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THE RELATION OF VISUAL ACUITY TO CONVERGENCE AND ACCOMMODATION [1]

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Measured visual acuity is usually expressed as the reciprocal of the angle that the minimally visible spatial extent or gap subtends at the observer's eye. This practice implies that the actual size of the acuity target and its distance from *O* are immaterial and that what determines the resolution threshold is the size of the retinal image of the object. Several experiments have, however, been reported showing that there are exceptions to this rule. The evidence appears to show that visual acuity is independent of observation distance when the distances are larger than one or two meters, but that it decreases with decreasing distances below this limit (1, 5, 7, 8, 9).

Various explanations have been offered to account for this phenomenon. The most prominent among these has been the suggestion that, since convergence and accommodation necessarily covary with the distance of the test object, either or both of them may be related to this phenomenon (3, 8, 10). So far no direct evidence has been available to evaluate this hypothesis. The experiment reported here was designed to provide such information.

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Method

Apparatus.—The apparatus consisted of three main parts: a haploscope for varying the convergence of *O*'s eyes, a continuously variable acuity target, and an optical system to provide uniform illumination of the target.

A commercial troposcope, Wottring Model 40 B, manufactured by American Optical Company, was modified to serve as a simple haploscope. The right arm of the haploscope was fixed, so that the right eye looking into it remained always in its primary position. The left arm could be turned both horizontally and vertically about its center of rotation which coincided, more or less, with the center of rotation of *O*'s left eye. The adjustments of the left arm were made to vary the convergence of the left eye. Thus all converging was done by *O*'s left eye only, whereas the right eye in its primary position saw the acuity target.

Each arm of the haploscope was 100 cm long. At the far end of the right arm was a circular opening through which the acuity target could be seen when exposed. A small bright dot, about 1 mm. in diameter, was reflected from a cover glass inside the arm and served as the right fixation point. A similar fixation point was also placed at the far end of the left arm. When the target was not exposed but both fixation points were turned on, the *O* looking into the instrument saw a totally dark field with two fixation points. When the convergence of *O*'s left eye corresponded to the setting of the left arm of the haploscope, the two fixation points were seen fused as one.

The acuity target consisted of two vertical parallel black lines seen against an evenly illuminated circular field 17.5 mm. in diameter which, at a distance of 100 cm., corresponds to visual angle of 1°. The width of the black lines, formed by two very taut wires, was .014 in. or 1 min. 15 sec. in angular measure. The distance between the two lines could be continuously varied by *E* and read to the nearest 10^{-4} in., corresponding to approximately $\frac{1}{2}$ sec. of arc.

The optical system consisted of a ribbon filament lamp, a pair of condensing lenses, a filter holder for the insertion of neutral density filters, a circular shutter disk, and a flashed opal screen. The acuity target was seen against this screen. The luminance of the screen, calibrated by means of a MacBeth Illuminometer, was kept constant at 19 mL. The exposure time of the target was controlled by the circular shutter and was constant at .25 sec. throughout the experiment. Various stops and screens were used in the optical system, as well as in the arms of the haploscope, to keep out stray light.

The eyes of a normal young *O*, owing to convergent accommodation, are accommodated for the convergence distance (4). To keep the target in good focus for all amounts of convergent accommodation, very small artificial pupils, .5 mm. in diameter, were employed.

Observers.—Seven men, aged from 22 to 29 yr., with a median age of 23 yr., served as *O*s. Six of them had no known visual defects, the seventh one was a slight myope.

Task.—The *O* sat in a light-tight but ventilated cubicle. His head was supported by the headrest of the haploscope. Looking into the instrument, his task was to fuse the two separate fixation points and then present the acuity target to himself by pressing a key. This key operated the shutter permitting the circular background of the two black wires to be illuminated for .25 sec. The *O* reported whether he saw one or two black lines by operating two other keys within his easy reach. The intervals between successive exposures were about 8 to 10 sec. Prior to the experiment proper all *O*s received sufficient practice in fusing the two fixation points under all degrees of convergence used in the experiment.

