ANALYSIS AND MEASUREMENT OF VISUAL ACUITY

A DISSERTATION
submitted in partial fulfilment of
the requirements for the award of the Degree
of
MASTER OF ENGINEERING
in
ELECTRICAL ENGINEERING
(Measurement & Instrumentation)

By

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C E R T I F I C A T E

Certified that the dissertation entitled "ANALYSIS & MEASUREMENT OF VISUAL ACUITY" which is being submitted by Shri T. Ramachandran in partial fulfilment for the award of Degree of Master of Engineering in Measurement & Instrumentation of the University of Roorkee, Roorkee is a record of student's own work carried out by him under our guidance and supervision. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is further certified that he has worked for a period of 8 months from Jan. 1977 to Aug. 1977 for preparing dissertation for Master of Engineering Degree at this University.

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ABSTRACT

Visual acuity in general may be defined as the ability of the subject to discriminate the minute details of objects in the visual field. It is generally tested by placing a standard set of letters of the alphabet of graded sizes at a stated distance (20 ft. usually) from the subject. There are several instruments in use today that simulate the 20 ft acuity testing by the use of prisms and convex lenses. They are commonly used to test vision for driver licensing purposes. Visual acuity as recorded with such instruments is often reduced mainly because of the phenomenon referred to as apparatus accommodation which blurs the target.

For the purpose of the present experiment, visual acuity is defined as the reciprocal of the standard deviation (in second of arc) in error, in setting two lines in alignment. The apparatus used is an improvement over the previously mentioned ones, in the sense, that it eliminates apparatus accommodation and proprioceptive feedback. The present experimental results have been obtained to investigate inter-subject variability, and measurements have been obtained on five subjects performing a visual acuity task in white light. Additionall y all the five subjects performed the acuity task in red, yellow and green ill uminations. This was done to compare the acuity levels of subjects in various illuminations. Results obtained

indicate an inter-subject variation of visual acuity between 0.03 second arc and 4.3 seconds arc. This value is considerably lower than the threshold of normal acuity which is of the order of 33.4 seconds of arc at a distance of 16 ft. Out of the five subjects one subject had a peak performance in red light, two in yellow and two in green light. These results agree closely with those obtained by earlier experimenters, who observed a peak performance either at the red end of the spectrum or in the middle of the spectrum in the yellow green.

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CHAPTER - I

INTRODUCTION

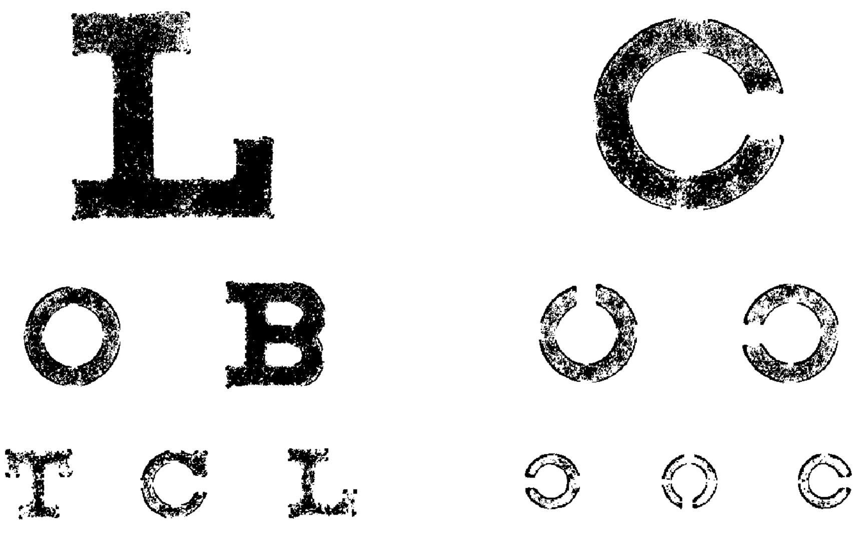
1.1 Definition :

Visual Acuity is the capacity to discriminate the fine details of objects in the field of view. It is specified in terms of the minimum dimension of some critical aspects of a test object that a subject can correctly identify. Good visual acuity implies that a subject can discriminate fine detail; poor acuity implies that only gross features can be seen.

The most common test of visual acuity is a standard set of letters of the alphabet of graded sizes, presented to the subject at a stated distance (Fig. 1). In clinical practice a series of test objects is used in which some critical aspect of each test object subtends an angle of 1 minute of arc at a standard viewing distance, usually 20 ft. for 'normal' visual acuity. The smallest test object that a subject can correctly identify is determined and the subject's visual acuity 'v' is given by the relation :

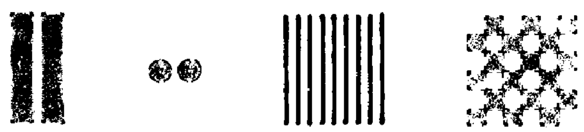
$$v = D'/D$$

where D' is the standard viewing distance and D is the distance at which this minimum test object subtends an angle of 1 minute of arc.



A B

THE TASK OF RECOGNITION. A_SNELLEN LETTERS OF THE ALPHABET B_LANDOLT RING TEST OBJECT. ACUITY IS DEFINED AS THE RECIPROCAL OF THE CRITICAL DIMENSION (Width of line, gap, or other) SUBTENDED AT THE EYE. THE SNELLEN LETTERS ARE COMPOSED OF LINES AND SERIFS HAVING A THICKNESS THAT IS ONE FIFTH THE HEIGHT OR WIDTH OF THE WHOLE LETTERS. THE LANDOLT RING CONSISTS OF A LINE WHOSE THICKNESS IS ONE FIFTH THE OUTER DIAMETER. THE GAP WIDTH IS ALSO ONE FIFTH THE OUTER DIAMETER



(a) (b) (c) (d)

FIG. 1 _THE TASK OF RESOLUTION. (a) DOUBLE LINE TARGET (b) DOUBLE DOT TARGET (c) ACUITY GRATING (d) CHECKERBOARD.

1.2 <u>Review Work</u> :

In 1923, Hartridge H. (12) determined that practicall y in every case in which the resolving power of the eye exceeds 60 seconds of arc, the visibility of a contour is involved. He also showed that where there is a constant difference of intensity there is usually a lower limit for the difference threshold than when there is a variation of intensity. Other factors which affect the difference threshold are intensity and retinal adaptation.

Hecht S. (13) in 1928, determined the relation between visual acuity and Illumination. He found that at low intensities visual acuity increases slowly in proportion to log I; at higher intensities it increases nearly ten times more rapidly in relation to log I; at the highest illumination it remains constant regardless of the changes in log I.

In 1932, Wilcox W. W. (25) concluded that Irradiation or the apparent shift of contours is the only cause of the variations of visual acuity with intensity. Irradiation is the phenomenon by which a bright object on a dark background appears subjectively enlarged.

The relation between visual acuity and Illumination for two trained observers were obtained by Schlaer, S. (21) in 1937. Two different types of test objects, a broken circle or 'C' and a grating were used (Fig. 1). The grating was found to give higher visual acuity at intensities less than about 30 photons and lower visual acuity above that. He concluded that detail perception is a function of a distance rather than an area.

In 1942, Shlaer (22) and his associates found that visual acuity is improved by conditions designed to increase the image contrast. This conclusion was reached by maintaining expdrimentally, the intensity discrimination in retina, as the limiting factor in resolution.

Hendley, C. D. (15) in 1948, found that visual acuity when plotted against brightness discrimination, yields data following Hecht's equation. The equation is :

$$KI = \frac{x^n}{(a - x)^m}$$

where,

I = brightness of light

$a - x$, x = concentrations of sensitive substances and photoproducts respectively.

m, n = orders of the photochemical and thermal reactions.

k = ratio of velocity constants of the two reactions.

$$V = \frac{\Delta I}{I} = C \left[1 + \frac{1}{(KI)^{\frac{1}{2}}}\right]^2$$

where, V = Visual acuity,

C = Constant

when m = n = 2

The effect of involuntary eye movements on visual acuity (16) was observed by Keesey, Ulker, T. (16) in 1960. He used three types of targets : Vernier, Line and Grating. He concluded that acuity is neither impaired nor enhanced by the involuntary eye movements, present while inspecting a test object.

In 1968, J. A. Foley - Fisher (8) made measurements of Vernier acuity in white and coloured light. The results indicate an inter-subject variation of threshold of vernier acuity between 4 seconds arc and 10 seconds arc. Peak performance was observed at the red end of the spectrum or in the middle of the spectrum in the yellow-green.

Foley-Fisher in 1973 (9) observed that Vernier acuity varies with target line length. The variation is such that an increase of line length results in a smaller threshold.

In 1973, a report was prepared in the U.S. on the visual acuity of youths. It showed that 70 % or 15.9 million of the youths 12 - 17 years of age have at least normal or better than normal acuity at distance.

In 1975, Gerald Westheimer and Suzanne P. Mckee (23) concluded that a stationary retinal image is not a prerequisite for good acuity.

Vernier Acuity which is one form of visual acuity is usually tested by the use of a straight line broken in the middle. The task is to appreciate small lateral displacements of one segment of the line.

Elwin Marg and his associates (18) observed the visual acuity development in infants, in 1976. They showed that adult visual acuity defined as the resolution of 1 minute of arc detail, is reached during the development of children any where from 7 years to as short a time as 2 years of age.

J. A. Foley - Fisher in 1976 (10) observed that there is an optimum line width for obtaining best performance in a vernier task.

In 1977, Geral Westheimer & Suzanne P. Mckee (24) showed that retinal stimuli can be tagged with differential local signs after having been pooled over regions extending several minutes af arc.

CHAPTER - II

FACTORS AFFECTING VISUAL ACUITY

The various factors which affect visual acuity are :

1. The dimensions of the retinal mosaic,
2. Size of pupil,
3. Intensity of stimulating light,
4. Contrast of test object to its background,
5. Duration of stimulus,
6. State of adaptation,
7. Distance of test object from the eye,
8. Refractive error,
9. Eye movements, and
10. Age of the subject.

2.1 Dimensions of the Retinal Mosaic :

It has generally been assumed that the major factor affecting visual acuity is the fineness or coarseness of the layer of receptors. However, the majority of the evidence suggests that the retinal mosaic is too fine enough to affect visual acuity.

2.1.1 Detection :

The dtection of a small test object depends primarily on brightness discrimination between the background and the diffraction pattern of the test object. The detection of bright points (stars) against a dark background has been thought to depend upon the fineness of the retinal mosaic. However, twinkling is mainly an atmospheric effect attributable to fluctuations in optical density of air intervening between the test object and the eye.

2.1.2 <u>Recognition</u> :

Landolt, C targets (Fig. 1) have been used to find the relation between distance of test object from the centre of fixation. Acuity was found to be maximum at the very centre of the retina. The loss amounts to 25% at a distance of 10 minutes of arc from the centre of fixation. Since Cone density also falls off in almost a similar manner, it has been presumed that Cone density plays a significant part in limiting acuity.

2.1.3 <u>Resolution</u> :

The limit of resolution can be defined as the limit for perception of separate and continuous grid lines. This was found to be 21 seconds of arc by Byram (4) using a double-slit diaphragm. This value is slightly smaller than the minimum angle for visual resolution (M.A.R.) with the natural pupil. Hence it can be concluded that resolution is actually limited under normal viewing conditions, by the effects of diffraction. Resolution would be little, if any, improved if it were limited, instead by the fineness of the retinal mosaic. Incidentally the value of 21 seconds is nearly the same as for the finest retinal cone receptor. i.e. the distance between rods or cones is approximately 2.0 to 2.3 microns or approximately 24 to 27 seconds of arc.

2.1.4 Localization :

It was pointed out very early that a point on the retina might actually be localized within a region smaller than any receptor cell; since an "averaging process" might act to fill the gaps between discrete receptor elements. Clearly the averaging must extend to the binocular situation, in which there is a considerable amount of independence in the rapid motions of the retinal image.

2.2 Size of Pupil :

Pupil size is an important factor in relation to visual acuity. A large pupil allows more light to the retina hence minimizing blur due to diffraction. On the other hand a small pupil minimizes effects of spherical, chromatic and other aberrations. Optimal acuity occurs for pupil of intermediate size; the size being dependent on conditions of illuminance, form and size of test object and individual differences from one eye to another. The size of pupil has major influence on :

2.2.1 Retinal Illuminance :

The Iris regulates the amount of light to the retina.

When field intensity is high, aperture is small resulting in a reduced retinal illuminance. The total range of reduction is about 16 to 1 as the natural pupil ranges approximately from 8 to 2 mm.

At high field intensities, the area of the pupil is reduced by 35% for each tenfold increase in field intensity i.e. a one log unit (factor of ten) increase in intensity causes an increase of about 0.8 log unit (a factor of 6.3) in retinal illuminance, and only about 0.2 log unit in visual acuity. Any possible loss of acuity through reduced retinal illuminance is off set by the increase in acuity resulting from other effects such as Stiles - Crawford effect and the reduction in optical aberrations of the eye as the pupil is constricted. (Stiles - Crawford effect is : Light entering the marginal zones of the pupil is less effective for retinal stimulation than is light entering the centre of the pupil.)

2.2.2 Optimal aberrations :

Spherical aberration does not have an important influence on measurement of visual acuity, at moderate to high intensity levels for the normal eye. It may, however, be a significant factor in night vision, where pupillary apertures are large enough to bring in significant blurring by aberration effects on the marginal rays.

Chromatic aborration effect on acuity is largely a function of the wavelength distribution of light used for viewing the test object. Acuity was found to be bettor (for all low to moderate levels of intensity) when sodium or Mercury lamps were employed rather than Tungsten incandescent lamps. However, above 4000 m candle intensities, acuity levels are same for all ill-uminants. It was observed that acuity was maximum in green or yellow light followed by that in red and blue light.

Both spherical and chromatic aberration effects can be reduced by constriction of the pupil to the small apertures that are normal for high field intensities. At such levels the aberrations are typically of minor importance by comparison with the effects of diffraction.

2.2.3 <u>Diffraction</u> :

The resolving power of an optical instrument is limited by the effects of diffraction. A single point in the field of view appears as a set of concentric circles consisting of a central cone of light surrounded by a series of dark and bright rings.

Angular radius of the first dark ring, α is given by the relation :

$\alpha = \frac{1.22\lambda}{d_o}$ where λ is the wavelength of the light forming the image forming lens. Two bright points are said to be resolved when the bright central core of one falls on the first dark band of the other (Rayleigh criterion).

2.2.4 <u>Acuity as a function of pupil size</u> :

Fig. (2) shows the relation between acuity and pupil size. It is seen that for all small pupillary diameters the acuity values are found to be slightly above the predicted ones. This finding is in agreement with the experience of astronomers who have consistently obtained better resolution than that predicted by the Rayleigh criterion. For example, Dawes suggested that the equation $\alpha'_s = \lambda/d_o$ be used instead of the Rayleigh equation $\alpha = \frac{1.22}{d_o}$.

A fairly constant level of acuity as the aperture increases from 2.5 to 5 mm represents a balance between the attendant reduction in the effects of diffraction and the increase in the effects of optical aberrations.

2.2.5 <u>Image Transfer Functions</u> :

At sufficiently high levels of luminance the effects of diffraction are limiting for artificially small sizes of pupil (e.g. less than 1.5 mm diameter). Diameters of about 3 mm are generally found to be optimal, but it is important to note that visual acuity changes very little over the normal range of from 2.5 to 5 mm diameter at high levels of luminance.

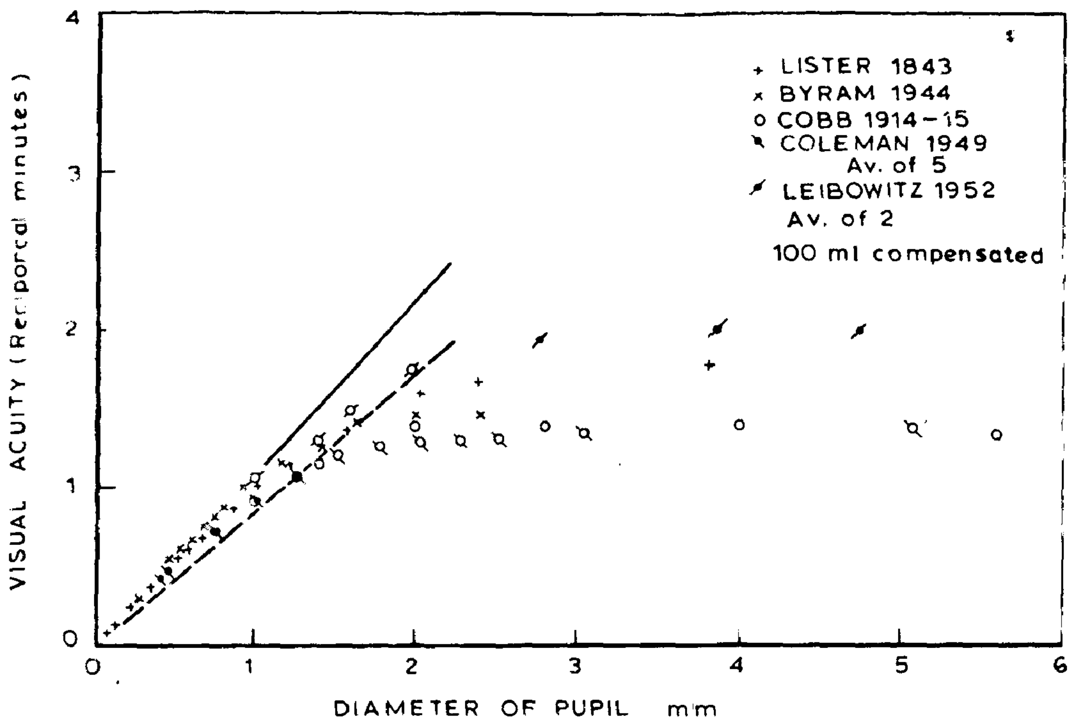


FIG. 2 _EFFECT OF PUPILLARY DIAMETER ON VISUAL ACUITY. POINTS ARE EXPERIMENTAL DATA OF SEVERAL INVESTIGATIONS. STRAIGHT LINES DEFINE (a) THE "RAYLEIGH LIMIT" AND (b) THE "DAWES LIMIT" ATTRIBUTABLE TO DIFFRACTION.

