches obtained in the absence of prisms and lenses as unity, relative size is plotted as a function of the equivalent distance. The horizontal lines in these plots represent a prediction based on the assumption that the oculomotor adjustments have no influence on perceived size. The diagonal lines represent a prediction based on the assumption that matched size is proportional to the equivalent distance, i.e., size constancy. It will be noted that the data are in good agreement with the size constancy prediction for the shorter observation distances, but that with increasing distances, the oculomotor adjustments have progressively less influence. The greatest change is noted between 100 and 400 cm. Within 1 m, the data points fall very close to the size constancy prediction, but with greater observation distances, their influence progressively diminishes.

The results of the accommodative measures are described in Fig. 3, which plots the relative accommodative distance as a function of equivalent distance. If the prism and lens technique of inducing and retaining accommodation were completely reliable, the data should fall along the horizontal line. It will be noted that for the short observation distances, the data fall very close to the theoretical prediction. At 100 cm, there is a slight tendency towards underaccommodation, i.e., a greater relative accommodative distance compared to the equivalent distance. This trend is even more marked at 400 cm.

Comparison of the results from the two phases of the present study reveals a very close correspondence, confirming that the insertion of the spherical lenses at different positions and the corrections used to determine the effective strengths were accurate.

Comparison of the data obtained in the previous Wisconsin study with those obtained in the present experiments reveals a slighter tendency towards constancy in the previous study up to 100 cm. In the previous study, it was not possible to darken the room completely, thus introducing some monocular cues in addition to those resulting from the oculomotor adjustments. This would account for the slightly greater tendency towards constancy in the previous experiment. There is no obvious explanation for the slight reversal in this trend observed at 400 cm. However, the generally close correspondence among the three sets of data is gratifying.

DISCUSSION

The results of the present experiment are of interest in relation to a number of theoretical issues. Regarding the role of oculomotor adjustments in size perception, it is clear that preservation of the normal coupling between accommodation and convergence results in a size correction which could account for size constancy at short distances of observation. Up to approximately 1 m, matched size is very close to an expectation based on the equivalent distance, or the distance at which the accommodation and convergence in force would normally obtain. At greater distances, as the strength of the oculomotor adjustments decreases, their influence is not adequate to account for size constancy. In the absence of other monocular cues, the data tend progressively towards the retinal image prediction.

Von Holst and Mittelstaedt (1950) have argued that size constancy is maintained by means of a corollary discharge which, in effect, compensates for changes in retinal image size at various observation distances. The present experiments were, in fact, stimulated by their theory and attest to its validity in relation to size constancy up to about 1 m. At greater distances, size constancy must be subserved by other mechanisms presumably arising from the context in which the stimulus is viewed. It is of interest to note that, although observing through a reduction screen lowers the tendency towards size constancy at greater observation distances, at closer distances reduction has progressively less effect (Harvey & Leibowitz, 1967). At about 1 m and less, size matches are identical with and without a reduction screen, implying that the oculomotor adjustments are adequate to account for size constancy within this observation range. Thus, there are at least two mechanisms subserving size constancy, oculomotor adjustments at near distances and contextual cues at greater distances.

