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MEASURED VISUAL ACUITY AS A FUNCTION OF PHENOMENAL SIZE

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THE OHIO STATE UNIVERSITY

OCTOBER 1955

WRIGHT AIR DEVELOPMENT CENTER

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FOREWORD

This report was prepared by Earl A. Alluisi of the Laboratory of Aviation Psychology, The Ohio State University, Columbus, Ohio. It is based upon an unpublished doctor's dissertation submitted in partial fulfillment of the requirements for the degree Doctor of Philosophy in the Graduate School of The Ohio State University. The apparatus used in the experiment was made available by the Psychology Branch, Aero Medical Laboratory, Directorate of Research, Wright Air Development Center, under Project No. 7186, Task 71551, with William J. White acting as Task Scientist.

The author wishes to express his appreciation to Dr. J. R. Kinzer, under whose guidance the research was completed, and to the other members of his reading committee, Drs. P. M. Fitts, G. A. Fry, and P. Ratoosh, for their helpful criticisms and suggestions. He wishes also to thank the members of the faculty and student body of the 1954 Summer Session of the College of William and Mary for so kindly volunteering to serve as observers in this study.

ABSTRACT

The usual definition of visual acuity implicitly assumes that acuity is independent of phenomenal size as long as the test object subtends a constant visual angle at the retina. Evidence from some previous studies indicates, however, that measured visual acuity might be bettered when the test object is made to appear larger even though its objective size on the retina remains constant. The present study was designed to test this notion.

In a daylight situation favorable to the operation of size constancy (condition S), 36 observers read a retinally projected visual acuity chart at three convergences, and, thus, at three apparent distances and three conditions of phenomenal size of the chart. An additional 36 observers read the same retinally projected chart under similar conditions, but in a stimulus-reduced night situation (condition R); for this group, phenomenal size of the test chart remained constant.

Acuities measured at the three convergences differed significantly among themselves in condition S, but not in condition R. This seems to establish measured visual acuity as a function of phenomenal size of the test chart. The effect was so small (less than one Snellen rating), it appears to be of little practical or clinical importance. It does, however, offer statistical support to those theories allowing for central factors in measured visual acuity.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Jack Bollerud

JACK BOLLERUD
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
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MEASURED VISUAL ACUITY AS A FUNCTION OF PHENOMENAL SIZE

Visual acuity is usually defined as "...the reciprocal of the minimal effective visual angle in terms of minutes of arc...." (6, p. 958). Such a definition implicitly assumes that acuity is independent of phenomenal size, provided the test object subtends a constant visual angle at the retina. Yet having once witnessed the size-constancy phenomenon, or the Honi phenomenon, or the phenomenal magnification of objects viewed through an iconoscope, or their phenomenal minification when viewed through a telestereoscope —having witnessed any of these, one might elect to challenge the implied assumption. This question is naively resolved to: Is measured visual acuity bettered when the test object is made to appear larger even though its objective size on the retina remains constant?

A search of the pertinent literature[1] indicates that acuity is functionally related to many variables and, further, that as usually measured it is composed of several factors. However, only one study has been primarily concerned with the topic here under discussion; this is Chapter VIII of McFadden's dissertation (21).

McFadden placed a visual acuity test pattern (parallel bars) first in the foreground, then in the background, of a "phenomenally tridimensional framework." In the first case, the test pattern appeared relatively close and small; in the second, it appeared relatively far and large. Although the objective sizes of the two figures were the same, the second yielded a higher visual acuity rating (was resolved farther from the observer) than the first.

This would seem to settle the issue except for Sloan's report (28) of Musylev's finding that acuity changed when the extent of background was varied. The extent of background might have functionally varied (the extent of its "whiteness" did vary) in McFadden's study as he moved the test pattern from the foreground to the background of his photograph of a country road. Because of the possibility of this confounding, it would be well to redetermine the relation of apparent size to measured visual acuity with a method differing from that used by McFadden.

The problem now is to measure visual acuity under conditions which effect changes in the phenomenal size of the visual acuity test object without concomitantly effecting changes in other variables of which visual acuity is known to be a factor.

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[1] See, for example, the recent reviews by Ogle (25), Senders (27), Sloan (28), and Walls (32), as well as the studies in (1) and (30).