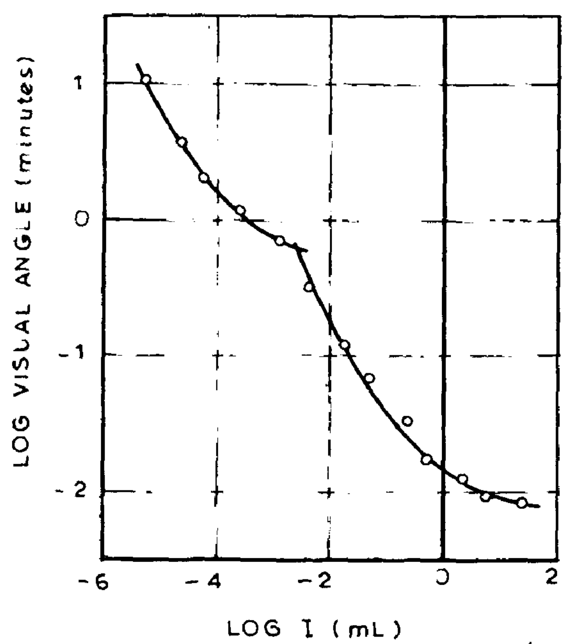


FIG. 3 _THE RELATION BETWEEN BRIGHTNESS OF BACKGROUND AND VISUAL ANGLE SUBTENDED BY THICKNESS OF LINE WHEN IT JUST BECOMES RESOLVED AGAINST THE ILLUMINATED BACKGROUND.

3. INTENSITY OF STIMULATING LIGHT :

It is common knowledge that large objects can be seen in dim light while small objects require bright light for viewing.

3.1 Detection :

Hecht and Mintz (14) used single dark lines over a range of nearly 7 log units in background illuminance. The acuity values obtained cover a range of more than 3 log units. The thresholds of width at the lowest and highest illuminance are as given below :

Width and Illumination :

Minimum	Maximum
16 minutes of arc	0.5 second of arc
4.47×10^{-6} mL	3.02 mL

The data (Fig. 3) show rod and cone portions fitted by separate curves.

Pirenne (20) obtained data on detection threshold for dark disks seen against a momentary (0.03 second) flash of background light in the peripheral retina of the dark-adapted eye. Acuity varies over a range greater than 2 log units.

Niven and Brown (19) provided data on the detection of a single bright target. An illuminated slit was presented against a dark background and the exposure time as well as the luminance of the slit was varied. The data were found to be consistent with the finding by Graham and Kemp (11) that there is reciprocity over a wide range between exposure time and the threshold increment in intensity.

3.1.1 Recognition :

Visual acuity increases slowly in proportion to log I at low intensities; at higher intensities it increases nearly ten times more rapidly in relation to log I; at the highest illumination it remains constant regardless of the changes in log I.

The number of Cones per unit foveal area is much greater than the number of rods per unit foveal area, which accounts for the relative rates of increase of rod and cone visual acuity with intensity. At the highest illumination all the cones are excited and no increase in visual acuity is possible.

If this division into rod and cone visual acuity is correct, a completely color blind person should have only rod visual acuity. It is shown by a study of the data of two such individuals that this is true.

Experiments were performed to find acuity as a function of intensity by Connor and Ganoung (5), Shlaer (21) and

Shlaer, Smith, and Chase (22), using a Landolt ring. The last two investigations also included data for a grating test object and data for red and blue light. The red line data fall on single continuous curves representing the pure cone vision. The blue line data fall on two distinct curves with a transition at about 0.03 photons. Values below this intensity represent pure rod vision. Those immediately above represent the cooperative activity of the rods and the cones, and yield higher visual acuities than either. All the rest of the values above this transition region represents pure cone vision.

The measurement with both test objects (Landolt ring and Grating), show a break at a visual acuity of 0.16, all values below that being mediated by the rods and those above by the cones, (Fig. 4). The grating gives higher visual acuity at intensities less than about 30 photons and lower visual acuity above that. The maximum visual acuity attainable with the grating under the same conditions is about 30% lower than that with the 'C'. It is shown that the limiting factor in the resolution of the eye for the grating is the diameter of the pupil when it is less than 2.3 mm and the size of the central cones when the pupil is larger than that.

The data for cones made with both test objects are adequately described by one and the same form of the stationary

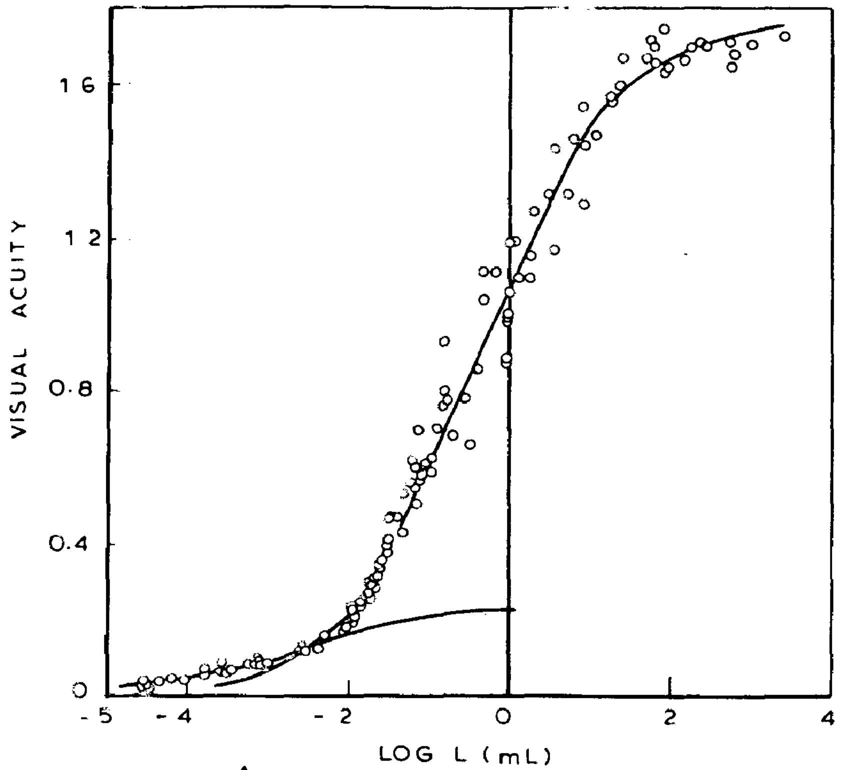


FIG. 5 _ KONIG'S DATA FOR THE RELATION BETWEEN VISUAL ACUITY AND ILLUMINATION, AS REPLOTTED BY HECHT (1934) THE SHALLOW CURVE FOR THE LOWER LIMB OF THE DATA IS AN EQUATION FOR RODS, WHEREAS THE UPPER CURVE IS FOR CONES. THE TASK IS ONE OF RECOGNIZING THE ORIENTATION OF A HOOK FORM OF TEST OBJECT.

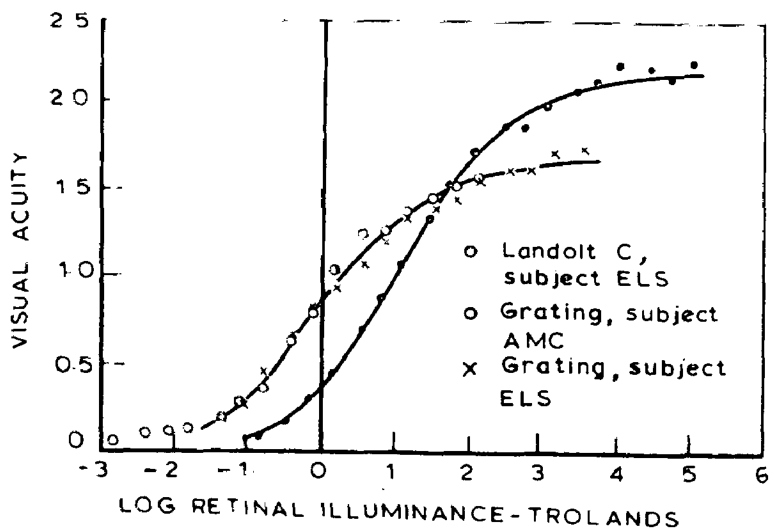


FIG 4 THE VARIATION OF ACUITY WITH RETINAL ILLUMINANCE FOR RESOLUTION OF A GRATING AND FOR RECOGNITION OF THE ORIENTATION OF A LANDOLT C TEST OBJECT. (From Shlaer)

state equation derived by Hecht (13) for the photoreceptor system.

Hecht Equation :

Assuming a photosensitive material 'S' which is changed by light to photoproducts P, A, B .... and which is reformed again by a thermal reaction of some of these products, Hecht equation for the stationary state is :

$$KI = \frac{x^n}{(a - x)^m}$$

where, I = Light intensity

a-x, x = Concentrations of sensitive materials and photoproducts respectively

m, n = Constants giving the orders of the photochemical and thermal reactions,

and K = Constant.

Setting the initial concentration, a = 1, the values for KI for a series of values of x may be computed for four cases where $m = 1, n = 1$; $m = 2, n = 1$; $m = 1, n = 2$; $m = 2, n = 2$. By putting these values in the form of their logarithms the nature of their dependence becomes independent of the values of the constants K and a, and may be plotted as log KI versus log x or log x^n for each of the four cases. In this form the curves may be used to test any set of data that are plotted in the form of visual function against log I by simple superposition. (Fig. 5). They then indicate the values of m and n.

When m = 2, n = 2, visual acuity is proportional to x^n and curve through cone data is obtained.

$$KI = \frac{\text{Visual acuity}}{(\text{Visual acuity}^{\frac{1}{2}}_{max} - \text{Visual acuity}^{\frac{1}{2}})^2}$$

This is identical with the form found to fit the data of intensity discrimination for the cones.

Keeping visual acuity proportional to x^n, the data for the rods may be fitted about equally well either when m = 1, n = 2 or when m = 2, n = 1. Choosing the latter to complete the similarity with the data of intensity discrimination,

$$KI = \frac{\text{Visual acuity}}{(\text{Visual acuity}_{max} - \text{Visual acuity})^2}$$

3.1.2 Resolution :

The variation of acuity with stimulus intensity has been studied with the help of grating test objects. Lower values for acuity at high intensities, are attained when a grating is employed as a test object as compared with the Landolt ring (Fig. 4). Shlaer concludes that the upper limit of grating acuity is set by the fineness of retinal mosaic, whereas for the Landolt ring the limit is set by more complex factors. Visual acuity, is shown by Shlaer to depend on the linear dimensions (critical widths) of the test objects rather than on their areas.

An apparent exception to this general trend is found in experiments for which the test object is of higher luminance than the background. Wilcox (25) for example, found that with such an object acuity reaches a maximum at moderate intensity levels and then declines sharply as the intensity of the test object is further increased. Wilcox's observations were based on a double bar test object consisting of two rectangles of fixed size placed side by side with the long axis vertical.

3.1.3 <u>Localization</u> :

Both visual and stereoscopic acuity are affected by intensity of stimulating light. (Stereoscopic acuity is the difference in retinal images formed in the two eyes). It was shown by Baker (1) that visual acuity is poor at Scotopic levels, where parafoveal or peripheral rod receptors predominate. As intensity level is increased, the thresholds of cone receptors increase and hence acuity increases sharply. With a further increase in intensity maximum acuity is attained, it is maintained over a wide range of high intensities.

4. VISUAL ACUITY AND CONTRAST :

Visual acuity depends upon the brightness contrast between the test object and the background.

Byram (3) found that a thin test line contrasting highly with its background is detected as easily as a wider line of low contrast, provided that their retinal images are of equal contrast. For disks, however, detectability seems to depend on a constant flux differential rather than a constant contrast. Byram found that a small disk of high contrast with its background is as easily seen as a larger disk of low contrast provided that the total change in light flux reaching the ratina is equal for the two.

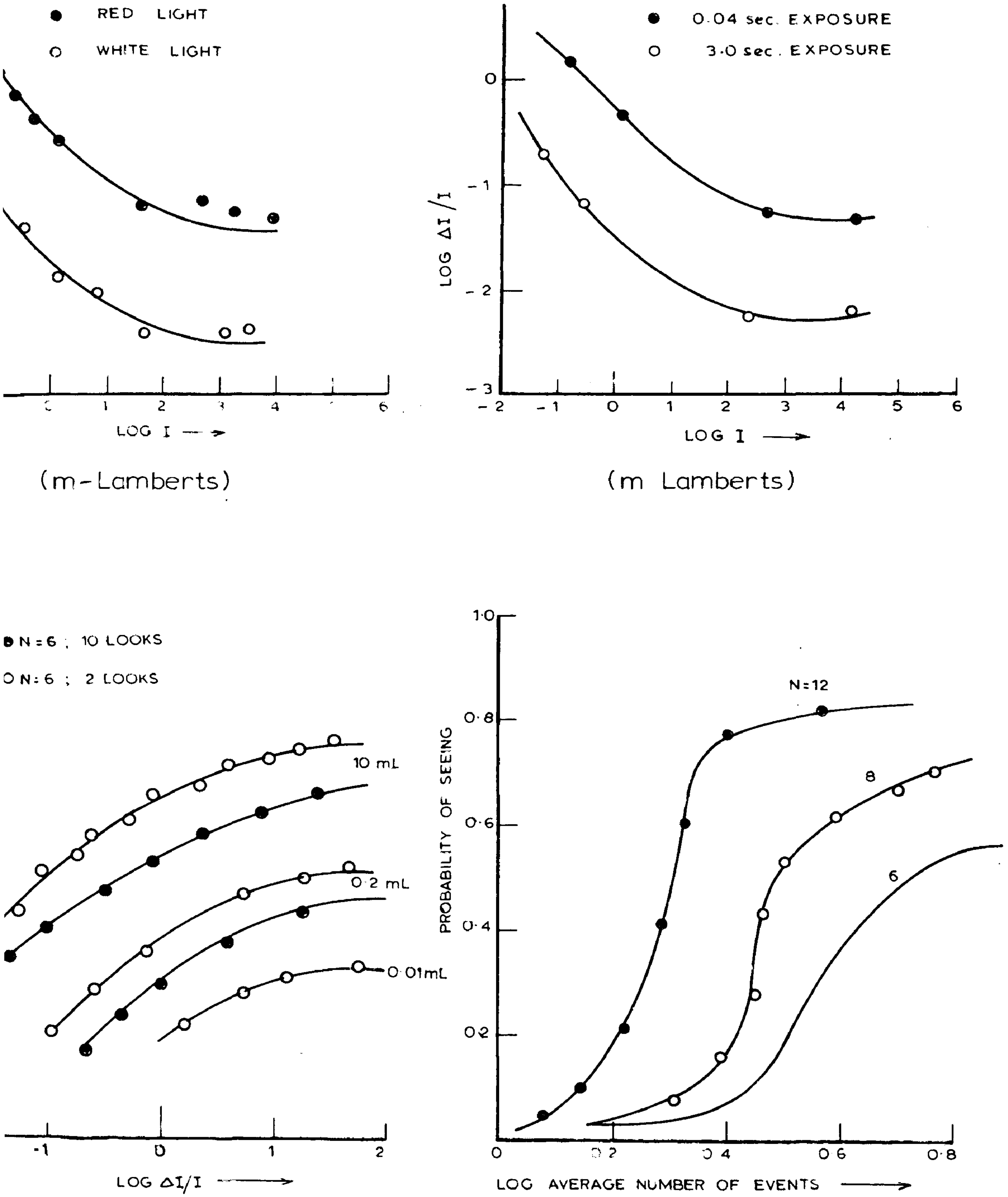
Hendley, C. D (15) made measurements with rectangular targets of length - width ratio 2, over a wide range of sizes, contrasts and brightness sufficient to determine the relations among visual acuity, brightness contrast and target size. The rectangles were from 2 ft to 50 ft wide; the contrast fraction, $\Delta I/I$, ranged from 0.01 to 40; the background brightness varied from 0.0001 to 2500 millilamberts. When $\Delta I/I$ or visual acuity is plotted as a function of brightness, the data do, in general follows Hecht's equation. The departure from a simple photochemical theory which the larger targets show is probably due to changes in the functional retinal mosaic with changing brightness.

