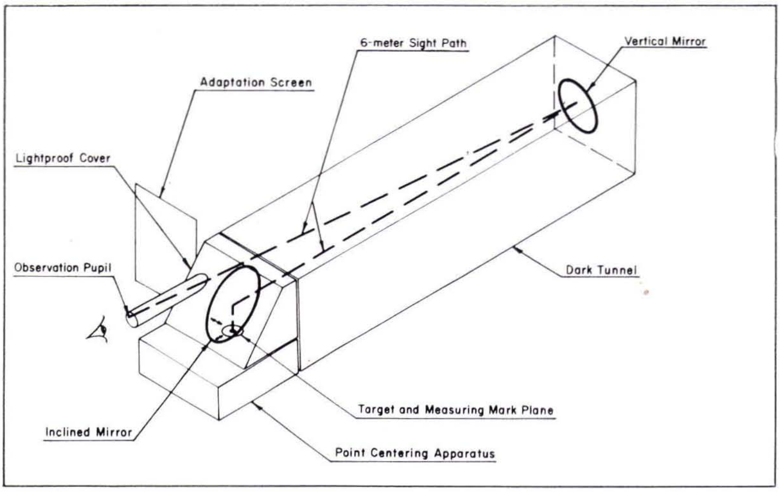

FIG. 1. The schematic arrangement of the apparatus designed to simulate comparator viewing.

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X-, Y-Correlation in Coordinate Measurement

Evidently no significant correlation exists on independent-axis systems.

INTRODUCTION

IN A recently published report (2) the writer described an investigation into some factors affecting the precision of centering black circular measuring marks in sharp circular targets representing artificial passpoints with homogeneous backgrounds of different contrasts, imaged in the vicinity of the fovea centralis. Under the conditions of the investigation, the critical variable was found to be the width of the annulus between measuring mark and target.

The measurements were not made in a comparator, but in a special apparatus designed to simulate comparator viewing by presenting the targets at the standard clinical testing distance of six meters. This enabled a vastly greater measuring sensitivity to be obtained. It has been demonstrated (Ref. 2, page 99) that comparators are not sufficiently sensitive to develop the full capability of the eye. Their comparatively coarse least-count masks fine thresholds, and possibly distorts the statistical behaviour of the measurements. A brief description of the apparatus and procedure is given below. Complete details appear in the above-mentioned report.

EXPERIMENTAL INVESTIGATION

The general arrangement of the apparatus and the six meter sight path is shown in Figure 1.

The targets were clamped to a moving carriage over a diffusing screen. Hand-operated micrometers were used to move the target in the *Y*-direction, and the measuring mark in the *X*-direction, along independent axis systems. The micrometer readings were taken by means of shaft encoders. At six meters, the least count of the encoder readout was equivalent to 0.02 second of arc subtended movement of the micrometer. The encoder outputs were processed in an Analytical Data Readout and Recording System, which gave a visual display and a punched tape record.

The targets were viewed monocularly through an artificial pupil four millimeters in diameter. A white adaptation screen was placed to provide the occluded eye with an adaptation level of 10 millilamberts. The general level in the laboratory was 15 millilamberts.

The targets were viewed against diffuse tungsten light, the brightness of the diffusing screen being 14 millilamberts for the high contrast targets, and 37 millilamberts for the low contrast targets. The lower brightness for the high contrast targets was found necessary to overcome a *fuzziness* around the edges of the annulus.

The targets were viewed against an extensive black background in the high contrast case and, in the case of the lower contrasts, against a circular field of uniform brightness subtending an angle of 2.1 degrees, surrounded by an extensive black background. The low contrast targets tested had background densities of 0.3, 0.9, and 1.2.

Most targets were prepared photographically, but where a very small annulus was required over a wide range of subtense angles, they were precisely machined out of aluminum. The measuring marks were machined from aluminum.

Double reflection was used in the system, and examination showed no evidence of polarization.

The Experimental Procedure

The method of adjustment, or repeated setting, was used rather than any of the *constant* methods, because it is the method used in photogrammetric practice, it is more amenable to statistical treatment, and the final judgment and setting requires direct participation by the observer. Series of 50, 30, and 10 readings were observed.