* * *

The reticle pattern in a binocular stereoscopic range finder subtends a constant visual angle at all times. As the reticle pattern is made to appear more distant (i.e., as one ranges farther into the field of view by reducing the convergence of the retinal images), one experiences a phenomenal increase in the apparent size of the reticle pattern. This phenomenal increase is so dramatic it is sometimes taken as a more-or-less physical feature of the range finder and is looked upon as a possible limiting feature of the instrument. Thus, in reference to a laboratory model binocular stereoscopic range finder, Harker and Brune (14) say:

"...The apparent relative size of the test object grows larger with increasing distance contrary to the behavior of a real object. This is a fundamental property of reticles. It arises from the fact that the reticle subtends a constant visual angle while the receding target subtends an ever smaller visual angle. Concomitant to this is the linear size relation of the test object to the reference object. If both objects are of the same shape, the assumption of linear perspective may operate to produce errors of localization...." (14, p. 7).

This increase in apparent size is a correlative manifestation of the size-constancy phenomenon.[2] "Size constancy" usually refers to the fact that as an object is made to recede from an observer, its retinal image diminishes in proportion to distance, while in perception it appears to remain constant in size. However, Holway and Boring (18) showed that when the receding object is made to subtend a constant visual angle, its apparent size increases as a function of distance. They showed further that the degree of such "size constancy" exhibited by an object is a function of the number of stimulus cues to distance available.

It would seem reasonable, then, to use a binocular-stereoscopic-range-finder-type instrument in conjunction with these phenomena of size constancy to induce changes in phenomenal size and, thus, to approach the present problem. With a visual acuity test as the reticle pattern, the convergence of the reticle beams could be changed under two conditions. In the first (condition S), full binocular cues to distance could be presented so that the fused reticle image would be localized at different distances (and, through the size-constancy phenomenon, as of different sizes). In the second (condition R), no cues to distance (other than the static convergence of the eyes) could be presented so that the depth localization of

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[2] For discussions of the size-constancy phenomenon see Boring (8), Graham (13), Koffka (20), and Vernon (31).

the test chart would be poor and, from the Holway and Boring data (18), apparent size would tend towards the "law of the visual angle." If measured visual acuity is a function of phenomenal size, then differences in the acuities measured at the different reticle convergences should occur under the first conditions, but not under the second.

Method

Apparatus.--A stereoptometer was the apparatus used. Because this instrument is reported in principle elsewhere (2, 3), the description given below is limited to the minimum necessary for comprehension of the experimental procedure.

Basically, the stereoptometer is a unit base, unit power, binocular stereoscopic range finder. It consists of two USAF reflex gun sights: one is mounted rigidly to a base, the other is mounted on a bearing which allows rotation about the optical center. The tangent of the angle of rotation is found by use of a thousandths-inch dial gauge measuring at a calibrated distance from the center of rotation. A schematic top view of the instrument is given in Fig. 1.

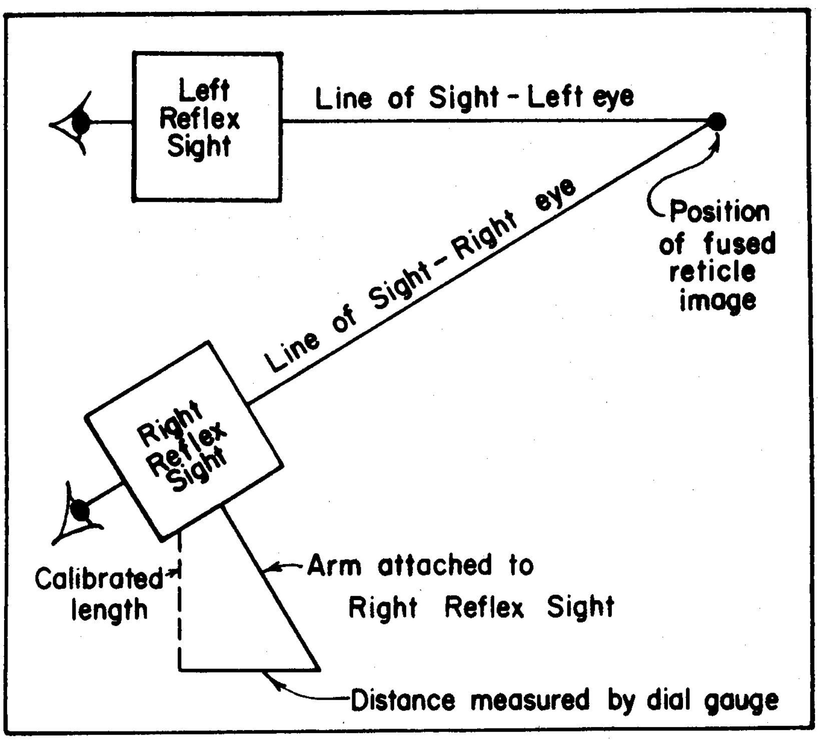

Fig. 1.--Schematic top view of stereoptometer; adapted from (2) and (3).