At low contrasts, as the brightness is reduced a point is reached at which the test object becomes invisible at any size.

At high contrasts, visual acuity reaches a maximum, whereas at low visual acuities, $\Delta I/I$ reaches a minimum which cannot be passed regardless of size.

The shape of the curves relating $\Delta I/I$ to brightness is not significantly altered by changing the exposure time. There is some evidence to show that a 3 seconds exposure of the target is equivalent to two looks of 0.2 second each (Fig. 6

In these studies the thresholds were determined by a frequency of seeing method, and the data have been considered in terms of a quantum theory of threshold seeing. I t was found that a threshold response involves between 4 to 8 independent critical events, which are largely inddpendent of size, brightness and criterion of seeing.



5 .. RELATION BETWEEN ΔI/I AND BRIGHTNESS

5. DURATION OF STIMULUS :

The effects of exposure time have been studied for detection of a thin bright line (Niven and Brown) (19). Bouman (2) and of a thin darl line Keesey (16). When exposure time is short and area of test object is small, there is reciprocity among the factors of time, intensity and area. In other words, detectability is directly dependent on quantity of light; this is even true for complex waveforms of energy in time. (Long) (17); Davy (6).

Angular detection threshold is the angle subtended by the diameter of a circular test pattern and acuity is the reciprocal of that angle. Since time and area are reciprocally related, time is inversely proportional to the square of the diameter of the liminal test patch. Hence acuity is approximately proportional to the square root of the exposure time, for small times and high levels of intensity.

For bright line detection, however, area is directly related to width of line. Hence acuity, or reciprocal width, should be proportional to exposure time. This is consistent with the findings by Niven and Brown (19) who observed that, for all small times, the product of time and angular threshold is nearly constant for any given level of stimulating intensity. The same is true for the dark line data of Keesey(1 for exposure times below 0.2 second.

For resolution, a sigmoid relationship has been observed between visual acuity and log exposure time. Acuity is strongly influenced by exposure time in the range of exposures upto about 0.1 second. Beyond that interval, exposure time becomes of little importance in determining acuity score. Debons and Hsia (7) have confirmed this observation. (Fig. 7). Further acuity scores are found to be maximal for moderate stimulating intensities. At high intensities they are significantly lowered. This effect may well be due to the fact that the eye is not adapted to the high level of stimulation in these experiments.

6. <u>VISUAL ACUITY AND STATE OF ADAPTATION</u> :

Experimentally acuity was found to be highest under conditions of approximate equality in luminances of adapting and test fields. This holds goo d for luminances from 10 to 10,000 ft-L. Below 10 ft-L, however, slgithly better acuity is found for conditions in which adapting level is lower than test level (Fig. 8).

Prolonged dark adaptation is necessary, of course, for achieving the rod vision that is necessary for viewing any test object at low intensity levels. Acuity is poor at those low levels, but it is still poorer when the dark adaptation of the eye is not complete. At high intensity levels, on the other hand, the eye must be given prolonged light adaptation in order

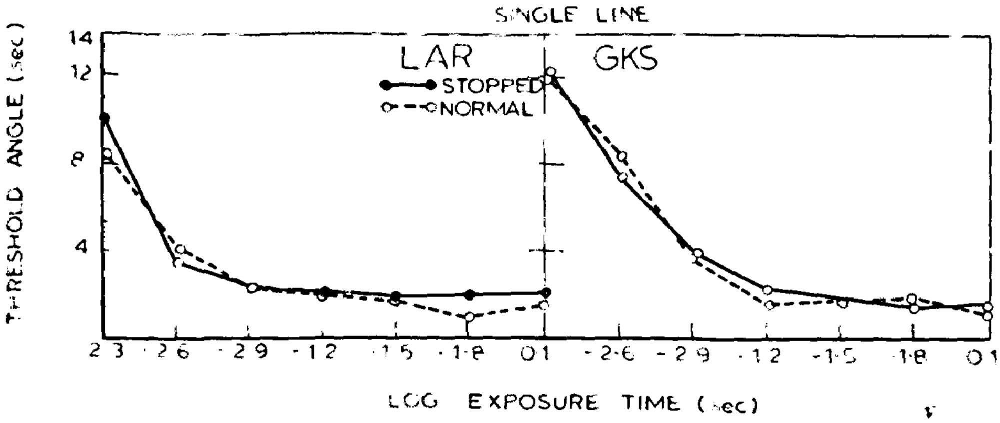


FIG 7 THRESHOLD CURVES FOR DETECTION OF SINGLE BLACK LINES AS A FUNCTION OF EXPOSURE TIME UNDER NORMAL AND STOPPED IMAGE CONDITIONS VIEWING. (FROM KEESEY, 1960.)

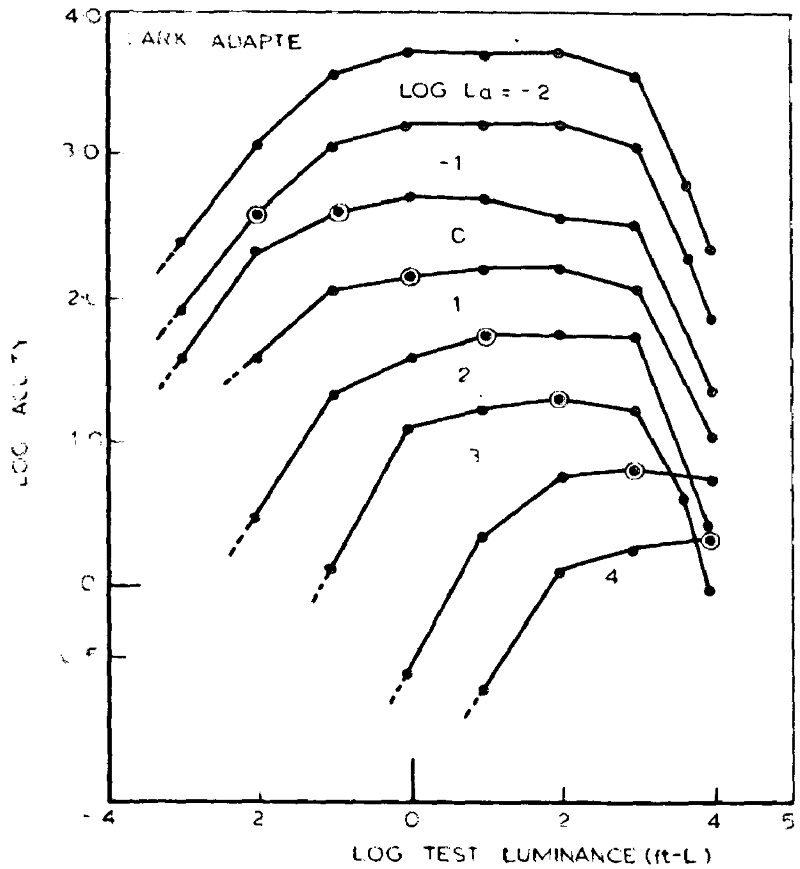
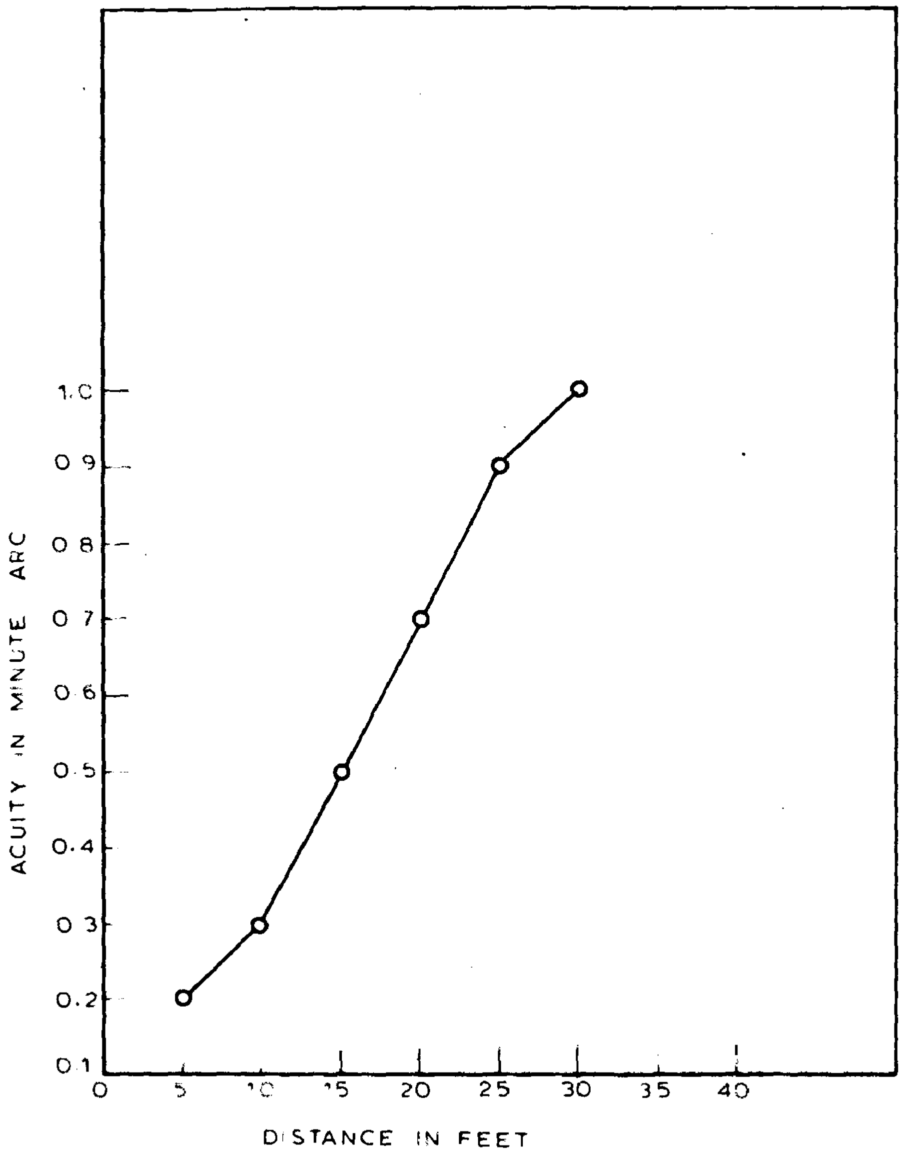


FIG 8 LOG ACUITY PLOTTED AGAINST LOG TEST LUMINANCE AT VARIOUS ADAPTING LUMINANCES, AS MARKED BESIDE THE CURVES. CIRCLES REPRESENT EQUAL TEST AND ADAPTATION LUMINANCES. ALL CURVES ABOVE THE LOWEST ARE SHIFTED UPWARD BY 0.5 ON THE ORDINATE SCALE. TO AVOID CONFUSION.



9 - RELATION BETWEEN ACUITY AND DISTANCE OF OBJECT FROM THE EYE

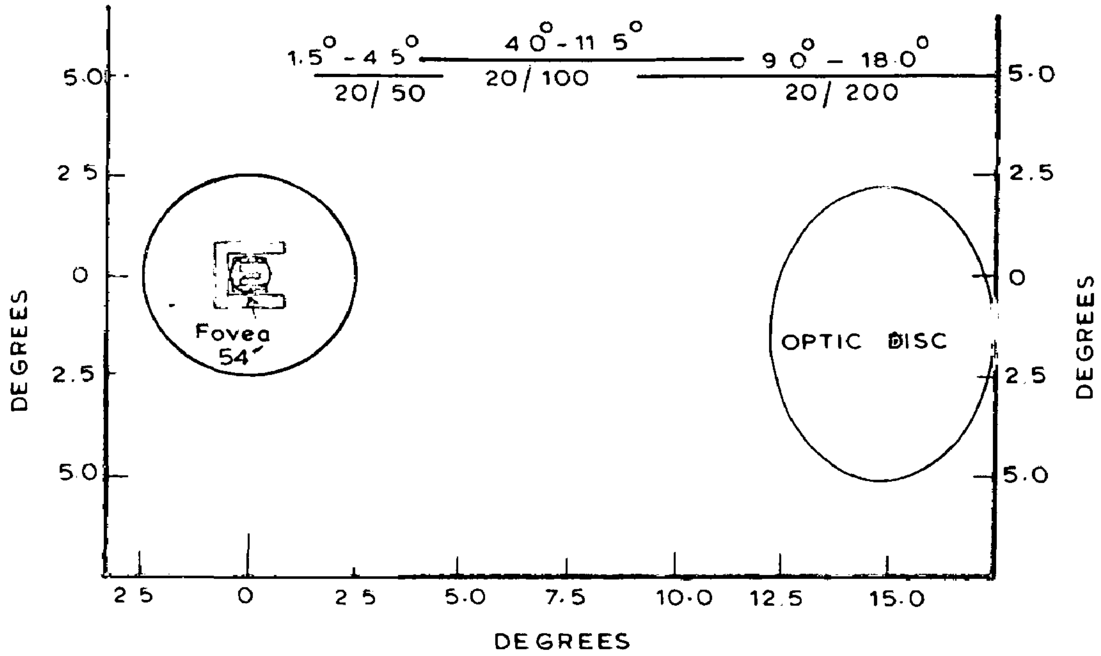
that the cones may function most efficiently. The phenomenon of glare or "irradiation" serves to reduce acuity when the eye is adapted to a dark background intensity (Wilcox (25)).

7. EFFECT OF DISTANCE :

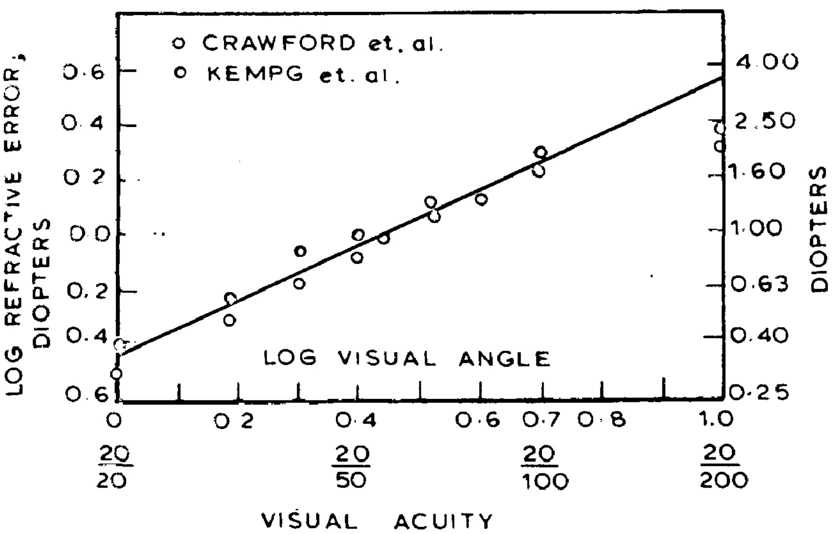
The measurement of visual acuity in terms of visual angle implies the constancy of resolving power at all testing distances. This is true only if the image is accurately focussed on the retina through accommodation or appropriate corrective lenses. This assumption is valid within minor limitations.

A 7% change in acuity was observed at distances of 30 ft and 2 miles. At short distances, however, acuity has been found first to increase and then to decrease (Fig. 9). In a series of tests conducted on 400 subjects with a mean age of 19 years and corrected to 20/20 at 20 ft. the mean acuity at 1 metre was equivalent to 20/12.3. At 40 cm the mean acuity was 20/14.6, and at 20 cm the acuity was 20/22.3.

A geometric projection of the 20/200 Snellen 'E' drawn to scale on the fovea is shown in Fig. 10. Fixated objects of larger visual angle fall on parafoveal retina. Here the regional differences in cone size , cone density and receptive fields at various levels of adaptation determine limiting visual acuity. At only 3.5 minutes from the foveal centfe,



10 - POSTERIOR POLE OF RETINA DRAWN TO SCALE. FOVEA IS 54 minutes IN DIA. JUST ABOUT SIZE OF IMAGE OF 20/200 TEST LETTER; 20/400 LETTER IMAGE ALSO SHOWN. MAX. VISUAL ACUITY OF DIFFERENT DISTANCES FROM FOVEA IS INDICATED



11 - RELATIONSHIP BETWEEN THRESHOLD VISUAL ANGLE & DIOPTERS OF SPHERICAL ERROR OF REFRACTION. (From Sloan, L. Measurement of Visual acuity, a critical review, Arch. Ophthal 45:705, 1951)

there is a 5% drop in visual acuity. Hence, there is only a small region on the retina, 7 minutes of arc, or 35 microns in diameter, within which the highest visual acuity can be obtained.

