A study of the assessment of the integrity of monocular vision

A STUDY OF

THE ASSESSMENT OF THE INTEGRITY OF

MONOCULAR VISION.

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AS A THESIS SUBMITTED FOR THE DEGREE OF

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THE ASSESSMENT OF THE INTEGRITY OF MONOCULAR VISION.

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ABSTRACT. This thesis brings together the results of a number of years of work devoted to the development and standardisation of a new instrument for the detection and evaluation of loss of function in the visual field.

The reduction in sensitivity of areas of the retina to light stimulation has an important significance for early indications of ocular and neurological pathology. There has been a considerable history to the development of techniques and of instrumentation for investigating the response of visual fields, but all previous methods have lacked the sensitivity required for clinical diagnostic work.

The purpose of this thesis is therefore to explore the effectiveness of a specific technique for the assessment of the integrity of monocular vision, and to show how the design of a new instrument for routine visual field investigation was evolved.

The method of multiple static quantitative perimetry applied to the central and mid-peripheral region of the visual field, with the stimuli exposed near the threshold of visibility under controlled conditions, is the basic procedure used for the assessment of the integrity of monocular vision. The necessary conditions that need to be controlled for such an investigation are reviewed and related to the development of the new instrument.

The standardisation of the sensitivity of normal subjects to flashed stimuli was determined initially on a prototype instrument, and later more rigorously on a production model. At the same time an independent research project on the perception of similarly flashed stimuli confirmed the data on threshold responses previously obtained. Clinical trials for the routine detection of abnormal responses demonstrated marked differentiation of normal and abnormal visual function.

It is concluded that multiple static quantitative perimetry is a viable and efficient method for investigating monocular visual integrity.

KEY WORDS : INVESTIGATION OF VISUAL FUNCTION.

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Lastly, but really firstly, the author would like to acknowledge sincerely the interest and patience shown by his wife, Inez, when he had to devote so much time and effort to this work, and for her original inspiration in interesting him in vision.

ILLUSTRATIONS.

APPENDICES.

SELECTED PAPERS BY C.H.BEDWELL ON MONOCULAR VISUAL PERCEPTION.

1. The design of instrumentation for the efficient investigation of the visual fields. Amer.J.Optom. 44: 609-633. 1967.

2. Technology and the prevention of blindness. Quest. 14. 17-20. 1970.

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6. The application of short duration flashed stimuli to visual field examination. Proc. Inter. Perimetric Soc. Marseille 1974. Pub. "Annee therrapeutique et clinique en ophthalmol. XXV." 1974.

7. The effect of pupil size on multiple static quantitative visual field threshold. Proc. Inter. Perimetric Soc. Tubingen. Pub. W.Junk, The Hague. 1976.

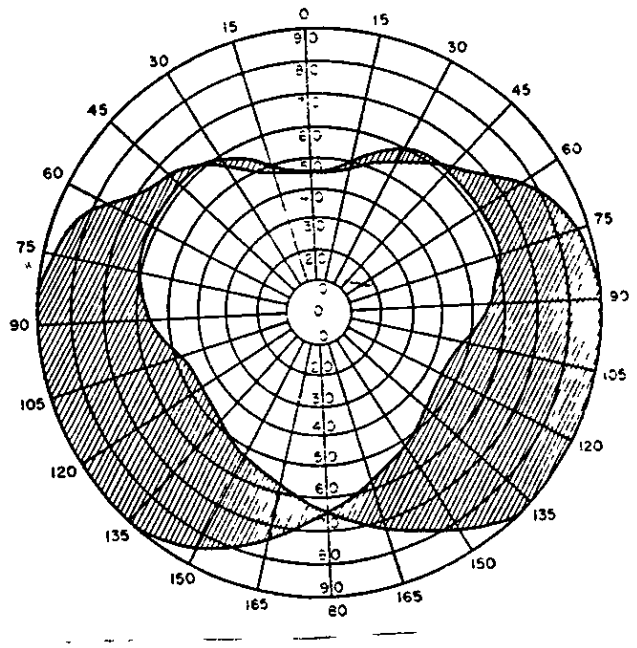

FIG. 1. Typical Visual Fields of right and left eyes showing binocular overlap.