The reflex sight consists of a source of illumination, a reticle disk placed at the focal point of a Mangin mirror, and a half-reflecting surface. The Mangin mirror transforms the divergent light rays from the pattern cut in the reticle disk into parallel beams of light. The half-reflecting surface reflects these parallel beams to the eye, while allowing transmission to the eye of light from the field of view. To a person looking through the reflex sight, the reticle image appears to be located at some indefinite distance in the "real" field. When two such sights are used as in the stereoptometer, the reticle image appears to the viewer to be located at a definite distance in the field of view, i.e., at the point determined to be at the intersection of extensions of the parallel beams from the two sights. A schematic side view of the reflex sight used is given in Fig. 2.

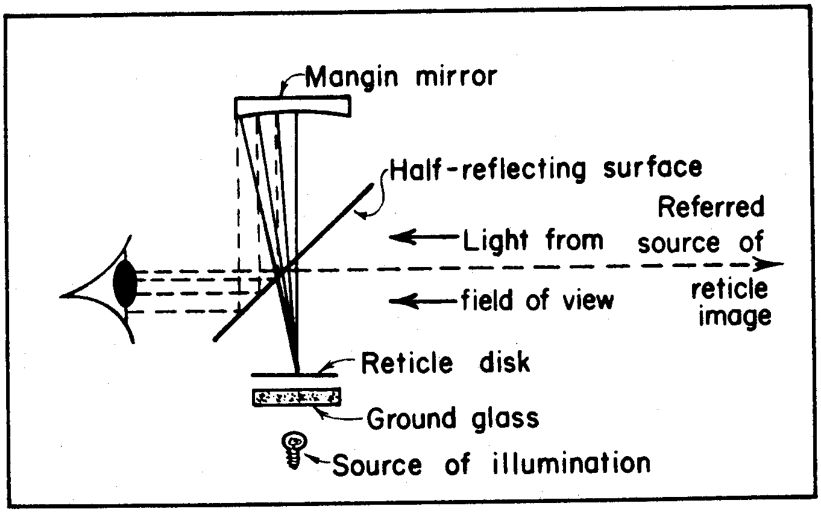

Fig. 2.--Schematic side view of a reflex sight; adapted from (2) and (3).

It should be noted that two additional advantages accrue from the use of this type of optical system with its resultant parallel beams. First, accommodation is not required to focus correctly the reticle image since parallel rays call for accommodation to infinity. Second, when two sights are used for binocular observation, as here, no adjustment for interpupillary distance is necessary since lateral displacement of one eye results in a like displacement of that eye's reticle image. Of course, differing interpupillary distances will result in differing apparent distances of the fused reticle image for a given convergence of the two sights.

Acuity targets.--The reticle disks were high contrast, fine grain, photographic negative reductions of a visual acuity test chart.[3] Only the lower eight lines of the chart were used. These allowed readings of a total of 60 acuity figures: four at 20/80, five at 20/60, six at 20/50, seven at 20/40, eight at 20/30, nine at 20/25, ten at 20/20, and eleven at 20/15. After magnification of the reticle pattern by the optical systems of the reflex sights, the test chart lines were calibrated as representing approximate Snellen ratings of from 20/112 through 20/21 at the position of O's eyes. Although the smallest acuity test figure presented was larger than the "normal" 20/20 Snellen rating, the reduced brightness and color contrast operated to lower the obtained acuities so that the pattern as presented was deemed adequate. All 60 letters on the chart were correctly identified only 13 times out of the total of 216 readings.

Field of view.--The stereoptometer was positioned with the reflex sights about four feet from a window so that the field of view was a relatively unobstructed view of the sky. A number of auxiliary objects (window frame, roof line with dormers, trees, etc.) were present in the field of view to aid in localization of the fused reticle image during the daylight hours (condition S). At night the field of view was a relatively undifferentiated black; no objects were visible to aid in the depth localization of the test chart (condition R). Variable polaroid filters, placed in front of the reflex sights, provided a means of reducing the brightness of the field of view. The letters of the reticle image appeared as yellow-orange images on either the daylight sky (condition S) or the night-black background (condition R).