Procedure.—In Part 1 of the experiment each *O* came for three experimental sessions. These constituted repetitions of the same procedure. In each session, lasting about 2 hr., including frequent rest periods, *O*'s acuity was measured for five different angles of convergence which corresponded to convergence distances of 25 cm., 33 cm., 50 cm., 100 cm. and infinity.

To determine thresholds of separation between the two black lines of the acuity target the so-called "up-and-down" method was used (2). The *O*'s threshold for each convergence angle in a given session was based upon 60 judgments. The order of convergence angles within sessions was counterbalanced.

Two *O*s made their observations in the first three sessions while their ciliary muscles were paralyzed by homatropin. Prior to each session, drops of 5% homatropin solution were applied to the conjunctival sacs of both eyes at 15-min. intervals. Applications were stopped when retinoscopic measurements revealed the refraction of the right eye to be the same for the convergence at 25 cm. as at 6 m.

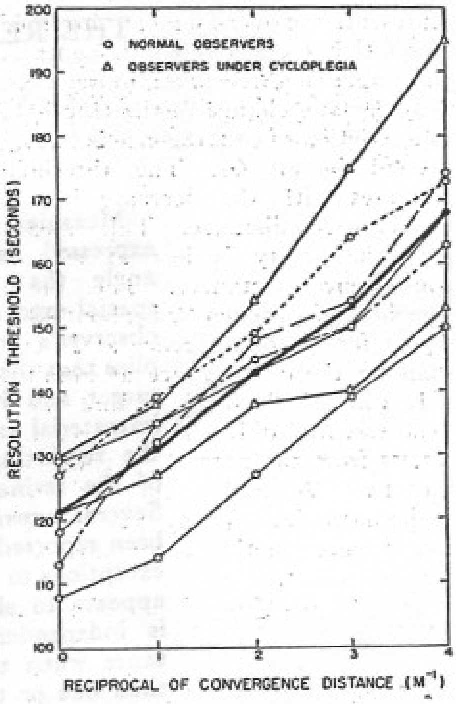

FIG. 1. Threshold separations of the minimally separable two black lines as a function of convergence. Means of individual unpracticed *O*s. The heavy line shows the grand mean.

In Part 2, following the initial three sessions, four of the seven *O*s were given daily practice periods of about 1 hr. in viewing and making judgments about the acuity target under the two extreme angles of convergence used previously. Two *O*s received such practice for 12 days, the other two for 15 days.

After the conclusion of the practice sessions the acuity of the four *O*s was again measured for the original five angles of convergence under the same experimental conditions as in the first part of the experiment.

RESULTS

The results of Part 1, in which seven relatively inexperienced *O*s were employed, are shown in Fig. 1. Threshold separation of the two parallel lines is plotted against the reciprocal of the convergence distance for all *O*s. Each point on the graph represents the over-all mean threshold of an O based on 180 judgments of the target in three different sessions. A systematic change in the threshold as a function of convergence is clearly present in all Os. The threshold increases with the decrease in the convergence distance. This means that the acuity is less at shorter convergence distances. The mean threshold of all seven Os is about 40% higher for the convergence at 25 cm. than for the convergence at infinity.

It will also be noticed that there is no essential difference between the results from the normal Os and from the two Os under the influence of homatropin. Acuity varies with convergence whether accommodation changes or not.

The results of Part 2, in which four relatively experienced Os were employed, are shown in Fig. 2. Each point on the graph represents the mean threshold of an O based on 180 judgments of the target in three sessions following 12 to 15 hr. of practice. By and large the effect found with unpracticed Os is now gone: the threshold of separation is

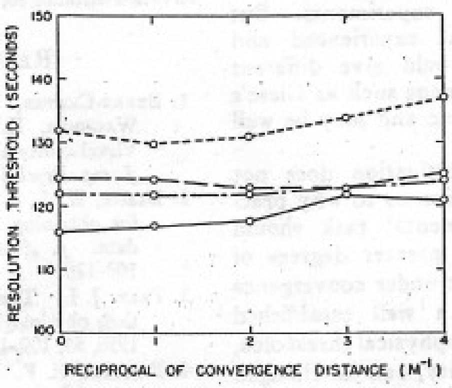

FIG. 2. Threshold separations of the minimally separable two black lines as a function of convergence. Means of individual practiced Os.