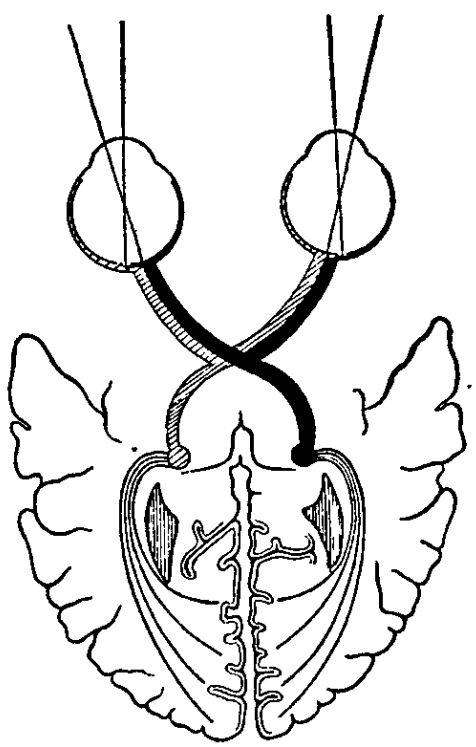

FIG 2. An outline of the visual pathway from the retina to the occipital cortex, showing how the visual field image from each retina is transmitted, that the nasal retinal fibres cross at the chiasma, while the temporal fibres do not, allowing all that is seen on the left of foveal fixation to be transmitted to the right cerebral hemisphere, and all that is seen on the right, to the left cerebral hemisphere. Representation of the macula areas in the occipital cortex is more wide spread than that of other areas of the retina.

I

THE ASSESSMENT OF THE INTEGRITY OF MONOCULAR VISION

(A) Introduction.

The use of two eyes enables a large field of view to be obtained, which, in the case of man, results in a considerable degree of overlap between the visual fields of each eye. (Fig 1). The lateral separation of the eyes permits the viewing of an object from two slightly different angles, and contributes to perception of depth. In normal circumstances, the eyes operate as a linked pair.

The retina is part of the total visual-perceptual mechanism and is linked to the visual occipital cortex in the posterior of the brain by the visual pathway. The visual cortex is divided into two, forming a part of each cerebral hemisphere. (Fig 2). Except for the immediate foveal area, the retina is also represented as two halves, the temporal retina in the occipital cortex of the same side, and the nasal retina in the opposite half of the cortex. To obtain single binocular vision when images of an object fall on the two retinae, the images must be contained within local retinal areas which work in correspondence.

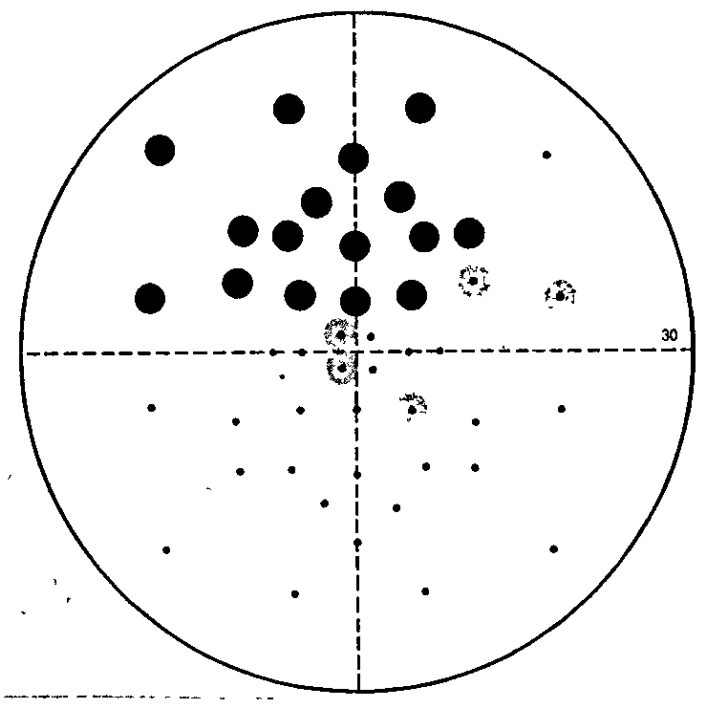

FIG 3. Case of severe loss of vision because of glaucoma, in the upper field of the right eye, which was unnoticed by the patient, even though vision in the left eye was amblyopic, or congenitally weak.