In all cases, the measuring mark was centered in the target with the X- and Y-micrometers, in no set order, and the setting movements were always in the same direction of rotation of the drums up to the final position. This meant that the approach was made from below in Y and from the right in X on all occasions. If there was any doubt about a setting, the mark was withdrawn and a new approach carried out. No limit was placed on the time to make a setting, but throughout the series, the average time for a setting was 0.3 minute. The indirect nature of the recording made it impossible for the observer to consciously check on his setting precision.

The basic measurements were made with measuring marks whose visual subtenses corresponded with those normally used in photogrammetric practice, 2.25 and 3.41 minutes of arc. The latter appears to be almost ideal for practical use, presenting no visibility problem, and offering no disturbance to stereoscopic correlation in point transfer. To clarify the significance of the annulus between measuring mark and target, an extreme measuring mark subtending 17.75 minutes was considered. To investigate the effect of retinal location of the annulus, measuring mark-target combinations were chosen to provide an annulus width of 0.15 minute of arc over a range of visual subtense angles from 18 minutes to 2 degrees.

To study the effect of contrast, a basic set of plates of density 0.3 was observed with measuring mark 3.41 minutes of arc. This density was chosen because the minimum density normally acceptable for aerial photographic plates is about 0.3 above fog. Density

Abstract: *The extent of correlation was studied between X- and Y-readings when black circular measuring marks are repeatedly centered along independent axis systems in sharp circular targets representing artificial passpoints with homogeneous backgrounds of different contrasts. The targets were viewed at a distance of six meters, and the setting apparatus had a least-count of 0.02 seconds of arc subtended visual angle. There was no evidence of correlation for measuring marks subtending 2–18 minutes of arc, with annulus widths 0–14 minutes of arc. This applied for high and low contrast targets in the light and dark adapted states.*

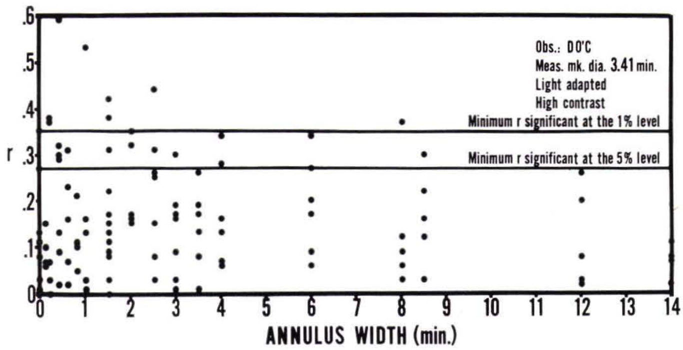

FIG. 2. Extent of correlation with a normal size measuring mark, based on series of 50 readings.

values of 0.9 and 1.2 were tested for the very small annulus widths where some difficulty was experienced in seeing the annulus.

To investigate the effect of working in a darkened room as often recommended by photogrammetrists, and to provide a basis for attributing any results to neural summation and interaction, a program was carried out in a completely darkened laboratory. Before commencing observations, the observer was dark-adapted for 45 minutes.

To minimize the effects of learning and experience, all targets were observed in order determined by lottery.

All settings were carried out with the head vertical. In addition to the principal observer DO'C, two independent observers were used. None of the observers had any astigmation or any visual abnormality likely to affect acuity (Ref. 2, page 182), but the observer MB was found to be in poor health as the work progressed. All observers were skilled and experienced in comparator measurement.

The Results

BASIS OF THE COMPUTATIONS

At the outset, it was assumed that the original observations were normally distributed. As a statistical estimate of the correlation between the X- and Y-readings, the correlation coefficient r was used.

$$r = \frac{S_{xy}}{S_x S_y}$$

where S_{xy} is the covariance of X and Y, S_x, S_y are standard deviations of X and Y respectively.