8. REFRACTIVE ERROR AND VISUAL ACUITY :

Several studies have demonstrated the acuity decrease corresponding to uncorrected refractive error. Fig.(11) depicts the relationship between log threshold visual angle and log diopters of uncompensated spherical error (myopia and hyperopia combined). Between 20/20 and 20/100, it can be seen that the relationship is linear. In simple astigmatism, the increase in the threshold visual angle is 80% of that produced by the same amount of spherical error.

9. EFFECT OF EYE MOVEMENTS :

Since eyes are never motionless, the retinal image of an acuity test object must affect different patterns of receptors from one moment to the next. Effects on visual acuity due to this motion may be :

(1) Motions may be so small that they have little visual effect.

(2) They may cause a "blurring" of the retinal pattern of stimulation, much as the shimmer of the atmosphere interferes with seeing stars through

a telescope or jiggling a camera produced a blurred picture.

(3) They may have the opposite effect in that they allow the visual receptors "scan" the contours of the test object. This will enhance the differential neural activity on which visual acuity depends. Scanning appears to be the basis for the apparently enhanced tactile discrimination in blind people who read Braille with their finger tips.

9.1 Extent of Eye Movements :

The unsteadiness of the eye is such, even under good conditions, that typically the retinal image is carried over a distance corresponding to a visual angle of about 3 minutes of arc during 1 second of time. The critical duration for visual acuity is an interval (0.1 second or less) during which the retinal image typically moves through an angle less than that of the separation between adjacent single central cones (Fig. 12).

9.1.1 Effect of Image Movement :

Eye is found to be remarkably steady over short intervals of time. It however wanders considerably even under good conditions when longer times are involved. This does not usually affect visual acuity but has the positive effect of maintaining vision during attempted steady state fixation of the test object.

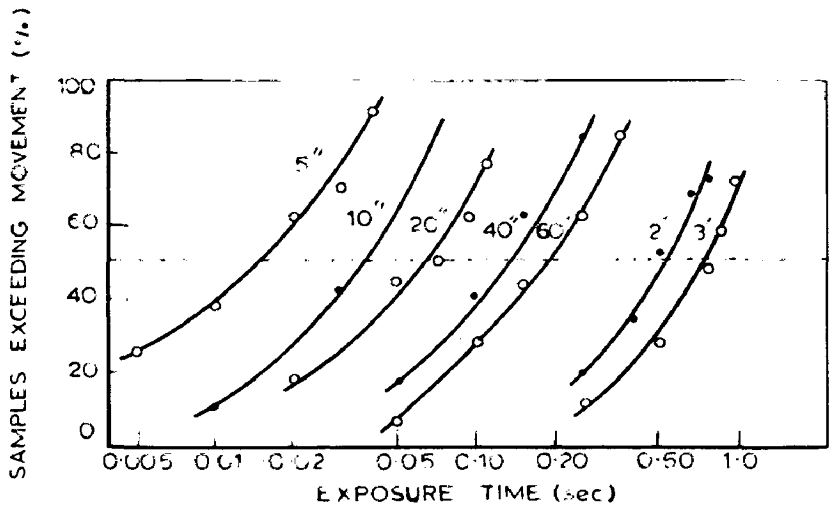


FIG.12 _ TYPICAL EXCURSIONS OF THE RETINAL IMAGE DURING OPTIMAL CONDITIONS OF VISUAL FIXATION. (FROM RIGGS, ARMINGTON, AND RATLIFF, 1954.)

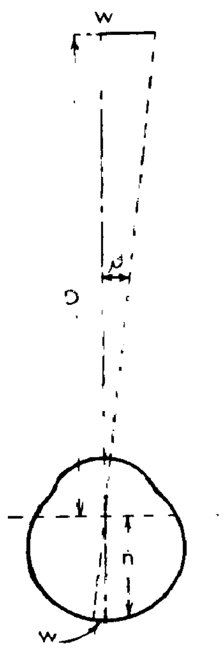


FIG 13 _ DIAGRAM TO ILLUSTRATE THE SPECIFICATION OF VISUAL ACUITY. THE WIDTH, w OF THE TEST OBJECT IS SO SMALL THAT IT CAN JUST BARELY BE DISCRIMINATED AT A DISTANCE, D, FROM THE EYE

9.1.2 Role of Voluntary Eye Movements :

Visual acuity is relatively poor for a moving test object even when the eyes appear to be successfully pursuing it. Smooth eye movements can occur upto 40 degrees per second. A contributing factor may be the central inhibition of vision that seems to be coupled with voluntary eye movements. The inter-dependence of eye movements and visual acuity is obviously dependent on a servomechanism of incomparable inefficiency and precision among our perceptual systems.

10. EFFECT OF AGE :

Adult visual acuity which may be defined as the resolution of 1 minute of arc detail, or 20/20 is reached during development of children anywhere from 7 years to as short a time as 2 years of age.

Evoked potential visual acuity was measured on 16 infants on different occasions, by Elwin Marg (18) and his associates, when the infants were from 1 to 7 months of age. They found that visual evoked potential acuity normally develops to the adult value or 20/20, by the 4th to 6th month postpartum. Their finding may have a parallel with the disclosure that in kittens the time of acuity development is the duration of the period of greatest sensitivity or susceptibility to the visual environment.

Objective determination of visual acuity by optokinetic nystagmus shows that infants 1 to 5 days old have visual acuity of at least 20/670. Visual acuity so obtained in children upto 3 years of age is summarised in Table I.

A report was prepared in the U.S. on the visual acuity of youths which includes binocular and monocular acuity, without and with correction, in 1973. 70% or 15.9 million of the youths 12 to 17 years of age were found to have normal or better than normal unaided binocular acuity at a distance. Almost 4% of the U.S. youths were unable to read at the 20/200 level unaided, significantly more than was found among U.S. children and slightly more than among U.S. adults. Boys 12 to 17 years of age were found to have substantially better binocular distance acuity than girls of that age, the differences being even more pronounced than among children and slightly greater than among young adults.

More than 1/3 (34%), or 7.7 million of the youths wear glasses or contact lenses. 55% of this group had moderately to severe defective acuity without their glasses or contact lenses, compared with less than 1% when tested with their own lenses.

Black adolescents were found to have substantially

TABLE - I

VISUAL ACUITY IN INFANCY AND EARLY CHILDHOOD

Age	Visual acuity
0.5 month	20/400
1.5 months	20/400
2.5 months	20/400
3.5 months	20/200
4.5 months	20/200
5.5 months	20/100
6.0 months	20/200
1.0 year	20/200
2.0 years	20/100
3.0 years	20/50

Data concerning infants 0.5 to 5.5 months of age from Fantz, R. L. in Kidd. A. H. editor: Perceptual development in children, New York, 1966. International Universities Press pp 143-173.

Data concerning children 6 months to 3 years of age from Schwarting. B. H. Amer. J. Ophthal. 38. 714-715, 1954.

better unaided visual acuity than White, a difference similar but more pronounced that that found among older children and young adults. The prevalence of atleast normal unaided acuity among youths was greatest in the South, the rate being significantly higher than for those in the Northeast and Midwest. With correction, however, no such significant, regional differences of acuity were found. Youths from families with incomes of less than $ 3000 per year had significantly better unaided acuity than those from families with incomes of $ 5000 or more.

C H A P T E R - III

TESTS OF VISUAL ACUITY

Visual acuity indicates the capacity to resolve and identify the fine details of objects in the field of view. It is generally specified in terms of the minimum dimensions of some critical aspect of a test object, that a subject can correctly identify.

There are three ways of specifying the width or other critical dimensions of a test object :

(1) Width of the object,

(2) The angle subtended at the eye by the test object

(3) The computed width of the retinal image

(Refer Fig. 13).

In clinical practice, using a series of test objects, determination is made of the small est test object that can be correctly identified by any given subject, and the subject's visual acuity 'v' is given by the relation :

$$v = D'/D \text{ (Snellen fraction)}$$

where, D' = Standard viewing distance (generally 20 ft. or 6 m)

D = Distance at which this minimum test object subtends an angle of 1 minute of arc.

Thus, the subject is said to have 20/30 vision if, at a viewing distance of 20 ft, he can just respond correctly to a test object which subtends an angle of 1 minute at a distance of 30 ft. This subject, then, has poordr than normal acuity.

Refer Fig. (12)

If, w = width of test object

β = angle subtended by the object at the eye (visual angle)

then β = w/D (radians) = $3450\ w/D$ in minutes of arc.

For small angles,

$v = 1/\beta = 0.00029\ D/w$

If, w' = image width of object on retina

then, $w' = nw/D$ where,

n = distance of retina from the nodal point of the eye

D = Distance of object from the nodal point of the eye.

If $n = 17$ mm, for a test object of 1 mm,

then $w' = (17 \times 1)/3450 = 0.0049$ mm or $= 4.9$ microns

Thus, neglecting the effects of diffraction, aberration etc. we may conclude that the image of a 1 minute test object has a width w' of about 4.9 microns on the retina.

Types of Acuity Tasks :

Depending upon the test objects and the manner in which they ard used four tasks are required of the subject in tests of acuity.

3.1 DETECTION

This involves stating whether an object is present or not in the visual field. For small objects three kinds of test situation have been used in experiments.

3.1.1 Bright Objects against a dark background :

Primarily this is a matter of absolute visual sensitivity. Under the most favourable conditions only a few quanta of light are needed for the detection of an object. Detection demands that at least one quantum of light falls on each of the few retinal receptors from the object, within a short interval of time. This condition can be satisfied by any bright object, no matter, how small, provided only that it sends enough light to the eye. Example : Stars at night each of which subtends a small fraction of a second of arc at the eye; the magnitude or apparent size of each is determined not by the angular size, but by thd amount of light which it sends into the eye. Due to the phenomenon of diffraction, the retinal image of a bright point is not in fact a point but rather a pattern consisting of a bright central disk surrounded by a series of concentric bright and dark rings. This means that all test objects which are small (critical widths less than 10 seconds of arc) provide the retina with nearly the same pattern of stimulation, regardless of test object diameter. Bright central disk formed on the retina by a point source has a diameter of 1 minute 34 seconds with a 3 mm pupil. This implies that no manipulation of object diameter will permit the measurement of visual acuity (in the sense of resolving visual detail) when bright targets are presented to the subject in a dark field.

3.1.2 <u>Dark objects against a bright background</u> :

The most satisfactory acuity test is offered by viewing dark figures against a bright field. With a dark line or disk a critical size can be found below which the object cannot be seen no matter how great the luminance of the background. The main consideration here is that of the pattern of illuminance on the retina in the vicinity of the image of the test object. The acuity for fine dark lines represents an intenity discrimination that is about as fine has ever been reported. This applies onl y to lines that are long enough so that a relatively large number of individual receptor cells is affected.

The detection of small dark disks or squares is similarly the result of reduced illuminance on the receptors affected by the image.

3.1.3 Low Contrast Test Objects :

Byram (3) has calculated the reductions in retinal illuminance caused by grey lines on a white background and vice versa. His data support the conclusion that, for the most part, the detection of a line target depends primarily on the amount by which its retinal image raises or lowers the illuminance on the affected receptors. This generalization holds good over a considerable range of line widths and object-to-background contrasts.

3.2 RECOGNITION :

This task involves naming the test object or to name or specify the location of some critical aspect of it. The object is generally large enough so that detection threshold is not a limiting factor. Examples of objects used in this test are the standardized letters of the alphabets (Snellen), and the Landolt ring or square as shown in Fig.(1).

In the case of the Landolt ring, the subject is asked to indicate the location of the gap. The size of the test object is gradually reduced until as its orientation is changed, the subject can no longer indicate the position of the gap. Visual acuity is then defined as the reciprocal of the angle in minutes subtended by a gap that is successfully designated 50% (or any other fixed percentage) of the time.

In clinical studies unit visual acuity is often taken as standard; recent observations have, however, shown that gaps subtending angles much smaller than 1 minute at the eye may be judged successfully by a good subject. Shlaer (21) found that with high luminance of background a gap of about 22 seconds can be recognized.

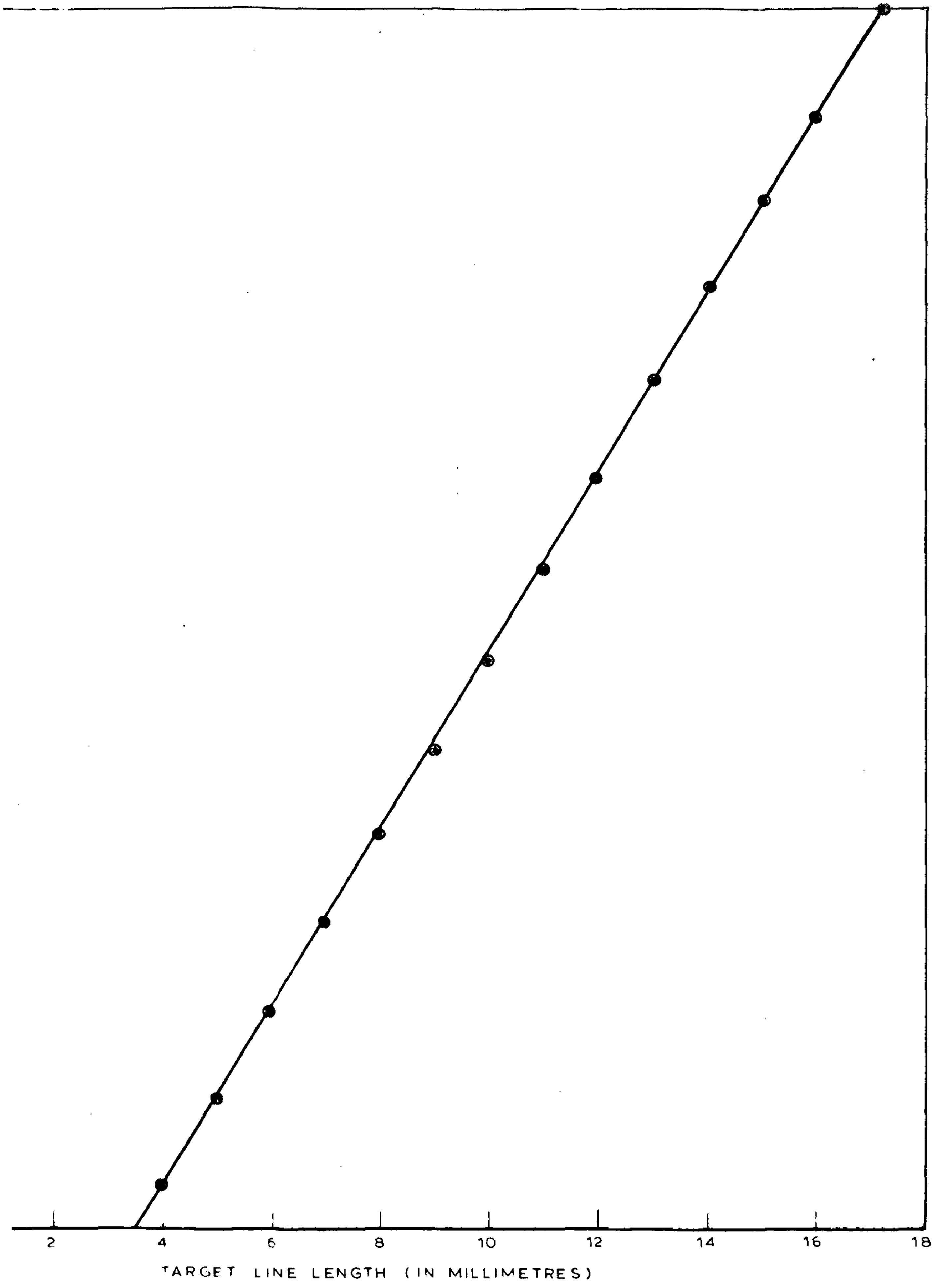
Recognition task is favoured in clinical studies of visual acuity, Shlaer (21) made use of the Landolt ring or 'C' in a study of acuity with white light at various levels of adaptatio n. Shlaer and his associates (22) also used it in a study involving red and blue lights. They demonstrated that visual acuity for 'C' test object was not much reduced under conditions in which the target to background contrast was greatly reduced; nor was there any significant increase in acuity under conditions of improved contrast. They argued that intensity discrimination can not be a limiting factor in Landolt ring acuity. Some other factor, such as the diameter of the foveal cones, seems to be the limiting factor at high stimulus intensities.

Theoretical interpretation of the recognition task is limited by the difficulty of analyzing its underlying factors. Acuity so measured may involve intensity discrimination, but other factors, including that of retinal cone diameter, probably make contributions, particularly at high intensity levels.

3.3 RESOLUTION :

In this task the observer must respond to a separation between elements of the pattern. The basic measurement is the minimum separable, that is, the minimal distance between objects for the discrimination of separateness. Typical test objects (Fig. 1) are pairs of bright or dark lines or dots, a row of alternate bright and dark lines (acuity grating), and a grid or checkerboard pattern first proposed by Goldman in 1943. These objects have in common the fact that each single element of the pattern would be clearly identified if it were present alone. The presence of neighbouring contours, however, makes it difficult for the subject to discriminate the separate elements of the pattern. Each dark line of a grating, for instance, would separately be seen with a minimum width of about 0.5 second of arc. The series of lines, however, can only be resolved if their separate widths are increased to at least 25 seconds arc under favourable conditions.