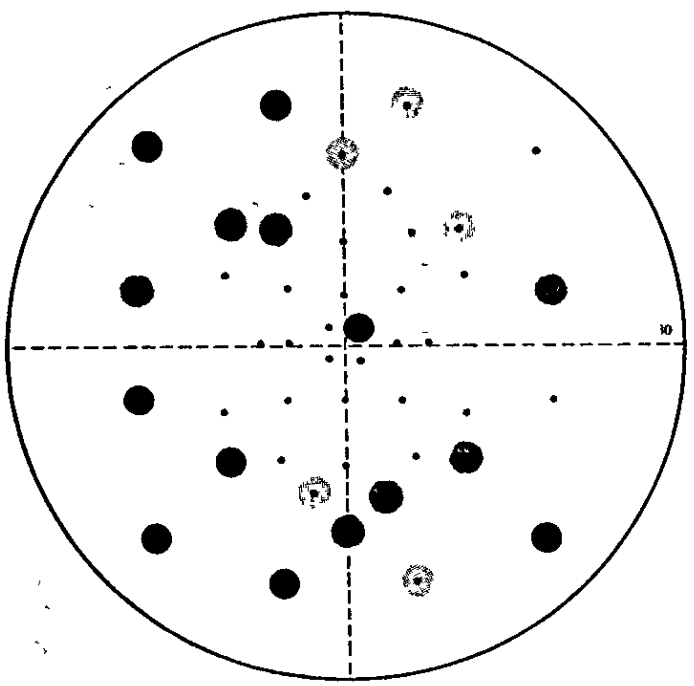

FIG 4. Case of a patient with a severe meningeoma which would not have been detected until too late, if visual fields had not been examined as a routine. There was no other supporting evidence that the condition existed.

Many important pathological conditions can cause slight reductions of vision in the field of vision peripheral to the fovea, and yet foveal vision e.g. as assessed by letter chart visual acuity, remains normal. These reductions of vision in the peripheral field are usually unnoticed by the patient, and cannot normally be detected unless specifically looked for. These irreversible losses then commonly continue to progress until they are so severe that the patient is finally aware of them.

One common ocular condition involving gradual, increasing, and yet commonly undetected reduction of vision, in the mid-peripheral field of vision at retinal level, is glaucoma, e.g. Fig 3. Here the likely incidence is nearly one in a hundred of all the population over forty years of age, or one in ten if there is an hereditary factor. Glaucoma is, in fact, one of the major causes of blindness. As the visual system is part of the brain, many neurological conditions can produce some reduction of vision, again often initially undetected, as foveal vision may not be affected, In such cases early detection of visual loss may actually save the life of the individual concerned. (Fig 4).

The investigation of the response of the retina outside the immediate foveal centre, is, therefore, of vital importance in assessing the integrity of the visual system, and ensuring that serious pathological conditions do not remain undetected.

(B) The Importance of the Investigation of Monocular Visual Perception.

The binocular overlap of the monocular visual fields involves the fovea and mid-peripheral field. In many pathological conditions causing early visual field loss, the vision of one eye only may be affected, or one eye much more than that of the other. Because of this visual overlap, there is even greater likelihood of the patient being unaware that there is anything wrong with his vision.

When investigating integrity of visual function, it is essential, therefore, to investigate the vision over the visual field in each eye independently, if many pathological conditions are to be detected, before considering the integrity of function of the binocular system. It is particularly important to investigate the visual field 0 to 25 degrees eccentric from the fovea, as it is in this area where early visual loss in many conditions is first manifest, and where there is binocular overlap.

(C) Objective of Thesis.

The purpose of this thesis is to consider the many factors involved in the investigation of the mid-peripheral monocular visual field for the assessment of integrity of visual function, and to show how properly designed instrumentation can be developed and utilized to detect sensitively and efficiently early reductions of vision.

The author was concerned in the joint development of a suitable instrument with Messrs Clement Clarke International and Mr.A.I.Friedmann F.R.C.S., The Royal Eye Hospital, London, based on an original design of Mr Friedmann. With this design a number of stimuli could be presented to the eye simultaneously from a single light source. A fixed plate contained apertures for multiple stimuli, and patterns of stimuli could be exposed by rotating an adjacent shutter-plate.

The author's particular contribution was in the photometric design of the instrument, so that the stimuli would present a similar luminance to the eye, and that the effects of obliquity of viewing, and variations of threshold due to retinal physiology, could then be allowed for by varying the sizes of the stimuli apertures. It was also necessary to ensure that the assessment of threshold was under controlled conditions to permit a standardised measure for visual loss .

Before entering into a detailed account of the pre-requisites for the development of a viable instrument, it is first necessary to review what had so far been considered as desirable conditions for perimetric investigation, and how later the design of a safe and viable instrument was considered.

II

THE GENERAL PROBLEMS INVOLVED IN THE INVESTIGATION OF THE VISUAL FIELDS.