The values of r for typical series observed

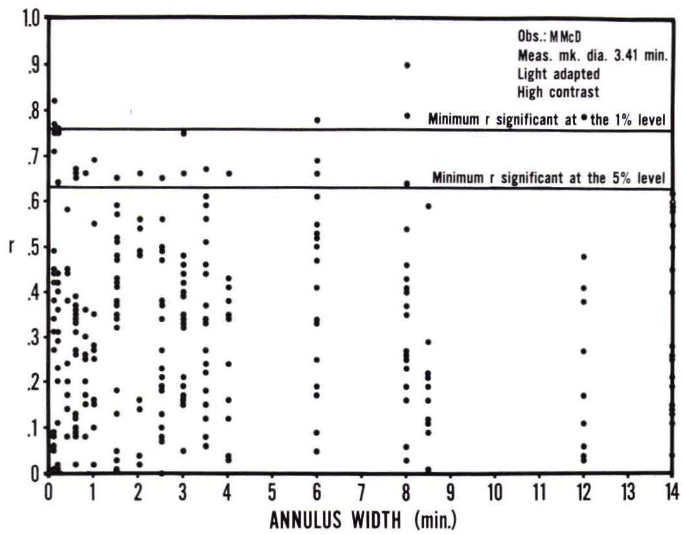

FIG. 3. A verification by an independent observer, using a normal size measuring mark, based on series of 10 readings.

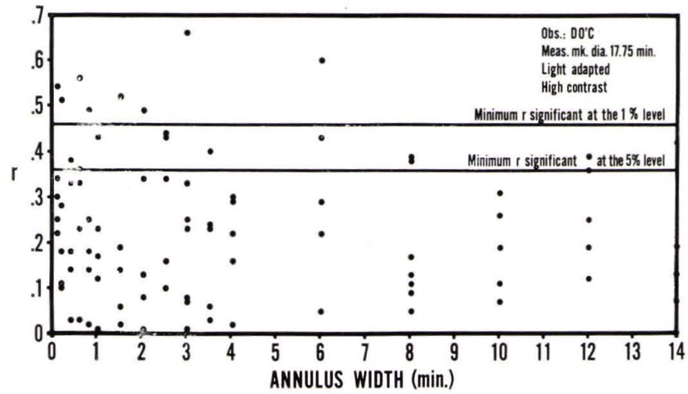

FIG. 4. Extent of correlation with an oversize measuring mark, based on series of 30 readings.

are plotted against annulus width in Figures 2 to 7. In testing the significance of the correlation coefficients, the t-distribution was used. The value of t was computed from

$$t = \frac{r}{\sqrt{1 - r^2}} \cdot \sqrt{n - 2}$$

where n is the number of pairs in a series.

The minimum values of r significant at the $P = 0.05$ and 0.01 levels were obtained conveniently from tables prepared by Fisher (Ref. 1, page 176). These values are superimposed on Figures 2 to 7. It was realized that these minimum values of r could be misleading for small samples such as the 10-series.

RESULTS

The results of all series were so nearly identical that only typical examples are shown in Figures 2 to 7. Inspection of these figures shows generally that the overwhelming majority of points lies below the $P = 0.01$ level, with the possible exception of observer MB, Figure 5. This suggests very strongly that there is little evidence of correlation between the X- and Y-readings in this investigation. This seems so clear from the 50- and 30-series that it is not surprising that it is indicated in the case of the 10-series, notwithstanding the limits of the theory applied to the latter case. It might be added, however, that the number of observations in a series did not appear to have any effect on the final form of the pointing relationships published in Reference 2.

This lack of correlation applied for all the measuring mark sizes tested, for the light and dark adapted states (results not shown), and for low contrast targets. The value of r did not seem to be related to the annulus width.

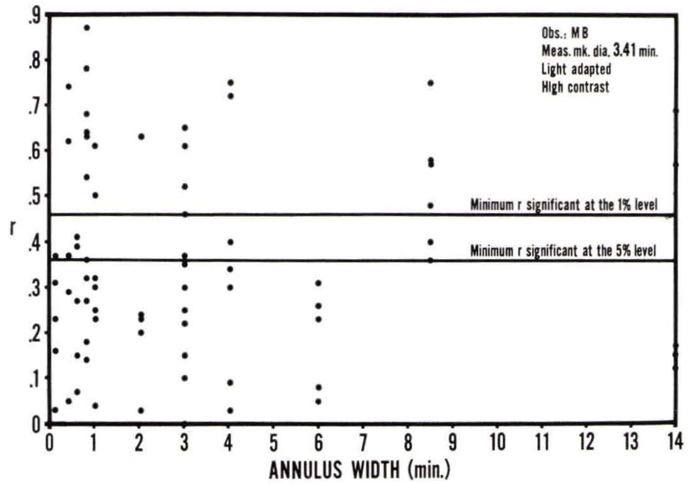

FIG. 5. Extent of correlation for an observer in poor health, based on series of 30 readings.