Visual acuity, in the context of resolution, is the reciprocal of the angular separation between two elements of the test pattern when the two images are barely resolved. This angular separation has sometimes been called the "minimum angle of resolution" or MAR. (Fig. 14). Visual resolution is akin to the "resolving power" of a camera or telescope. The



4 _ VISUAL ANGLE VS TARGET LINE LENGTH

theoretical limit of this resolving power may be calculated on the basis of the wavelength of the light and the diameter of the pupil (Table II).

3.3.1 Resolution of bright test objects :

MAR for two bright sq uares or disks depends, upon the kind of illumination and the size of the test object employed. Values in the vicinity of 1 minute of arc have been reported for stars on a dark background by early astronomers. Somewhat higher values (about 3 minutes) have also been reported later.

For the resolution of parallel bright lines, threshold values that reached a minimum of slightly under 1 minute of arc at moderate lèvels of luminance have been reported. Resolution becomes poorer at levels above and below this optimum luminance.

It was felt that resolution would improve markedly if the width of the bright lines were increased; it would finally approach a limit in the detection of the fine dark line separating two large areas of light.

3.3.2 Resolution of dark objects :

The resolution of two fine dark disks or lines also depends on the dimensions of the test object. A threshold separation of under 30 seconds for fine dark lines at a medium

TABLE - II

VISUAL ACUITY

Snellen	Decimal	Visual angle (minutes)	Log scale	Snell-Sterling (%)
20/10	2.0	0.5		
20/12			- 0.2	
20/16			- 0.1	
20/20	1.0	1.0	0	100
20/25	0.8	1.25	+ 0.1	
20/32	0.8	1.25	0.2	
20/40	0.5	2.0	0.3	83.3
20/50	0.4		0.4	
20/63			0.5	66.7
20/80	0.25	4.0	0.6	
20/100	0.2	5.0	0.7	50.0
20/120			0.8	40.0
20/160			0.9	33.3
20/200	0.1	10.0	1.0	20.0
20/250			1.1	16.7
20/320			1.2	12.5
20/400	0.05	20.0	1.3	0

and high level of background luminance was observed. It is evident that broadening the lines would reduce this value almost indefinitely as the region of separation begins to approach that of a single bright line seen against a dark background.

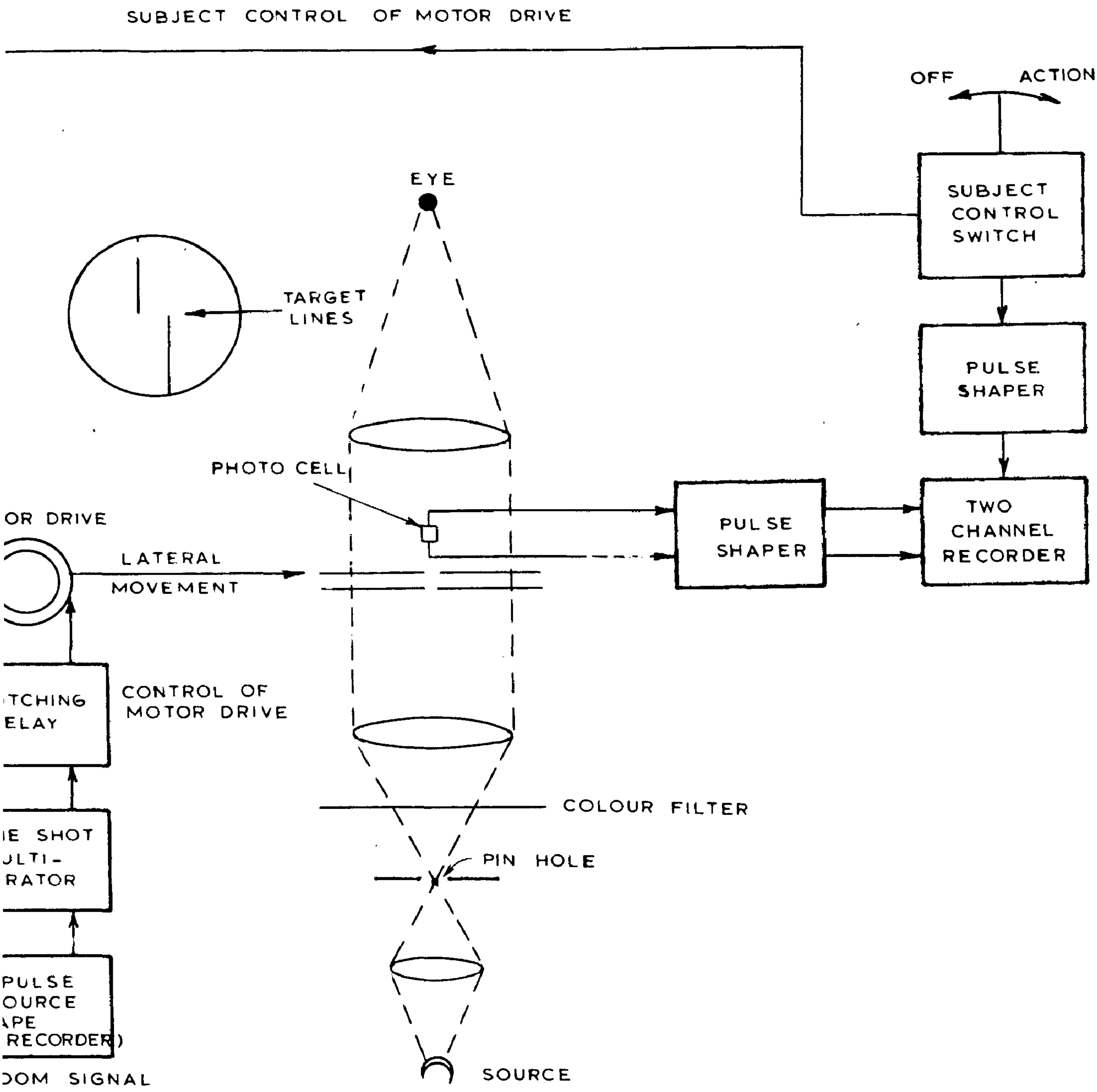
3.3.3 Grating test object :

This consists of a set of parallel light and dark stripes and provides a favoured means of determining visual resolution. Generally the widths of the light and dark elements are made equal. It is generally accepted that the minimum width of stripe for grating resolution is in the neighbourhood of 1 minute of arc at moderately high intensity levels. Some of the other values are : 64 seconds, 50 seconds, 52 seconds, 56 seconds, 40 seconds etc.

In effect, resolution has been widely regarded as the most critical aspect of visual acuity, since a very long time. Results can be meaningfully related to the pattern of retinal illuminance as given by calculations of diffraction effects within the eye and to the separation between individual cones in the retinal mosaic.

4. LOCALIZATION :

Certain forms of visual acuity depend on the discrimination of small displacements of one part of the test object with respect to other parts. Examples are Vernier acuity and Stereoscopic acuity. Vernier acuity is often tested by the use of a straight line broken in the middle. The task is to appreciate small lateral displacements of one segment of the line. When carefully performed, this experiment yields displacement thresholds nearly as small as those for the detection of single black lines. Thresholds of vernier acuity performance were found to vary between 4 seconds arc and 10 seconds arc by J. A. Foley - Fisher (8).



LOCK DIAGRAM OF APPARATUS FOR THE MEASUREMENT
F VISUAL ACUITY

FIG. 15

CHAPTER - IV

EXPERIMENTAL DETERMINATION OF VISUAL ACUITY :

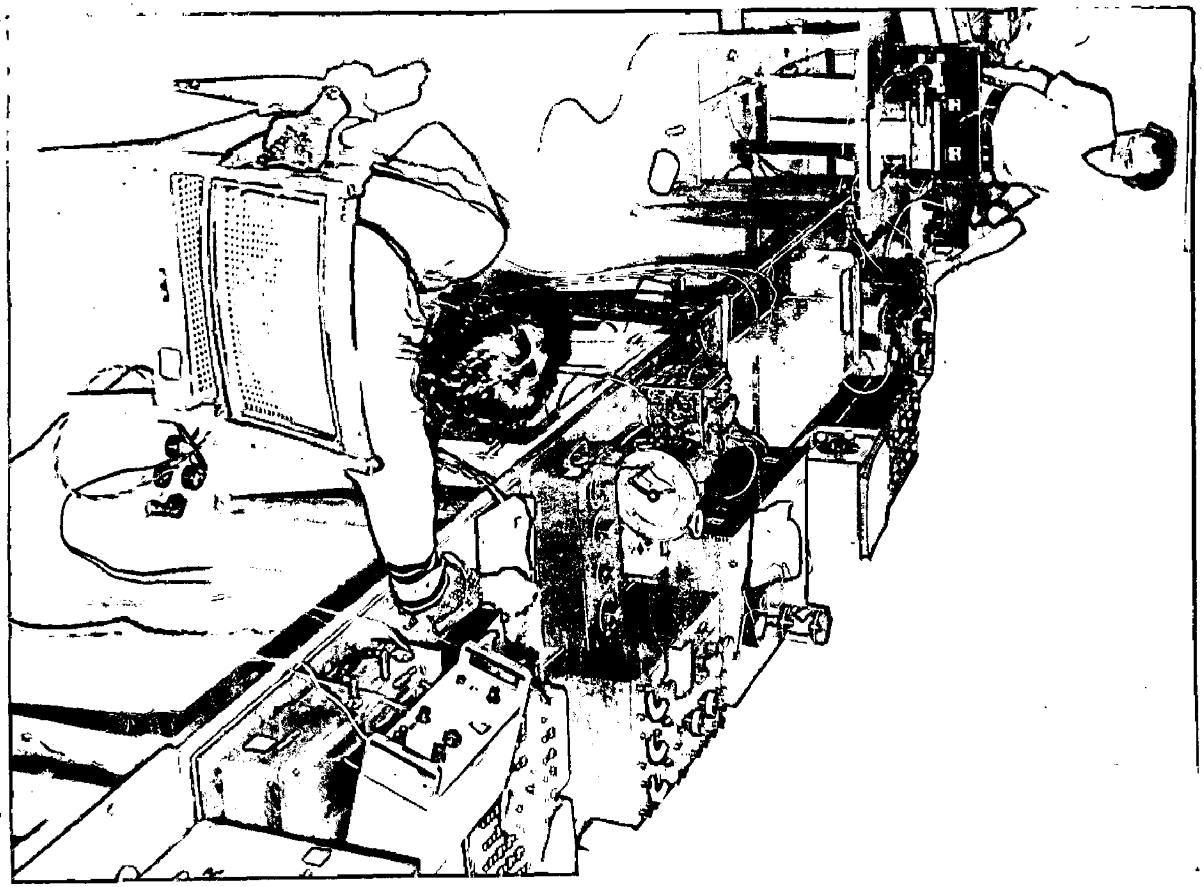
4.1 GENERAL :

Visual acuity is defined, for the purpose of the present experiment, as the reciprocal of standard deviation (in second of arc) of the error in setting two lines in alignment. The number of subjects in these determinations is usually limited to three or four, since the measurements as a whole indicate the probability of considerable inter-subject variation. The present experimental results have been obtained to investigate such inter-subject variability and measurements have been obtained on five subjects performing a visual acuity task in white light. All the five subjects were also tested for acuity in Red, Grden and Yellow light.

An outline block diagram of the apparatus is given in Fig. (15). The target lines have a width of 2.5 mm each and each line has a length of 75 mm. The lines were cut from two brass plates, one fixed and the other movable.

Movement of the movable plate and hence of the target line was imparted by a small d.c. motor by suitable cam arrangement (Figs. 16 and 17). The motor was caused to be driven by a 6 V d.c. relay. The relay in turn was operated by

Fig. 17 - Photograph showing the subject watching the moving plate.



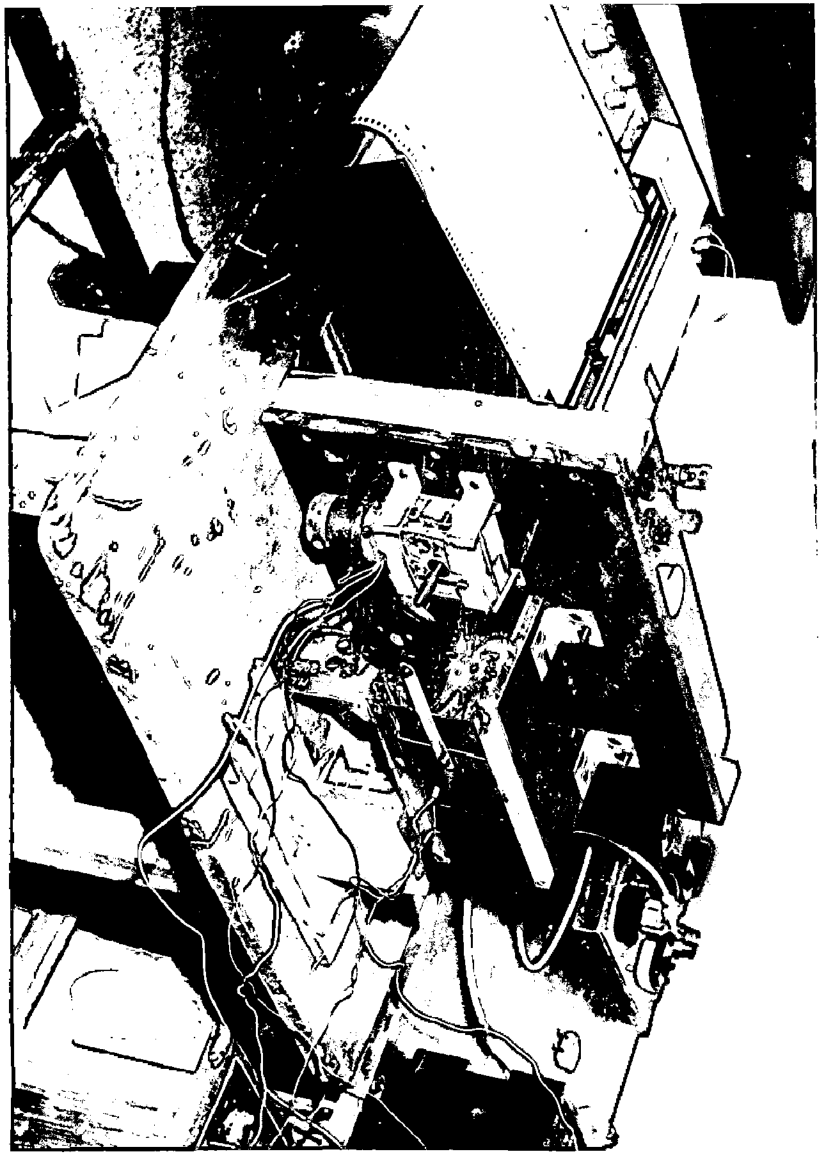


Fig. 16 - View of the Apparatus

a one-shot multivibrator. Input to the multivibrator was a series of pseudo-random pulses fed from a Tape Recorder. The pulses were purposely chosen to be random to eliminate any propriceptive feedback in the subject. The subject control switches consisted of a toggle switch with Left-Off-Right-action, operation.

A source of light was placed behind the plates and whenever the two slits (lines) were in alignment, light would pass through the slits in the plates. This was picked up by a photocell connected in a battery circuit having a fixed resistance. As the plate moved from side to side with the help of the motor, the photocell picked up the momentary pulse of light emanating through the slits when they are in perfect alignment. This momentary light pulse is converted into a voltage pulse by the photocell and its associated circuit. These pulses were recorded on a single channel pen recorder.

The subject was made to sit in a relaxing chair facing the plates at a distance of about 16 ft. from them. The subject was asked to indicate the instant of the alignment of the target lines, by pressing the subject control switch, connecte to another single channel pen recorder. The instants of pressing the switch were thus recorded on this recorder.

The error in each alignment is then the difference of instants (times) of indication of alignment of the lines in the two recorders. The experiment was repeated with green, red and yellow light by placing appropriate filters between the source of light and the subject.

Each subject was given two sessions of 15 minutes each. The mean and hence the standard deviation of error (in second of arc) was found in each case. The reciprocal of the standard deviation as defined before, gives the acuity of that subject for that particular light, in second of arc. The average standard deviation could be taken as an indication of the threshold for comparison with the results of other workers. The reciprocal of standard deviation is taken as the Index of Performance.

The function of each block of Fig. (15) is as described below :

4.2 BLOCK DIAGRAM EXPLANATION :

Tape Recorder :

This forms the source of the random signal, taped previousl y. This signal is used to trigger the one-shot multivibrator. The random signal eliminates any proprioceptive feedback in the subject, i.e. the subject is kept guessing all the time about the sudden movement or abrupt stoppage of the movable plate. This would result in the performance of the subject being much more close to his actual or true performance.