Clinical work commonly has to be undertaken under adverse conditions of shortage of time, staff, and with inadequate facilities. In the case of vision and the eye we are dealing with a highly complex perceptual system, and investigation can be difficult.

What functions are felt necessary to investigate depends very much, therefore, initially on the experience and skill of the practitioner concerned. Aspects of clinical importance may thus be noticed by one consultant, whereas the less experienced might consider the eye and the visual system to be within normal limits.

There can be quite wide variations, amongst normals, of the physiological appearance of many structures, and also variations in threshold, for example, in various tests on visual perception. In addition clinical diagnosis involves decisions as to whether what is observed and assessed is within physiological limits, or is abnormal and pathological. To aggravate the situation many clinical investigations are laborious and time consuming, and are, in consequence, commonly only undertaken when the practitioner feels it necessary to do so, unless instrumentation has been so designed that tests can be sensitively and

speedily undertaken as a routine. In consequence there can be many cases where the signs may be insufficient to indicate that visual field investigation is necessary, particularly to the less experienced, and yet a loss with serious implications may be present.

The examination of the visual field is complicated because thresholds of visibility vary with different positions of eccentricity from the fovea, i.e. over different retinal areas, due to the influence of retinal physiology, and also with the methods employed, and the conditions under which the tests are undertaken.

In considering, therefore, the design of suitable instrumentation for the sensitive and efficient investigation of the visual fields, various variations, which may be within physiological limits, must be taken into account when observed reductions in visual threshold are to be interpreted as either normal or pathological responses.

It is thus necessary to undertake tests under the most suitable conditions for efficient diagnosis, with the best possible controls of the variables that are likely to affect the data obtained. Under these circumstances concentration can then be on the main variable with which one is concerned, considerably aiding the

interpretation of any data recorded. In the case of visual field investigation, the important consideration is whether the threshold of vision over a certain retinal area is likely to be above normal physiological limits, how much it is above, and the area over which the effect is occurring. As the visual field may need to be examined in more than one clinical unit, and by different examiners, and often over a period of time, it is particularly important to ensure that testing conditions can be accurately repeated.

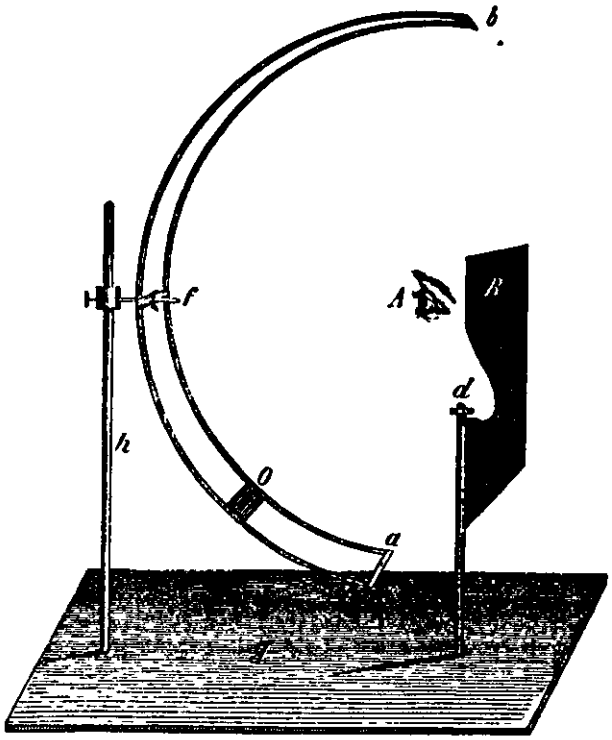

FIG 5. The Aubert arc perimeter.

FIG 6. The Bjerrum screen for campimetry.

III

HISTORY OF VISUAL FIELD INSTRUMENTATION.

The importance, clinically, of detecting losses in the visual field, in the diagnosis of various pathological conditions, was first realised by Von Graefe (1856).

The earliest known instrument for this purpose, a simple semi-circular arc, was designed by Aubert (1857), (Fig 5). In this simple perimeter the patient placed his eye at the centre of curvature of the half-circle of a bent metal rod, and looking with one eye at the centre of the arc, said when he could see an object moving in his peripheral visual field.

These early instruments were only able to detect the more established peripheral visual field losses, and were quite inadequate for detecting early reductions in the mid-peripheral field of vision.