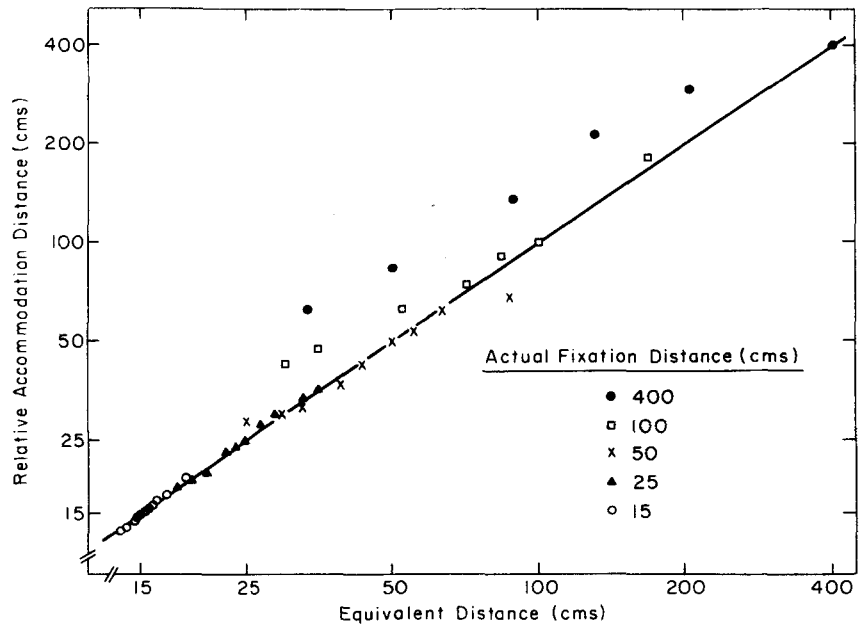

Fig. 3. Relative accommodation distance, as determined by the laser scintillation technique, as a function of the equivalent distance (defined as the distance at which the accommodation and convergence in force would normally correspond). Data were obtained for test objects at the indicated actual fixation distances.

It is also interesting to note that size matches obtained from young children are very close to those obtained from adults at near observation distances. The data of both groups are well within the prediction based on size constancy. At greater distances, although the adults maintain size constancy, the data obtained from children tend progressively away from this theoretical prediction (Leibowitz, Pollard, & Dickson, 1967). An assumption consistent with this observation is that the near distances are subserved by the oculomotor adjustments which are learned fairly early in life, whereas the greater distances are subserved by monocular cues whose acquisition requires many years of experience and is not complete until the adolescent years. It is also highly likely that the cue value of the oculomotor adjustments is facilitated by the reaching and grasping behavior of the young child at an early age, thus providing feedback for size-distance information at the closer observation distances. The effect of instructions on size matching for children and adults is also consistent with a two-mechanisms interpretation. Although the size matches of adults are notoriously sensitive to instructions (Gilinsky, 1955), this effect diminishes with decreasing age and disappears for young children (Rapoport, 1967). Either the young children are unable to change their attitudes as a result of instructions or size mediated by the oculomotor adjustments is less amenable to interference by verbal means than when based on monocular cues. In any event, the present data, considered along with previous studies in the literature, suggest strongly that at least two mechanisms are involved in size and perception. At close distances, the oculomotor adjustments are adequate to account for size constancy, context is superfluous, and matches obtained for both children and adults are identical. At greater distances, the oculomotor adjustments are no longer adequate, the presence of context is essential, and a long period of learning is required before its meaning can be related to size matching.

The results of the laser accommodation measurements confirm the efficacy of the method used to produce accommodative changes. They do not provide direct confirmation of the effectiveness of convergence, but it may be assumed that convergence was also appropriate since none of the Ss, who were specifically asked, reported double vision. We are assuming, therefore, that accommodation measures reflect both the state of accommodation and convergence. For the shorter observation distances, the correspondence between the accommodation in force and a