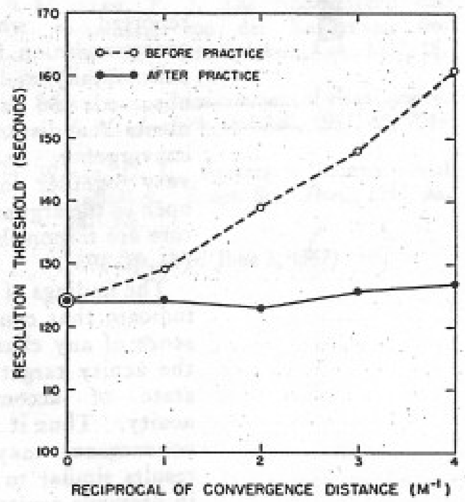

FIG. 3. Practiced vs. unpracticed Os ($N = 4$). Threshold separations of the minimally separable two black lines as a function of convergence.

essentially the same for all degrees of convergence. For two Os there still remains a small effect similar to that found with unpracticed Os—the threshold is somewhat higher for smaller convergence distances. But even for these two Os the magnitude of the effect is no greater than about 4%.

In Fig. 3 are shown the mean thresholds of the four Os in both Part 1 and Part 2, following the practice period. The difference between the two curves is obvious.

DISCUSSION

Freeman's "anomaly of visual acuity" (5) has remained a puzzle for over a quarter of a century: visual acuity is less for very close targets than for far. Although there is no known mechanism by which accommodation or convergence might influence visual acuity these two oculomotor adjustments have been brought in to explain the phenomenon (3, 8, 10). So far, to the best knowledge of the writer, no experiments have been reported in which convergence and accommodation have been isolated experimentally and their effect on acuity observed. In acuity-distance experiments the distance of the test object, convergence, and accommodation all vary together and this leaves the door open to the argument that "psychic" factors are responsible for the phenomenon (11, p. 495).

The findings of the present experiment indicate that convergence alone, in absence of any changes in the distance of the acuity target and regardless of the state of accommodation, influences acuity. Thus it seems that changes in convergence may have produced the results similar to Freeman's "anomaly" in previous acuity-distance experiments. The previous results, however, can be regarded as anomalous only as far as the basic principles of physiological optics are concerned. The present experiment suggests that the anomaly disappears when the past history of the *O* making acuity judgments is taken into consideration. The *O*s with some skill in the task yield results which are in good agreement with the principles of physiological optics.

It is, of course, quite possible that the findings of this experiment cannot be generalized to account for discrepancies between theory and empirical facts in the acuity-distance experiments. But the hypothesis that experienced and inexperienced *O*s would give different results in an experiment such as Giese's (7) is directly testable and may be well worth considering.

The present investigation does not permit any explanation as to why practice in the experimental task should affect acuity under greater degrees of convergence and not under convergence at infinity. It is a well established fact that most psychophysical thresholds, including visual acuity, can be changed by practice (6), but the mechanisms underlying it are not too well understood. A precise analysis of what has been here loosely called "practice" might be helpful in delineating the direction in which the answer should be sought.

At present it is only reasonable to assume that practice does not affect the power of retinal resolution. Thus the differences in acuity for close targets between practiced and unpracticed *O*s are probably related to the observational procedures that these *O*s use. It looks as if something—we cannot yet say what it is—confuses the unpracticed *O* so that he cannot for near objects, or with greater degrees of convergence, take the same advantage of his power of retinal resolution as he can for far objects, or with small angles of convergence.

Summary

In this experiment the acuity of the *O*s' right eye in its primary position was measured while the left eye changed its convergence. The acuity target, at a constant distance from *O*, consisted of two parallel lines.

Acuity was found to decrease with increasing angles of convergence when relatively unpracticed *O*s were used. This effect was shown to be independent of changes in convergent accommodation. For *O*s who had received longer practice in the experimental situation, acuity was found to be independent of both convergence and convergent accommodation. The results were discussed with reference to the previous experimental findings that measured visual acuity decreases with observation distance for relatively small distances.

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