Bjerrum (1890) realised that vision improved from the periphery to the fovea, and, that in investigations for conditions such as glaucoma, simple arc perimeters were not sensitive enough. The smallest diameter of a white painted target that could be used satisfactorily was 1 mm, and that when such a target was used at the common distance of a third of a metre from the eye, the angular subtense at the eye was far too large to allow for a critical investigation. Bjerrum therefore designed a simple flat black screen large enough to investigate this mid-peripheral

visual field, (campimetry,) which the patient could view at one or two metres. (Fig 6). The small painted targets then used would subtend proportionally a much smaller visual angle at the eye, therefore considerably increasing the sensitivity of the investigation. The projection of the visual field on to a flat surface rather than a curved one, did not in practice introduce a great deal of error for 0 to 25 degrees eccentricity.

The Bjerrum screen was much more effective in detecting mid-peripheral visual field loss particularly for such conditions as glaucoma, than was a simple perimeter, and has been regularly used for this aspect of visual field investigation until the 1950's, when improved methods of visual field instrumentation started to become available. To be reasonably effective, this technique of visual field investigation requires considerable experience, and has really to be developed as an art to ensure clinical adequacy. This means that delegation of visual field investigation is unsafe until the necessary expertise has been developed. Even then considerable variations in what is detected can occur, depending upon the conditions under which the investigation is undertaken, and on individual variations of technique.

With these classical techniques and instruments there was neither adequate control of the level of light adaptation under which the visual field was investigated, nor was there any control of stimulus luminance. It was

FIG 7 (a)
Goldmann Bowl
Perimeter (1945),
view from
operator's side.

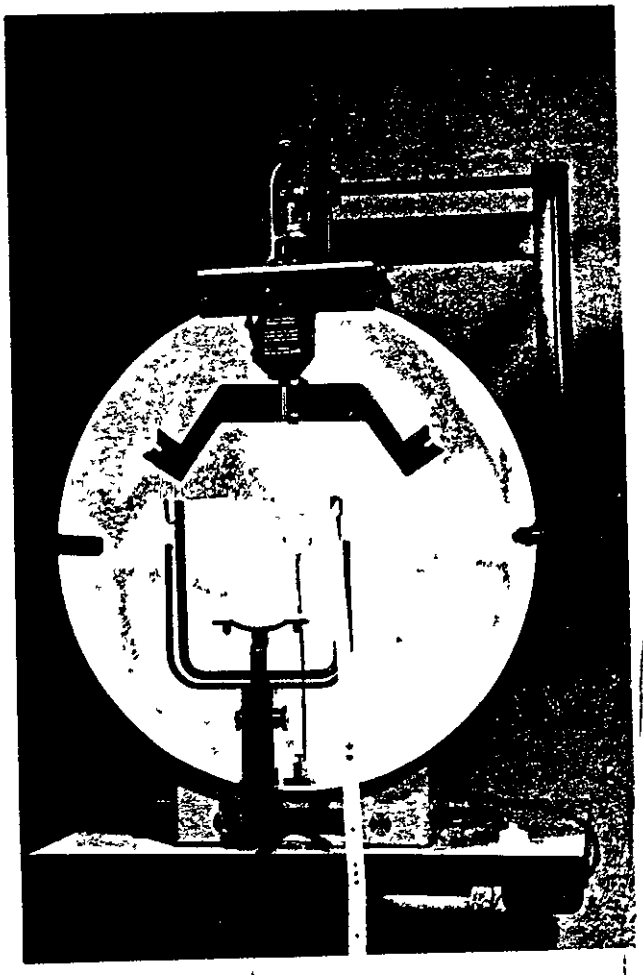

FIG 7 (b)
Goldmann Bowl
Perimeter,
view from
patient's side.

only as a result of the work of Goldmann and the introduction of the Goldmann (1945) bowl perimeter in conjunction with Haag-Streit (Bern), that any major advance was made.

The Goldmann perimeter, (Fig 7a & b), consisted of a white-surfaced bowl, which was evenly illuminated over its surface by a hidden light source allowing the bowl to act as a hemispherical integrator. The stimulus used was an illuminated spot of light projected on to the bowl surface by a mechanically controlled pantograph system, with provision for both the size and the luminance of the stimulus to be controlled by apertures and neutral density filters in the optical system. Coloured filters could also be introduced in the optical system. A simple visual photometric device, and later a light-meter, was employed to allow the correct setting of luminance for bowl and stimulus from one light source. The pantograph projection system enabled an accurate recording to be made on a trans-illuminated visual field chart at the back of the bowl.