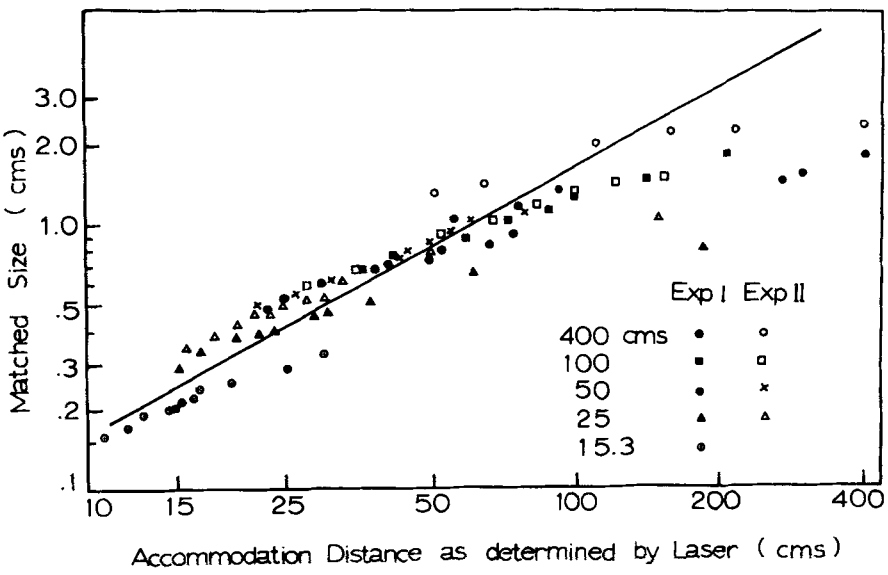

Fig. 4. Matched size as a function of the accommodation distance as determined by the laser scintillation technique. Data were obtained for the five indicated actual test object distances.

prediction based on lens strength is very close, but at greater distances there is a tendency to underaccommodate. It is interesting to note the discrepancy between equivalent distance and the relative accommodation distance for the greater observation distances. A question that could be asked is: To what extent can these differences account for the size matching results? In order to factor out the discrepancy between equivalent distance and actual accommodation distance, the data have been replotted in Fig. 4 as matched size as a function of the accommodation distance as determined by the laser, i.e., the actual accommodation (and convergence) in force. The data fall very close to the size constancy prediction up to 1 m and then begin to systematically drift away from the size constancy prediction. This function summarizes succinctly the results of the present experiment.

REFERENCES

GILINSKY, A. The effect of attitude upon the perception of size. American Journal of Psychology, 1955, 68, 173-192.

HARVEY, L. O., JR., & LEIBOWITZ, H. W. Effects of exposure duration, cue reduction, and temporary monocularity on size matching at short distances. Journal of the Optical Society of America, 1967, 57, 250-253.

HENNESSY, R. T., & LEIBOWITZ, H. W. Subjective measurement of accommodation with laser light. Journal of the Optical Society of America, 1970, 60, 1700-1701.

HENNESSY, R. T., & LEIBOWITZ, H. W. Laser optometer incorporating the Badal principle. Behavior Research Methods & Instrumentation, 1972, 4, 237-239.

HOCHBERG, J. Space and movement. In J. W. Kling and L. A. Riggs (Eds.), *Woodworth and Schlosberg's Experimental psychology.* (3rd ed.) New York: Holt, Rinehart & Winston, 1971. Pp. 477-480.

INGELSTAM, E., & RAGNARSON, S. I. Eye refraction examined by the aid of specific pattern produced by coherent light. Vision Research, 1972, 12, 411-420.

LEIBOWITZ, H. W., & MOORE, D. Role of changes in accommodation and convergence in the perception of size. Journal of the Optical Society of America, 1966, 8, 1120-1123.

LEIBOWITZ, H. W., POLLARD, S. W., & DICKSON, D. Monocular and binocular size-matching as a function of distance at various age levels. American Journal of Psychology, 1967, 80, 263-268.

OGLE, K. N. *Researches in binocular vision.* Philadelphia: Saunders, 1950. Pp. 123-126.

RAPOPORT, J. L. Attitude and size judgment in school age children. Child Development, 1967, 38, 1187-1192.

VON HOLST, E., & MITTELSTAEDT, H. Das Reafferensprinzip. Naturwissenschaften, 1950, 37, 464-476.

NOTE

1. The ophthalmic lenses in the Penn State experiments were located 6 cm from the S's eyes. This separation was necessary in order to position the beam-splitting mirror for the laster optometer measurements in front of the left eye. The change in effective lens power resulting from this separation has been taken into account in the presented data. However, these data do not include compensation for magnification (Ogle, 1950). The maximum effect of magnification with the 3 diopter lenses is 15%, and it diminishes rapidly as the lens strengths are reduced. Because of the relatively small magnitude of the magnification factor in relation to the range of matched sizes, it is considered to be of negligible consequence in the interpretation of the data.

(Received for publication February 21, 1972; revision received July 26, 1972.)