Observers.--Two groups of 36 Os each were used. The condition-S group consisted of 19 males and 17 females; the age range was from 17 to 41 years with median age at 22. The condition-R group consisted of 23 males and 13 females, 14 to 47 years of age with median age at 26. Two additional volunteers were rejected when they failed to exhibit fused binocular vision. Assignment of Os to groups was quasi-random, the limiting factor being the temporal availability of the volunteers (day or night). No attempt was made to match groups or individuals.

Procedure.--Visual acuity measurements were made under the two conditions (S and R) discussed above. In each of these conditions, acuity was measured for each O three times in succession, i.e., once at each of three different convergences of the reflex sights. Three angles were selected to provide for the apparent distance of the reticle image (in condition S) being once well within the accommodative range, once at about the normal testing distance, and once

[3] Bausch and Lomb Optical Company's Snellen-rating, illiterate, direct-reading visual acuity test chart. The illiterate (E's) chart was selected as probably being less biased with form perception than the usual letter charts.

well beyond the accommodative range. The three convergences used were (A) 2°30', (B) 30', and (C) 5'. For an interpupillary distance of 2.4 in. (61 mm.), these represent approximate radial distances of (A) 4, (B) 23, and (C) 1400 ft.

The order of presentation of convergence angles was varied systematically over Os. Each group of six Os represented a replication of the six possible permutations (ABC, ACB, etc.). By so obtaining the three successive measurements from each O, gross changes in illumination of the field of view, the sky background, etc., were controlled within Os, but not between them. In addition, a control for the learning of the specific letter sequence of the test pattern was obtained by requiring that each O first read from left to right the entire chart, then from left to right the smallest three lines attempted, then these three lines from right to left.

Instructions.--The following instructions were read to each O before his first visual acuity measurement:

"When you look through these two sights, you will see a chart such as that used in an eye examination. You are to read down as far as you can, telling me 'up, down, right, or left' according to the position to which the open end of the capital E is pointing. If you can not tell for sure in which direction a given E is pointing, guess--try to get as many as you can. We shall do this three times; sometimes with the chart close, sometimes far. Ready?"

It should be noted that these instructions were not entirely correct for condition R. Since only the test chart was present in the field of view under that condition, there was little chance for a depth localization of the chart. It was thought best, however, to use identical instructions with the two conditions. Several of the Os in condition R did spontaneously remark to E that they could discriminate no differences in the apparent distance of the test chart at the different convergences of the reticle beams. These Os were told that it was "very difficult to see such a difference in a dark-field situation," and they were apparently satisfied with this explanation.

Measures and tests.--The data collected were the number of letters correctly identified out of the 60 possible. Since there was no reason to assume normality of the distribution of correctly identified letters,[4] it was decided *a priori* to use a nonparametric statistic to test the overall significance of results. Friedman's Chi-square-r (11) provided such a test. Thus, for each O, the three

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[4] Because the separate lines of the test pattern represented discrete changes in visual angle, and therefore in measured acuity, there was good reason to expect a non-normal distribution of raw scores.

convergence conditions were rank ordered on the basis of the acuity performance. These rank scores for the convergences were then summed, and Chi-square-r's were computed separately for the two experimental conditions (S and R).

The working hypothesis that acuity is a direct function of phenomenal size would indicate that for condition S the acuities obtained at C should exceed those obtained at A, and likewise B should exceed A, and C should exceed B. To test these predictions would require a nonparametric equivalent of the critical ratio; Brandt's sign test (9) was selected as satisfying these statistical requirements.

Results

Table 1 presents the means of the raw scores and the rank scores for the two experimental conditions. Friedman's Chi-square-r test on the sums of ranks for condition S yields a significant Chi-square-r of 34.76; for 2 df, p is .001 with a Chi-square of 13.82. Furthermore, Brandt's sign test applied to the pairs of convergences rejects the null hypothesis at probability values less than .001 in the case of each pair. From this it is concluded that the acuities at C exceed those at A, those at B exceed those at A, and those at C exceed those at B.

Table 1

Mean Number of Letters Correctly Identified Out of 60 Possible

and Mean Ranks for Three Convergences Under Two Viewing Conditions

Mean Score	Convergence*		
	A	B	C
Condition S (N = 36)			
Number Correct	52.1	54.1	55.5
Rank	1.32	1.97	2.71
Condition R (N = 36)			
Number Correct	49.9	50.2	50.5
Rank	1.94	1.96	2.10

*The convergences were: (A) 2°30', (B) 30', and (C) 5'.