Variable mechanical controls were provided for correct positioning of the eye at the centre of the bowl, and the eye could be observed, and the pupil size measured, by a telescope at the rear of the bowl. The stimulus was moved across the surface of the bowl, until it could be seen, and its position recorded on the chart at the rear. Likewise any areas where vision was missing could be explored and noted. By using both a combination of different stimulus sizes and known stimulus luminances,

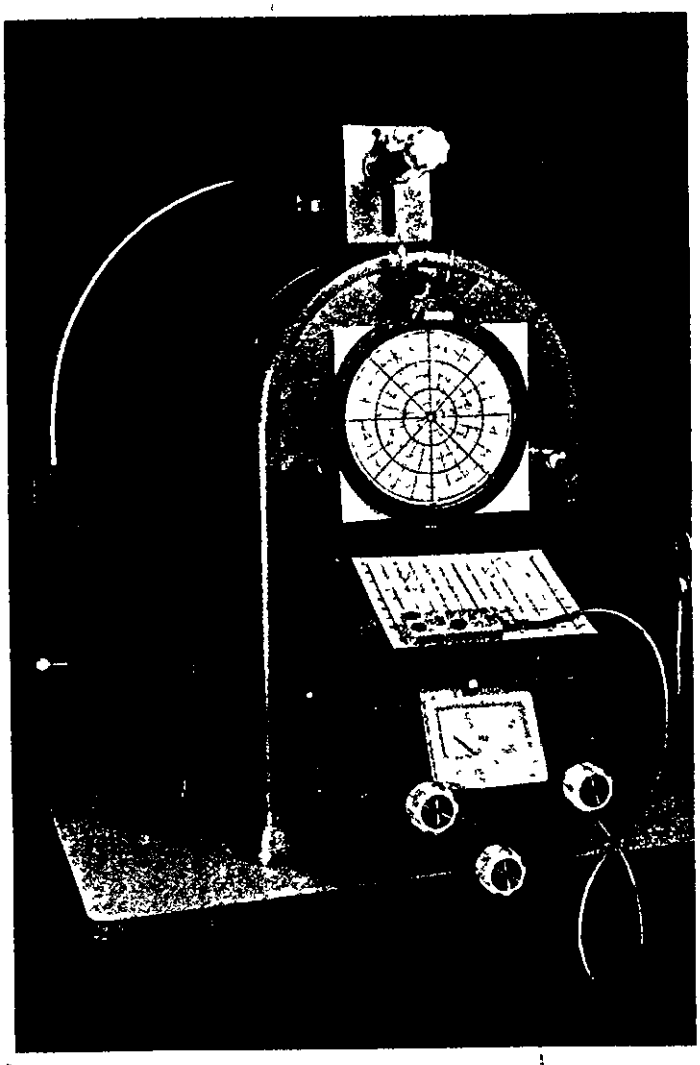

FIG 8 (a).
Tubinger Perimeter view from operator's side.