Monostable Multivibrator :

Input to the multivibrator is the pseudo-random pulses from the Tape Recorder. The pulses first pass through a Differentiator before reaching the multivibrator.

Differentiator :

The random pulses ffom the tape recorder are differentiated and rectified by diode D_1 (Fig. 18) to pass pulses of appropriate polarity to transistor T_1 of the multivibrator.

The time constant of the differentiator is given by the relation ,

$$T = RC$$

Choosing R = 20 Kilo Ohm and C = 0.1 micro farad

$$\therefore \quad \text{Time constant} = 20 \times 10^3 \times 0.1 \times 10^{-6}$$

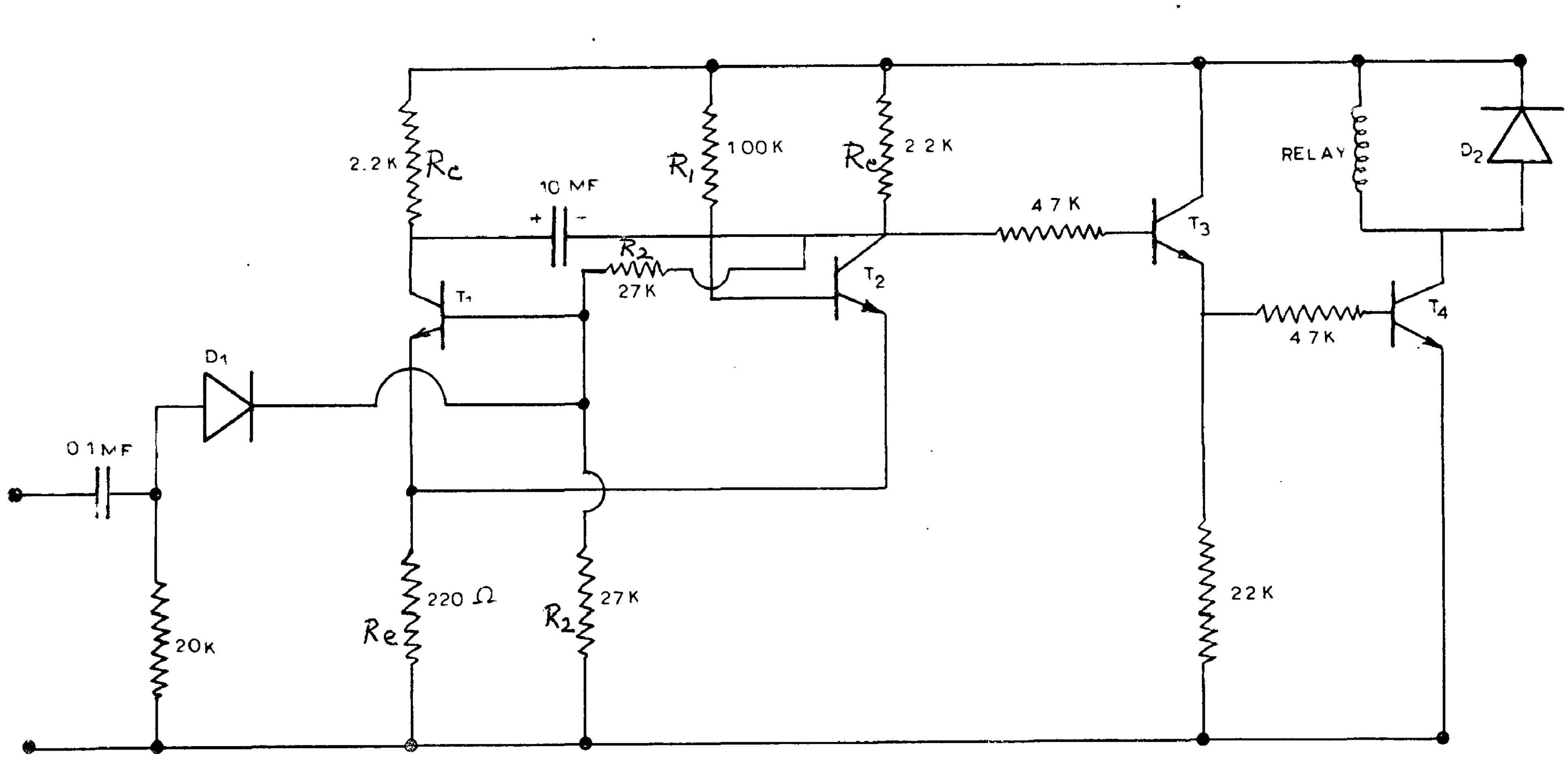
$$= 2 \text{ milli second}$$

Multivibrator Design :

Transistors T_1 and T_2 are NPN transistors (2 N 2369). These transistors are used generally for fast switching action. For the 2 N 2369, transistor :

I_C = 10 mA; V_{CE} = 1V; h_{FE} = 40/120;

For a supply voltage of 12 V,



TRANSISTORS : T_1 AND T_2 → 2N 2369

T_3 → SG104

T_4 → 2 N 3020

DIODES : D_1 AND D_2 → IN 60

RELAY = 6 V.D C. RELAY

FIG. 18 _ DIAGRAM OF MULTIVIBRATOR AND RELAY CIRCUIT

Emitter Resistance :

$$R_e = \frac{V_{ce}}{I_{c(sat)}} = \frac{2}{10 \times 10^{-3}}$$

$$= 200 \text{ ohms}$$

R_e was chosen as 220 ohms.

Collector resistance $R_e = \dfrac{\text{Supply voltage} - V_{ce}}{I_c}$

$$= \frac{12 - 2}{10} = 1 \text{ Kilo Ohm.}$$

Chosing R_c = 2.2 K

$$\frac{R_1}{R_1 + R_2} = \frac{1.5}{2} \quad \ldots \quad (i)$$

Also $I_b = \dfrac{12 - 2.6}{R_2} - \dfrac{2.6}{R_1} \quad \ldots \quad (ii)$

From (i) $1.5\,R_1 + 1.5\,R_2 = 2\,R_1$

or $1.5\,R_2 = 0.5\,R_1$

or $R_1 = 3\,R_2 \quad \ldots \quad (iii)$

Also, $\dfrac{I_{c(sat)}}{h_{FE}} = I_b = \dfrac{9.4}{R_2} - \dfrac{2.6}{R_1}$ from (ii)

$$= \frac{9.4}{R_2} - \frac{2.6}{3\,R_2} \text{ from (iii)}$$

Chosing $h_{FE(min)} = 30$

$$R.H.S. = \frac{28.2 - 2.6}{3\,R_2} = \frac{25.6}{3\,R_2} = \frac{8.5}{R_2}$$

$$L.H.S. = \frac{10}{30}$$

$$\therefore \quad \frac{8.5}{R_2} \geqslant \frac{10}{30}$$

$$\text{or} \quad \frac{R_2}{8.5} \geqslant \frac{30}{10} \geqslant 3$$

$$\therefore \quad R_2 \geqslant 25.5 \text{ Kilo Ohm}$$

Chosing R_2 = 27 Kilo ohm

From (iii) $R_1 = 3\,R_2$

= 3 x 27 Kilo Ohm

= 81 Kilo Ohm

Chose R_1 = 100 Kilo Ohm.

Chosing C = 10 micro farad

time constant of the circuit,

$$t = 0.69 \times R_1 \times C$$

$$= 0.69 \times 100 \times 10^3 \times 10 \times 10^{-6}$$

= 0.69 second

The output of the Multivibrator is taken from the collector of transistor T_2.

Switching Relay :

Output of Transistor T_2, is passed through transistors T_3 and T_4 for purposes of current amplification. A 6 V d.c. Relay is connected to the collector of transistor T_4. When the multivibrator gets triggered, the relay gets energized, otherwise it stays in the OFF position. A diode (D_2) is also connected across the rel ay for protection of transistor T_4. Depending upon the signal from the tape recorder, the multivibrator gets ON and OFF alternately and consequently the rel ay also gets energized and deenergized correspondingly.

Motor Drive :

The 6 V d.c. relay operates a small motor. The motor used is a 28 V, Universal motor. This motor is coupled to the movable plate by means of a pulley and hook arrangement. This results in the linear movement of the plate from one end to the other as the motor rotates (angular rotation) or stops depending upon whether the relay gets deenergized or not. i.e. The motor is given suitable voltage for its operation through an Auto Transformer and its continuous movement is interrupted by the momentary energization of the relay.

Target Lines :

The target lines each 2.5 mm in width and 75 mm in length are formed by cutting slits of these dimensions in two brass plates. The plates are placed lengthwise and supported on grooves cut from a brass rod. One plate, is kept fixed and the other movable. The whole assembly is fixed to a Bakelite sheet which forms the base of the apparatus. The Bakelite sheet has a hole cut out in the middle to accommodate the light-source. The brass plates are placed one behind the other and matched so that the slit in each coincides with that in the other perfectly. The movable plate is set facing the subject while the fixed plate lies hidden behind it. The movable plate moves from end to end in the groove along the length of the fixed plate. The rotatory motion of the universal motor is converted into linear motion of the movable plate by suitable arrangement.

Pulse Shaper :

An oscillator was used to provide continous pulses of magnitude 2 V and at frequency of around 15 C/S to the single channel recorder connected to the subject control switch. Whenever the subject pressed the control switch to indicate alignment of the slits (lines), this momentary pulse would overlap the continuous signal to the recorder from the oscillator.

Subject Control Switch :

This was an ordinary ON-OFF switch, the switch being generally in the OFF position. As the movable plate continued its to and fro motion, the subject was asked to indicate the exact instant of the alignment of the two slits (by viewing the light passing through them) by pressing the control swithh. This instant was recorded on single channel recorder (clevite corporation, U.S.A.) as a pulse over the continuous signal from the oscillator. I t should be remembered that the control switch is always in the OFF position except for the instant it is brought to the ON position, by the subject, to indicate alignment of the slits (lines).

Two Channel Recorder :

Since a single unit two channel recorder was not availabl two single channel units were used. The two units for identification purposes can be discriminated as: Clevite Corporation (U.S.A.) recorder and Philips recorder.

Clevite Corporation Recorder :

This was basically a two channel recorder but since only one unit was in working condition, it was used as a single channel pen recorder.

This rocorder had three adjustable paper speeds : 5, 25 and 125 mm/soc. The recordor was operated at the speed of 5 mm/occ or 300 mm/min. throughout the experiment. As mentioned earlior a continuous signal from an oscillator was givon to this recordor. Over this signal was superimposed the momentary pulses given by the pressing of the subject control stitbh.

Philips Recorder :

This single channol pen recorder had varying speeds of 0.5 mm/min to 500 mm/min. During the entire course of the experiment, the recordor was run at a speed of 250 mm/min. The output from the photocell and its associated circuit was recorded on this rocorder.

The recorded outp ut of this recorder gives the instant of the actual alignment of the slits (lines) in the plates. On the other hand, the Clevite Corporation recorder output gives the instant of alignment of lines as decide by the observer. Tho difference in the instants (or times) of the two records, is then the error in alignment.

Tho results of the experimental work carried out and the conditions reached therein are discussed in the succeeding chaptor.

CHAPTER - V

RESULTS & CONCLUSIONS

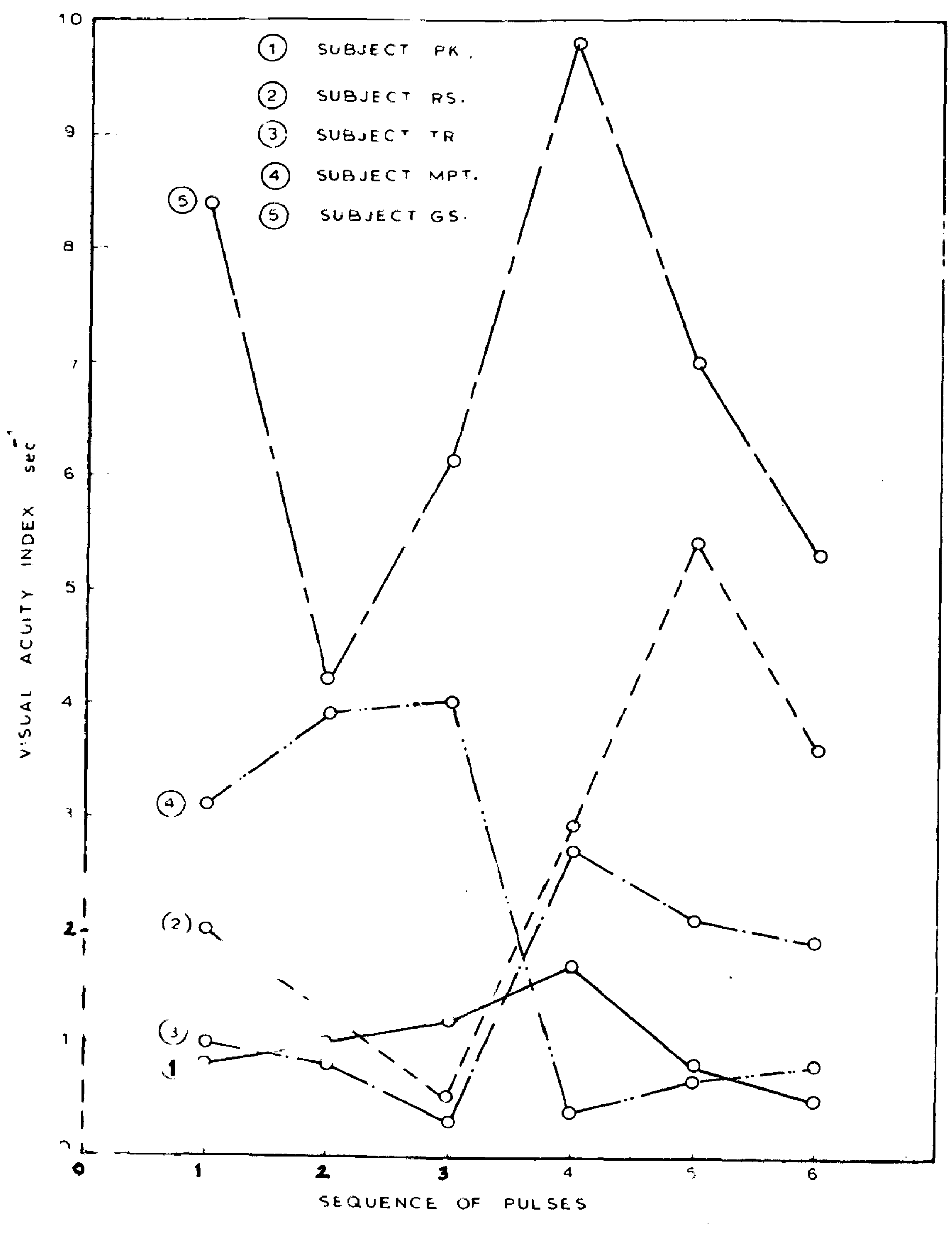
Visual acuity tests were carried out on five subjects in both white as well as coloured light, Each subject was given two sessions of 15 minutes each. The error in each alignment given as the difference in instants (times) of the output of the two recorders were determined. A total of 30 readings was considered and split into six groups of five readings each. The mean and standard deviation for each group was calculated. The reciprocal of the standard deviation known as the Index of Performance was obtained for each of the five subjects in white, red, green and yellow lights. The results are as shown in Table III.