The Chi-square-r obtained with the summed ranks for condition R is .514. This is associated with a probability value between .70 and .80, and so the null hypothesis is not rejected. Furthermore, Brandt's sign test applied here says that differences in measured acuity as great as, or greater than, those obtained between C and A, B and A, and C and B, could have occurred by chance alone with probabilities of .491, 1.000, and .617, respectively.

The strength of the ranked relation is pictured in Fig. 3, where the sums of ranks (and mean ranks) for both conditions are plotted along with the values expected for perfect and for zero relations.

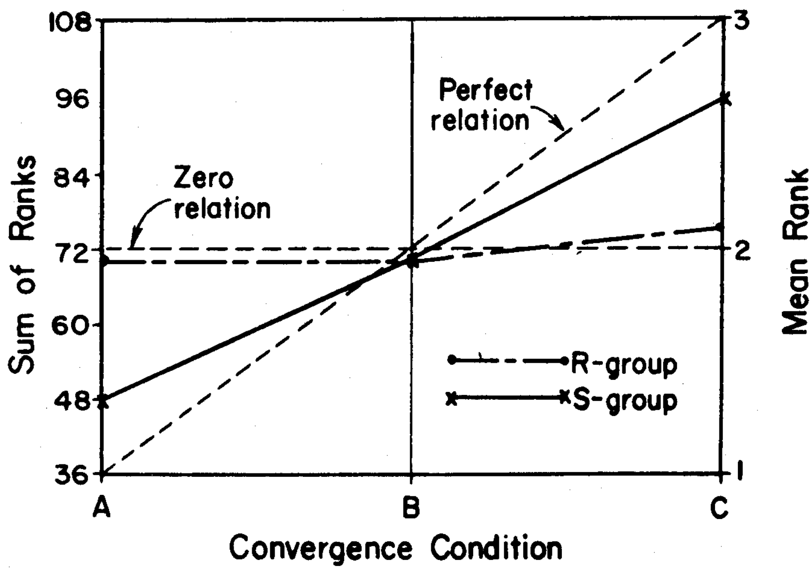

Fig. 3.—Expected and obtained rank scores for two experimental conditions (S and R) under three convergence conditions.

Discussion

Before concluding that measured visual acuity is a function of phenomenal size, it is first necessary to entertain the possibility that changes in accommodation occurred in such a way as to account for the results obtained. This consideration is necessary since blurring of the parallel rays of light and consequent lowering of the measured acuities would occur with increasing accommodations.

There appear to be two possible ways in which accommodation could have systematically varied: (a) It might have varied with the changes in convergence, or (b) It might have varied with the apparent distance of the test chart. The first would indicate a function of convergent accommodation; the second, proximal accommodation.

With regard to the first, Morgan (22, 23, 24) has found no convergent accommodation operative within the limits of convergence used in the present study. Even so, were it operative here, the acuities measured at the greatest convergence (and, therefore, at the greatest convergent accommodation) would have been less than those obtained at the other convergences for both condition S and condition R. Because the measured acuities did not differ for the different convergences in condition R, it may be concluded that the changes obtained with the different convergences in condition S were not due to convergent accommodation.

The second presents a more difficult picture. Proximal convergence (convergence occurring as a function of O's conscious estimate of the position of a viewed object) is known to operate under certain conditions (5, 15, 17, 22, 23, 24, 26, 29). The data for proximal accommodation, however, are less convincing. Morgan (22, 23) and Hofstetter (15) say that there is none, but Ittelson and Ames (19) report a demonstration of both proximal accommodation and proximal convergence. This was accomplished in a monocular task wherein apparent distance was changed by use of different sizes of a familiar object suspended at a constant distance. Hofstetter (16) has raised an objection to the interpretation of this study by Ittelson and Ames. However, with binocular observation and introspective reports from three Os, Ittelson and Ames (19) report accommodative changes (blurring of a starpoint) as the projected size of a familiar object was continuously varied to give the impression of an object of constant size moving back-and-forth radially. Measurements of the exact accommodation changes were not made in this situation, but measurements of convergence showed no changes. One would have expected changes in convergence as a function of the operation of accommodative convergence, however!

Assuming that proximal accommodation did operate perfectly in condition S of the present study, the accommodations for the three apparent distances would have been approximately 1/425, 1/7, and 1/1.2 diopter at C, B, and A, respectively. In other words, the accommodative difference between distances C and B would have been approximately 1/7 diopter, whereas that between distances B and A would have been approximately 5/7 diopter--roughly five times as great. On this basis, the differences expected between the acuities measured at A and B would be much greater than those expected between the acuities measured at B and C. Since this was not the case, it would appear reasonable to infer that proximal accommodation did not operate here.