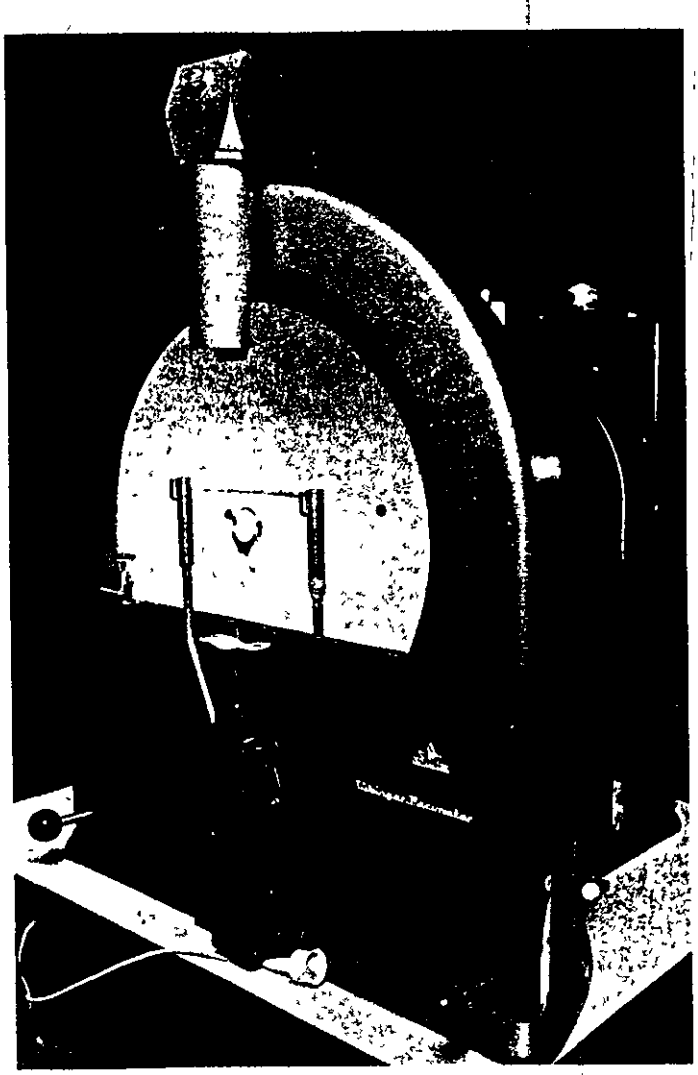

FIG 8 (b)
Tubinger Perimeter view from patient's side.

a much more sensitive investigation of the visual field was possible.

As the value of this more sophisticated method of visual field examination was realised, other bowl perimeters were developed, based on Goldmann's original principal. The most sophisticated, and with many variations of facilities for specific research purposes, was that devised at Tubingen, by Harms, (1960) in association with Oculus, (Tubingen) (Fig 8a & b), The Tubinger Perimeter.

Despite these developments time and skill were still required to undertake this type of investigation, and therefore visual fields tended to be examined when the clinician felt it necessary to do so, rather than as a routine.