5.1 DISCUSSION :

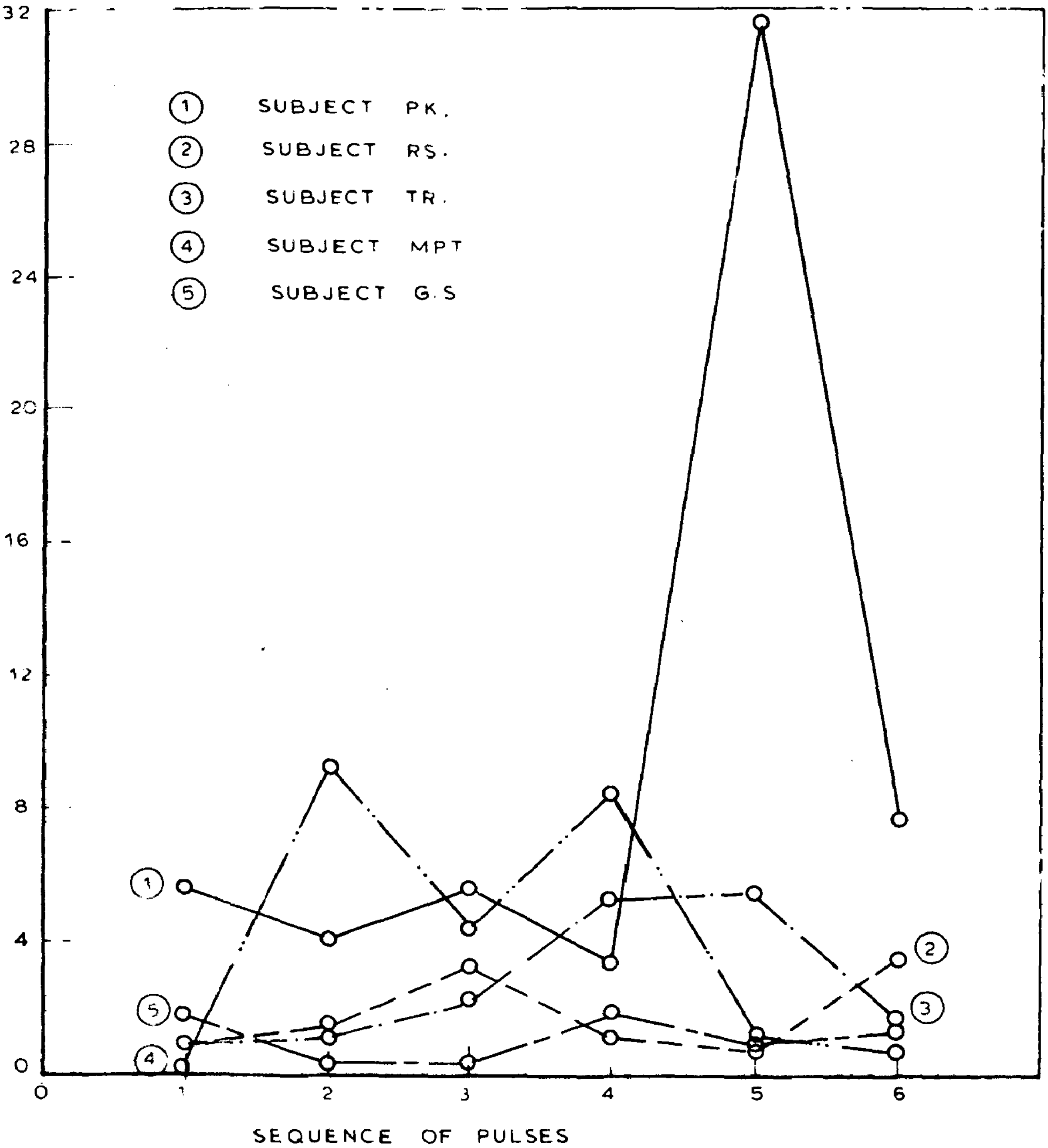
The visual acuity thresholds obtained for the five subjects lie between 0.03 second arc and 4.3 second arc. This value is considerably lower than the threshold of normal acuity which is of the order of 33.4 second of arc for an object width of 2.5 mm and distant 16 ft. from the eye.

The best single performance for any one experimental session (subject PK in red illumination) Fig. (20). gave a threshold of 0.3 second of arc. It is considered therefore that although exceptional subjects may exist with visual acuity thresholds less than 0.3 to 0.4 second arc the smaller thresholds if any, obtained may be due to a failure of jects :

	low light				Green light			
	jects				Subjects			
RK	R	MIT	GS	RK	RJ	TH	MIT	G
I Set								
0.838	363	0.969	2.394	0.348	5.045	0.766	2.070	0.635
II Set								
1.013	710	0.894	0.804	0.549	2.471	0.732	0.542	0.862
III Se								
1.180	355	0.773	1.106	0.666	6.881	0.477	0.715	1.814
IV Set								
1.721	516	3.480	3.072	10.206	1.328	1.815	2.088	0.587
V Set								
0.794	551	1.769	1.942	3.686	0.742	0.499	0.312	1.080
VI Set								
0.501	562	0.749		1.359	0.769	2.475	0.398	2.865

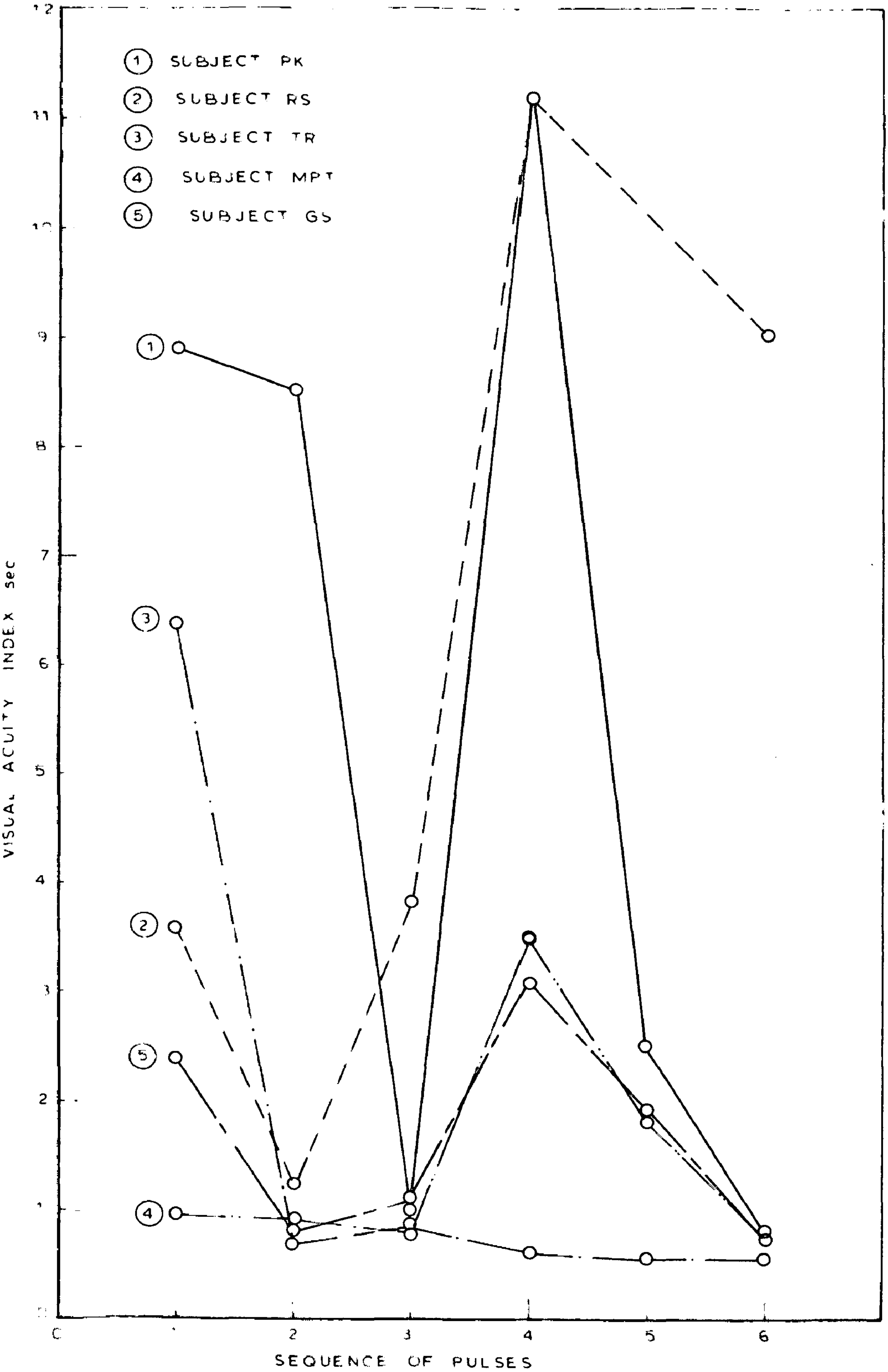


19 - VISUAL ACUITY PERFORMANCE IN WHITE LIGHT

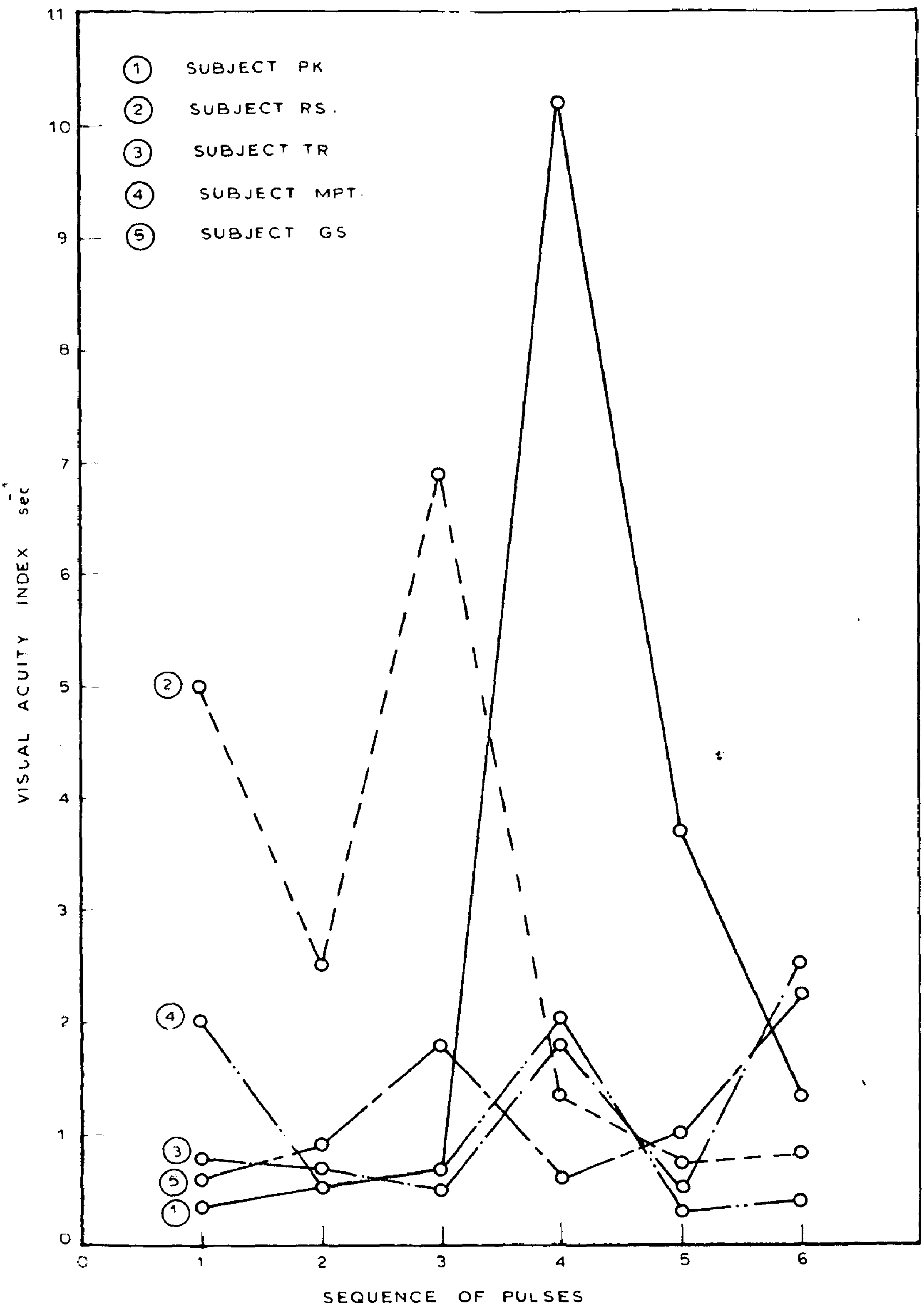


VISUAL ACUITY PERFORMANCE IN RED LIGHT

FIG. 20



21 VISUAL ACUITY PERFORMANCE IN YELLOW LIGHT

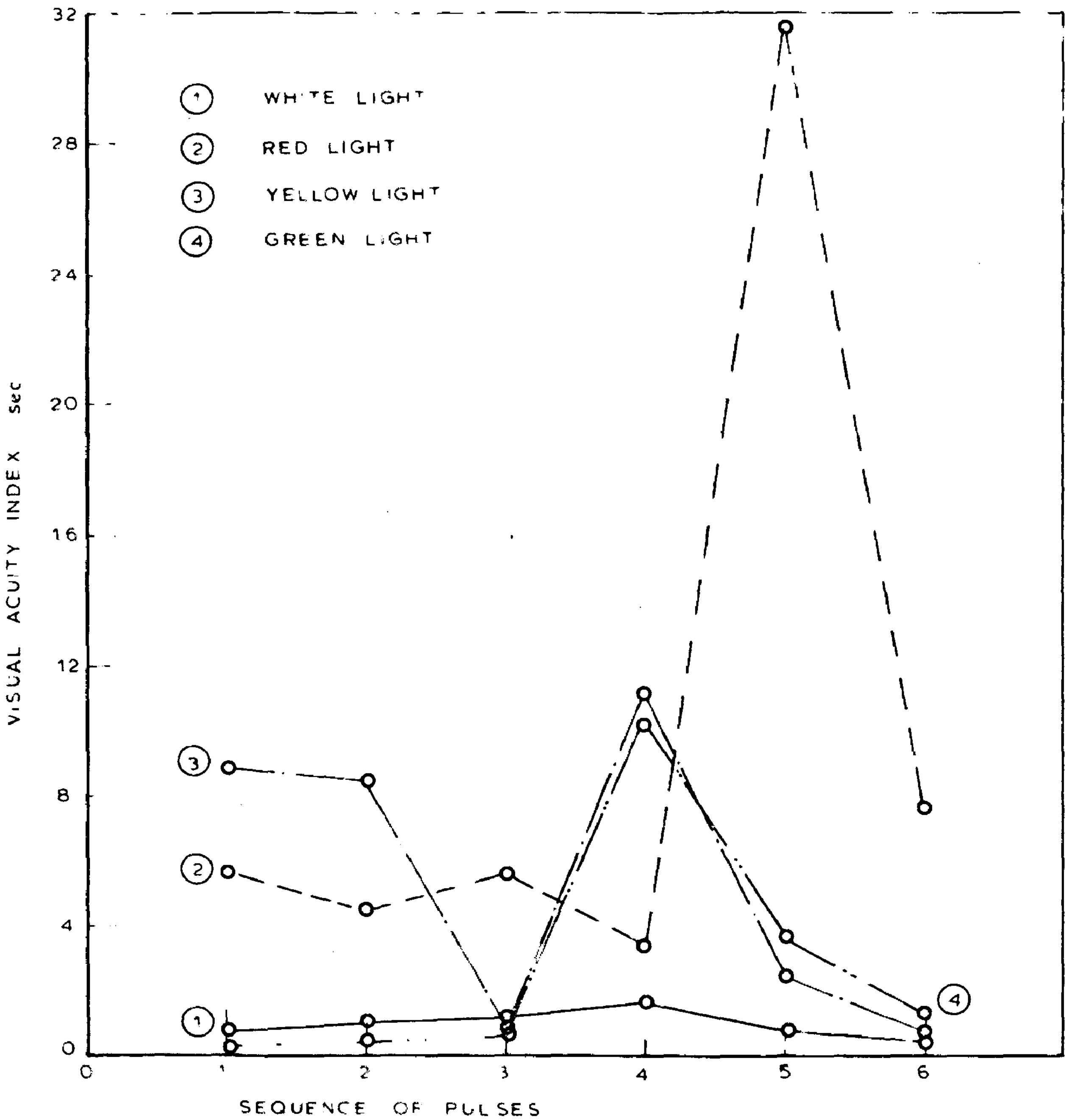


.22 _ VISUAL ACUITY PERFORMANCE IN GREEN LIGHT

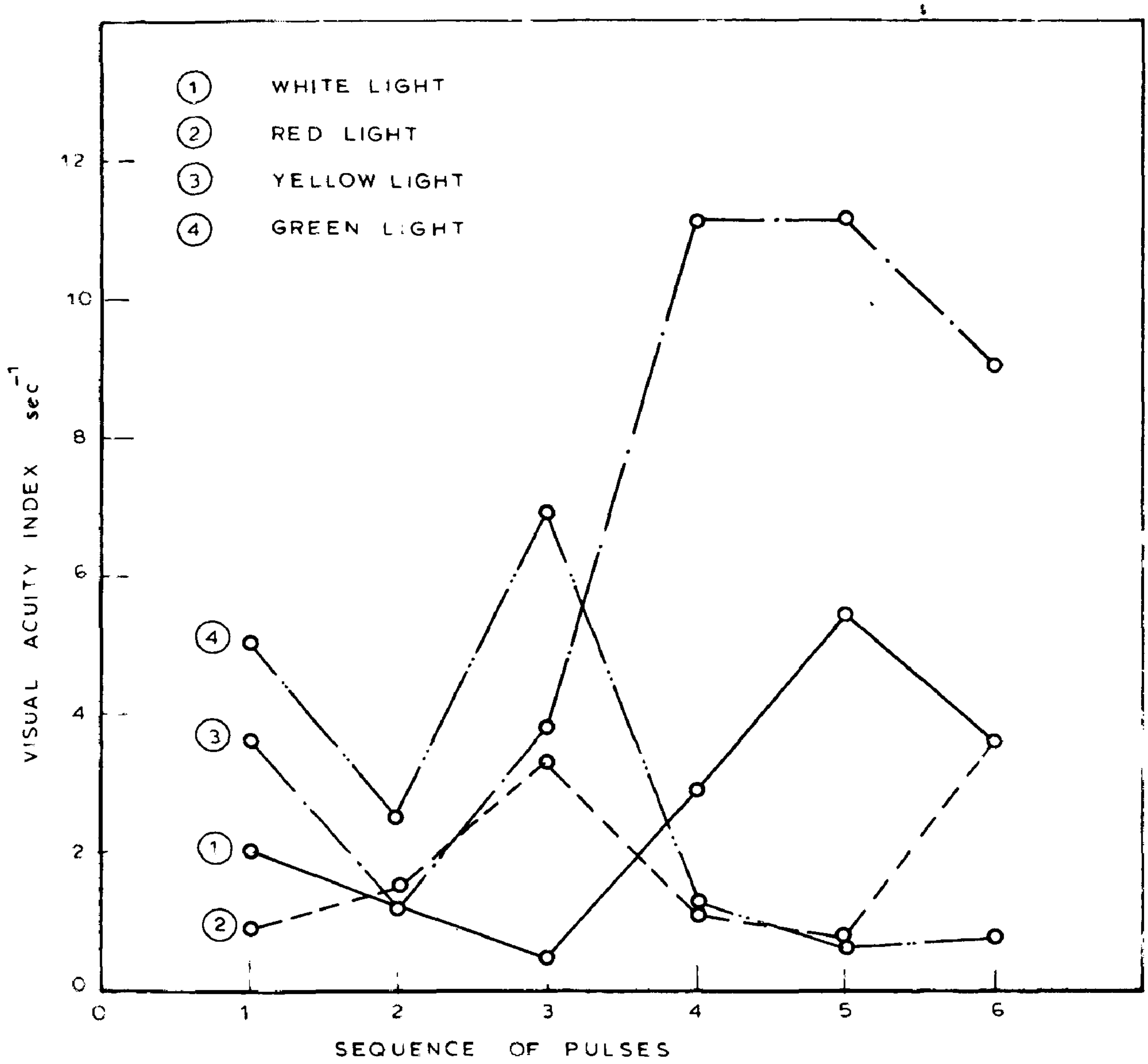
Proprioceptive feedback.