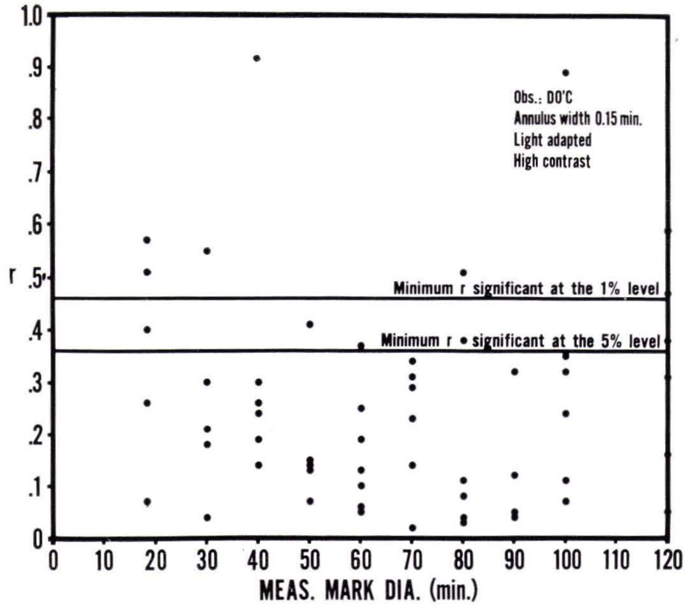

FIG. 6. Extent of correlation for a constant minimum annulus width, over a wide range of measuring mark sizes, based on series of 30 readings.

DISCUSSION

Experiments of this type are difficult to conduct because of limitations which seem to be fundamental to all psychophysical problems; the desire for objectivity cannot be fully satisfied because the response of a subject is involved. Any threshold has to be measured repeatedly and an average found because it will vary from moment to moment, particularly if very fine readings are being taken. The threshold and any related statistical variates may be obscured by variability in time.

The indicated lack of correlation seems to apply for different observers, although the results of observer MB are different from the others, and some correlation is indicated. However, a possible explanation for this may lie in the remarks made earlier concerning his health. One got the impression, as the work progressed, that this observer was virtually *locking-on* to a particular setting, and repeating it almost irrespective of target size.

As these results were obtained with an instrument of great sensitivity, caution should be used in any comparison with results obtained from relatively gross comparators.

CONCLUSIONS

On the basis of the assumption that the instrumental configuration used here represents a satisfactory simulation of comparator view-

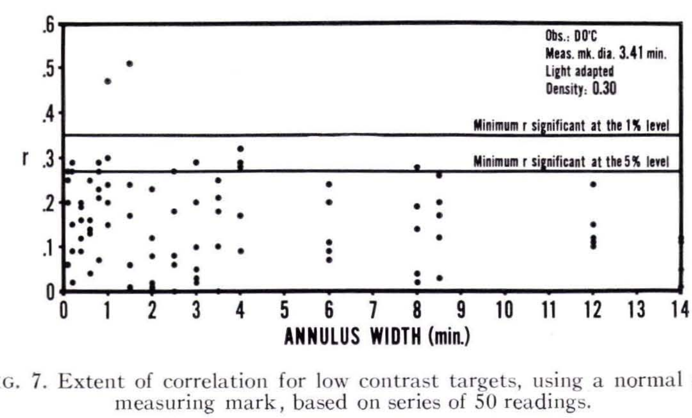

FIG. 7. Extent of correlation for low contrast targets, using a normal size measuring mark, based on series of 50 readings.

ing conditions, there does not seem to be any significant correlation between coordinate settings made on independent-axis systems. This applies irrespective of annulus width and measuring mark size in the range tested, and is not affected by the contrast nor adaptation level.

References

1. Fisher, R. A. *Statistical Methods for Research Workers*, 2nd Ed., Oliver and Boyd, London, 1928.
2. O'Connor, D. C. *Visual Factors Affecting the Precision of Coordinate Measurements in Aerotriangulation*. USAEGIMRADA Research Note No. 21, February 1967.

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