The results, then, agree with McFadden's conclusion (21) that measured visual acuity is a function of phenomenal size. The striking fact is not so much the magnitude of the differences as it is their consistency. The finding that the greatest actual mean difference was of the order of only four letters or so (between the C-A difference in condition S) indicates that this effect is of little practical or clinical importance. It is of theoretical significance, however, in illustrating once again that, as Senders (27) concludes: "In attempting to determine the basis on which an observer makes a discrimination of a small angular separation, it is no longer possible to consider nothing more than a distribution of intensities on the retina. Nervous processes...are most certainly involved...." (27, p. 488)—a conclusion similar to one drawn by Boring with reference to interpretation of the Aubert-Foerster phenomenon (8, p. 249).

The type of central factor in acuity supported by these data, however, is not of the order of Jaensch's explanation of the Aubert-Foerster phenomenon (see 7). Jaensch argued that when objects differ in apparent size, their central excitations differ in extension whether or not the retinal images differ. He then reasoned that the greater the extension of excitation, the more diffuse and undifferentiated the margins of excitation, and the less the differentiation. Were his theory correct, measured visual acuity would be an inverse function of apparent size rather than the direct function obtained in this study.

The results obtained here also relate to the generalization of the Aubert-Foerster phenomenon itself. This phenomenon refers to a situation of equal retinal images, equal illuminations, and both large and small acuity test objects. With these conditions, it is found that the smaller (and, therefore, closer) objects are resolved farther out in the periphery than the larger (and farther) objects. The results of the present study indicate that it is probably not correct to generalize Aubert's results to the central retinal region, i.e., to refer to a greater centrally measured acuity for smaller (and closer) objects than for larger (and farther) objects.

Another facet of these results concerns the relation of measured visual acuity to the distance between the test object and the testee. Beebe-Center and his associates (7) in a review noted contradictory findings in the earlier studies of this question. They concluded that those previous studies failed to present a definitive answer because such factors as learning, extent of field-of-view, illumination of background, etc., were not adequately controlled. Their own studies (7) showed visual acuity independent of distance from the eye for a range of from 12.5 ft. to 2.83 mi. Dimmick and Rudolph (10) report similar results; acuity was independent of distance for the range 5.94 ft. to 113.20 ft. Altman and Rowland (4) found no difference between acuities obtained at 20 ft. and those obtained in a commercial device which optically simulates the distance of 20 ft. However, Giese (12), in measuring visual acuity at eight distances over the range .20 to 10 meters, found acuity increasing significantly from .20 to 1.0 meters.

In her review of this topic, Sloan (28) concludes that "...For distances of two meters and greater, it seems probable that under adequately controlled conditions acuity is practically independent of distance...(but) there appears to be valid evidence that at relatively short distances acuity decreases significantly with decrease in distance...." (28, p. 19).[5] The point to be made here is that perhaps some of the differences among these seemingly contradictory findings could be explained in terms of differences in phenomenal size changes of the test object within the separate studies. At least, such an explanation can be suggested.

Summary and Conclusions

In a daylight situation favorable to the operation of size constancy (condition S), 36 Os read a retinally projected visual acuity chart at three convergences and, thus, at three apparent distances and three conditions of phenomenal size of the chart. An additional 36 Os read the same retinally projected chart under similar conditions, but in a stimulus-reduced night situation (condition R); for this group, phenomenal size of the test chart remained constant. The data support the following conclusions:

1. Acuities obtained at the three convergences differed significantly among themselves in condition S, but not in condition R. This seems to establish measured visual acuity as a function of phenomenal size of the test chart.

2. This effect was so small (less than one Snellen rating), it appears to be of little practical or clinical importance. It was sufficiently consistent, however, to offer statistical support to those theories allowing for central factors in measured visual acuity.

3. Evidence for convergent accommodation was negative, as was evidence for proximal accommodation.

4. The data suggest that the Aubert-Foerster phenomenon is specific to the periphery and should not be generalized to the central retinal region.

5. It is suggested that these results might partially explain contradictions found in studies relating visual acuity to distance of measurement.

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[5] This conclusion of Sloan's (28) militates, as do the data of this study, against the generalization of the Aubert-Foerster phenomenon to the central retinal region.

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