The results of visual acuity performance in coloured illumination given by Baker (1) in 1949, give an order of superiority of red, yellow, white and blue whilst those of later researchers give an order of yellow, white, red and blue. In neither case was a performance in green illumination given, but these results indicate two possible distributions. Either a peak performance at the red end of the spectrum diminishing towards blue or a peak performance in the middle of the spectrum diminishing towards either end. Of the present results one subject (PK) fig. (23) gave a distribution in agreement with the first case and the remainder were consistent with the later distribution Figs. (24) and (25) and (27). It would therefore appear that both types of distributions occur and subjects fit into one or other category. Also Figs. (19) to (22) give a comparative study of the performance of the five subjects, in white, red yellow, and green lights.

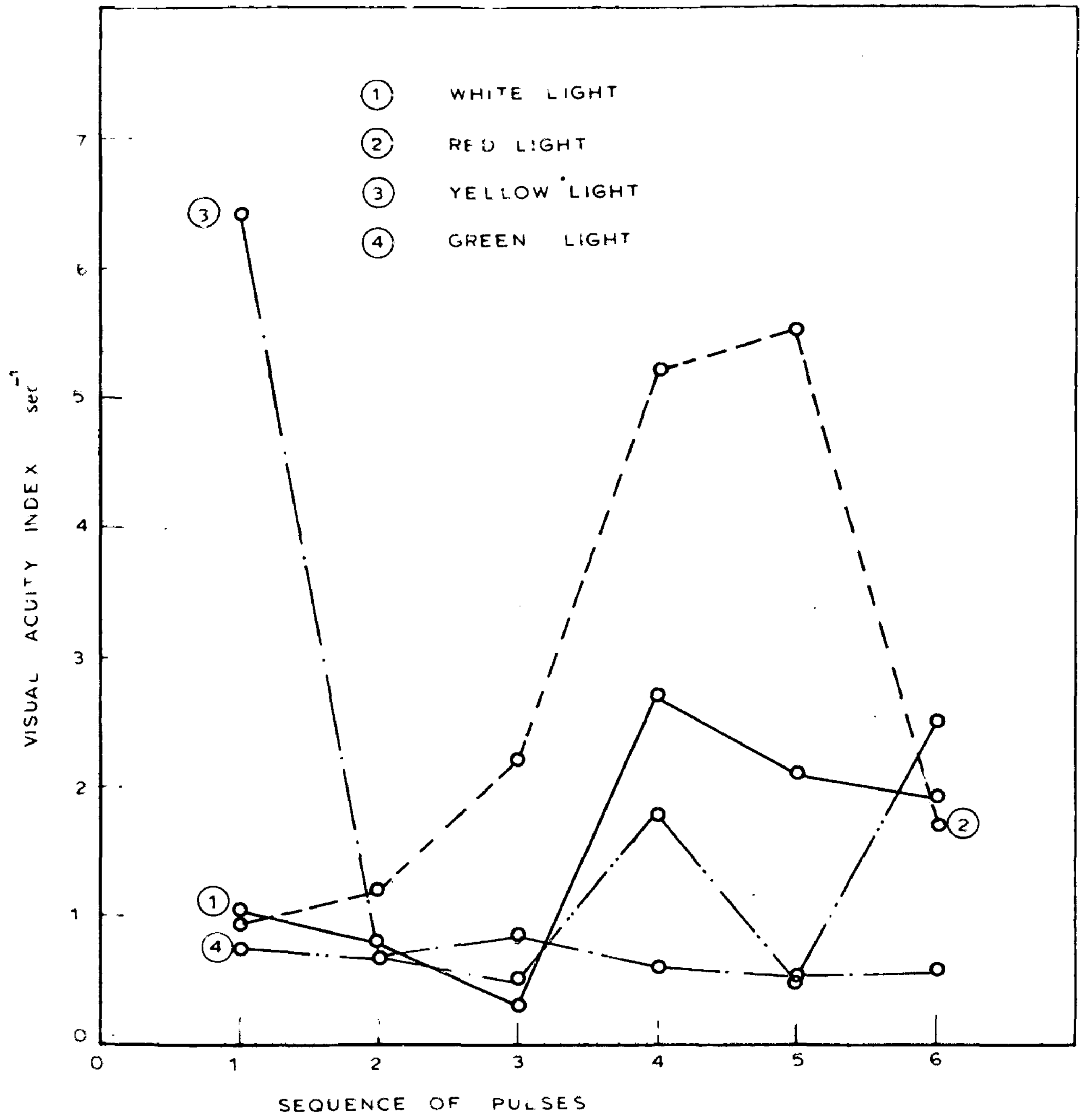
It has been known for over 50 years that individuals differed in their assessment of correct alignment of vernier type scales, and optical range finder operators of the first World War were assigned an individual zero correction. The present results indicate that such an effect in a purely visual one and in no way related to a possible proprioceptive



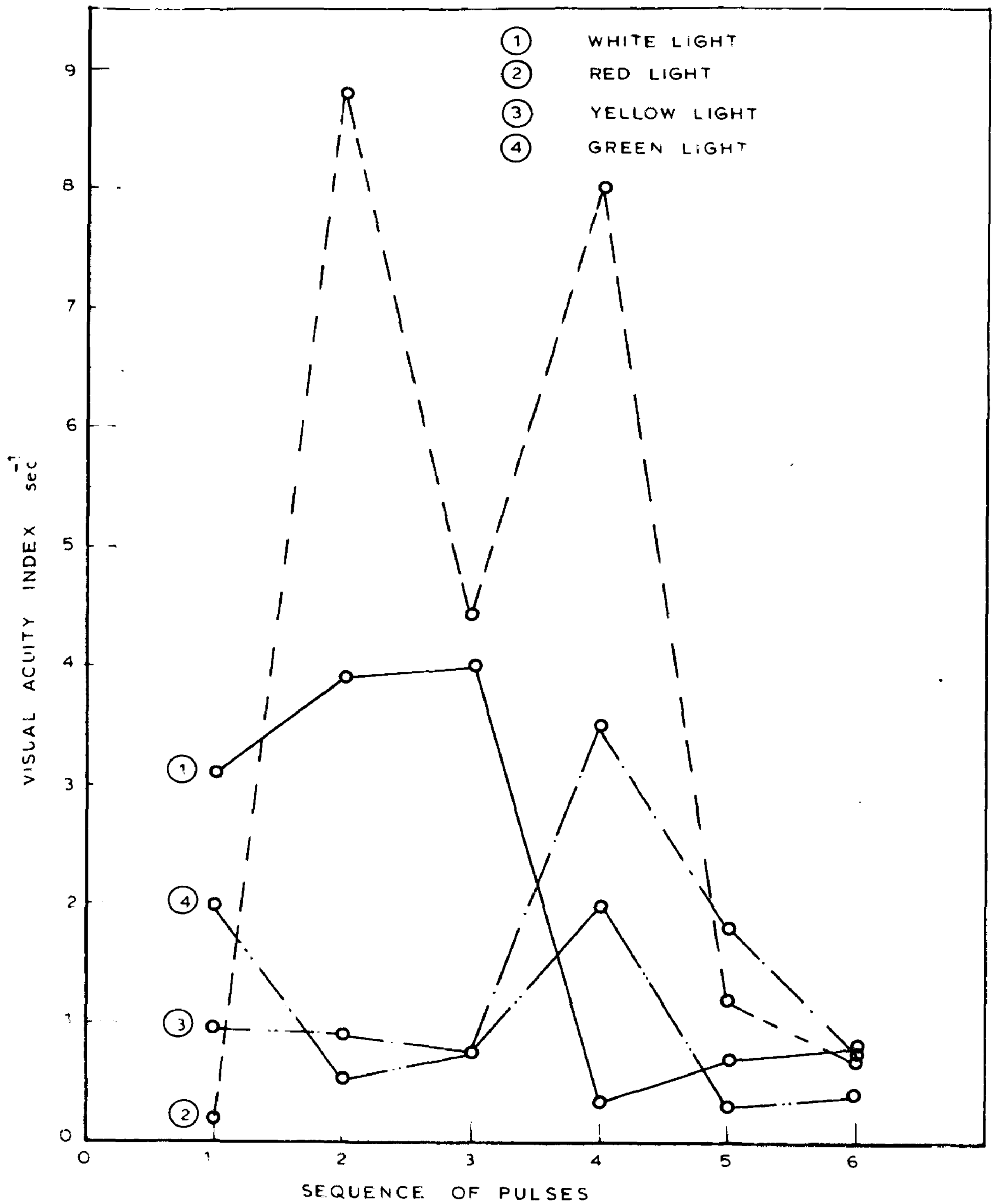
3 VISUAL ACUITY IN DIFFERENT LIGHTS: SUBJECT PK.



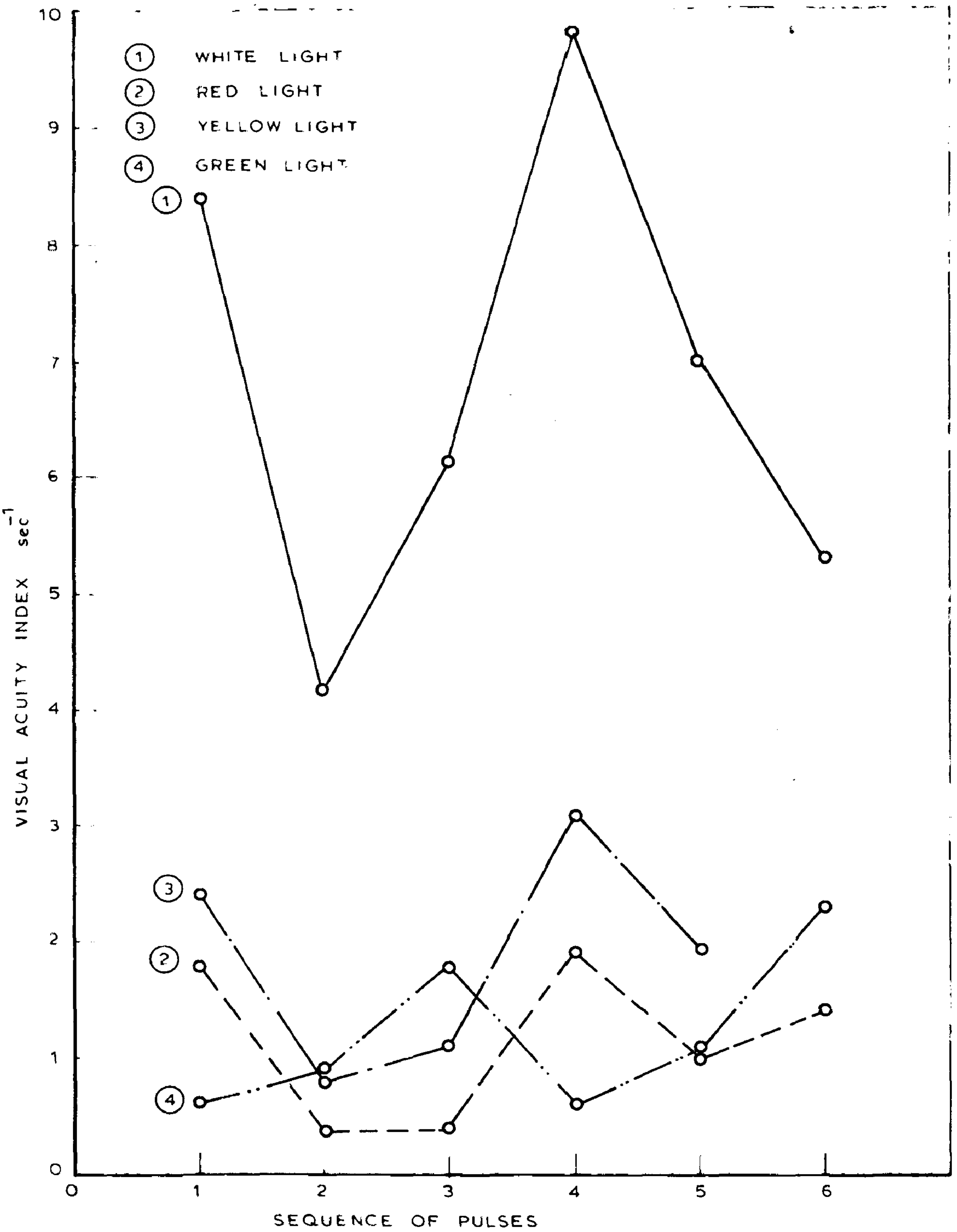
1-VISUAL ACUITY IN DIFFERENT LIGHTS: SUBJECT RS



5. VISUAL ACUITY IN DIFFERENT LIGHTS: SUBJECT TR.



5 VISUAL ACUITY IN DIFFERENT LIGHTS: SUBJECT MPT.



?7_VISUAL ACUITY IN DIFFERENT LIGHTS: SUBJECT GS feedback. It is possible that the effect may be due to imperfections in the optics off the eye, or to irregularities of the retinal mosaic.

There was no evidence that shorter or longer times occurred in earlier or later experiments and the short and long times were found to be distributed randomly in all sequences of experiments. The results therefore indicate that the human system fails to optimize itself to obtain the best possible performance by the correct solution of an optimum time to be spent in making each alignment. It is suggested that a limit is imposed on the temporal summation of information giving improved performance, by the time interval for which a subject can maintain concentration on the task. Subjects will then tend to make judgements well within the time limit of concentration in order to reduce the probability of having to "start again".

5.2 SUMMARY OF CONCLUSIO-NS AND PROBLEMS ENCOUNTERED :

(a) Thresholds of visual acuity performance vary between 0.4 second arc and 4.3 second arc.

(b) Subjects fall into two classes when perfoming visual acuity tasks in coloured illumination, with either a peak of performance at the red end of the spectrum, or peak in the middle of the spectrum in the yellow-green.

(c) Subjects each possess an inherent zero-error in making visual alignments which is entirely a visual phenomenon.

(d) The Universal motor while in operation had considerable noise level and so also Clevlite Corporation Recorder. This would have per-haps disturbed the subject. This disturbance, however, being common to all the subjects would not make any significant difference in the overall result. However, it is desirable to use an audio signal in the room of the magnitude of the motor noise thereby eliminating any error.

(e) The motor could not be run continuously for more than 15 minutes at a stretch as it used to get heated up furiously. It would have been better if the motor could have been kept running for half an hour or so continuously. This would help in finding the acuity even under extreme strain of the eye watching the moving slit (line).

(f) The movable plate also got heated up due to friction while moving in the groove of the brass rod. Supporting the plate on rollers would perhaps remedy this malady.

(g) Owing to labk of time and various other ~~constants~~ constraints the experiments, could not be, unfortunately, performed on a greater number of subjects. Also number of experimental sessions could not be increased for the same reason.

5.3 SCOPE FOR FURTHER WORK :

(a) Tests may be conducted by using standard illumination, with varying distances of object from the eye.

(b) The target kine length could also be varied to study its effect on acuity.

(c) Also target line width may be varied to study how it affects the acuity.

(d) Provision could be made in the optical system for the insertion of a small correction lens in order to produce the best image on each subject. This would help in determining whether a subject needed correcting lens for a particular colour light or not, and if so its power.

This being a maiden venture, more interesting results and side by side, more improvements may be in store for future experimenters.

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