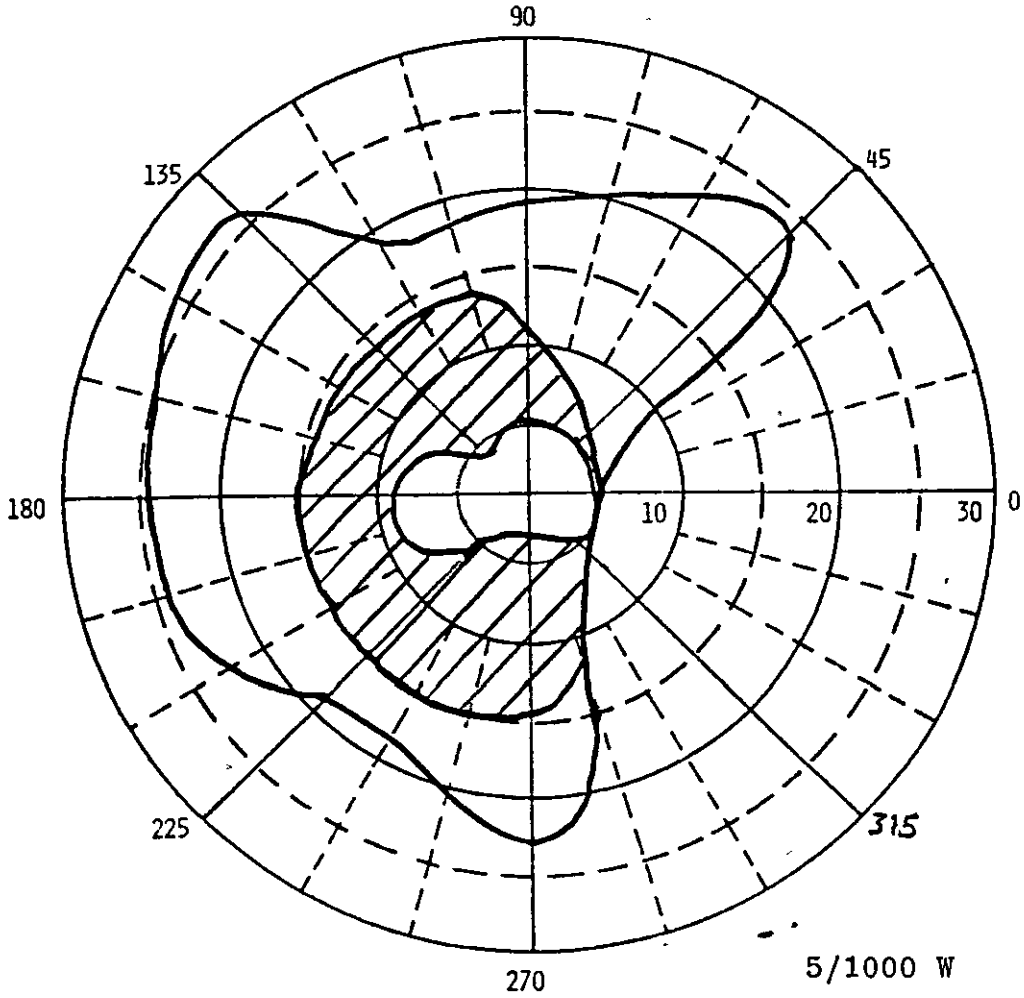

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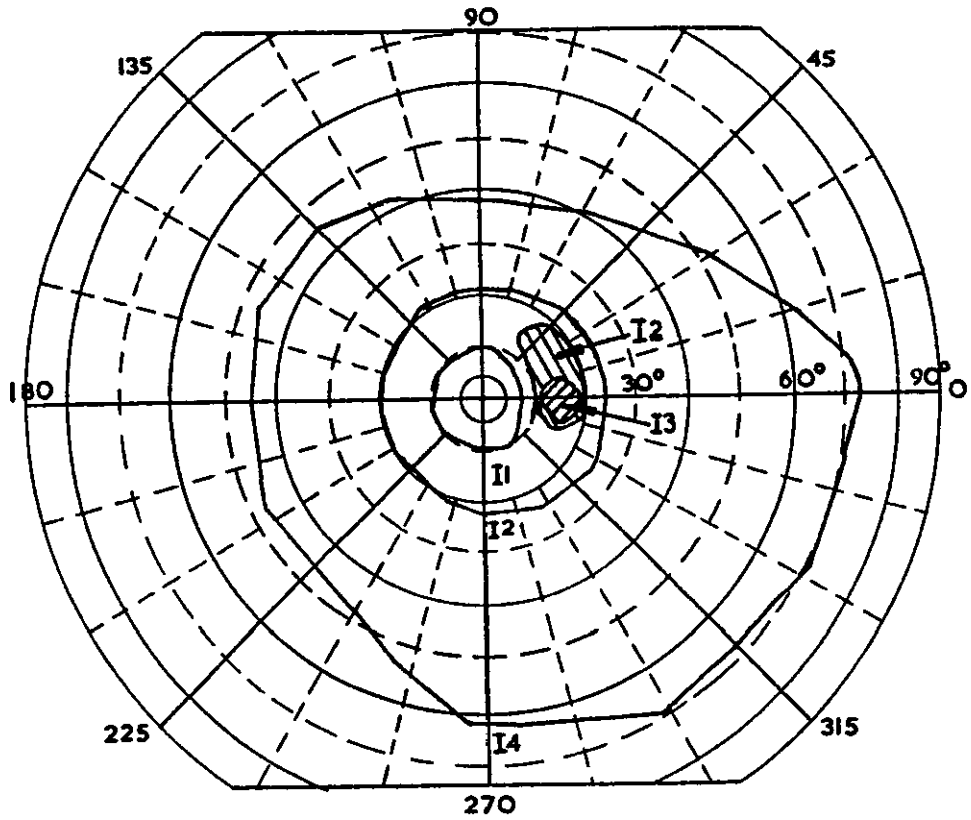
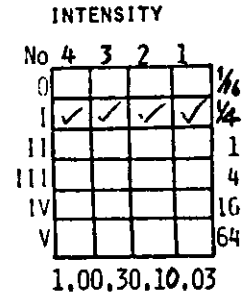
FIG. 9. Kinetic Visual Field Chart for glaucomatous visual field loss using the Bjerrum Screen.





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GOLDMANN PERIMETER.

FIG 10. Kinetic Visual Field Chart for glaucomatous visual field loss using the Goldmann Bowl Perimeter.

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IV

THE APPLICATION OF STATIC STIMULUS PRESENTATION TO VISUAL FIELD "SCREENING".

All the techniques and instruments discussed so far, involve a kinetic approach to visual field investigation, whereby the stimulus is introduced into the field of vision from where it cannot be seen, and moved, usually towards the fixation point, until it can be seen, and the limits of the field at that position then noted. Any position where the stimulus disappeared, would be recorded as vision being lost. When the whole field had been investigated along a number of radial, or meridional lines, the area over which vision was lost for that stimulus would be recorded as a scotoma. The shape and position of this area would then give a diagnostic indication of the likely pathology producing this reduction of vision. Typical kinetic visual field charts for field loss in glaucoma are shown using the Bjerrum screen, (Fig 9), and for the Goldmann bowl perimeter, (Fig 10).

Another approach to perimetry is to explore certain points of the field, one at a time, by using static quantitative perimetry. In this technique certain points are examined, usually along a meridian where there is a suspect depression, and the threshold of visibility, usually in terms of stimulus luminance, noted for these points.

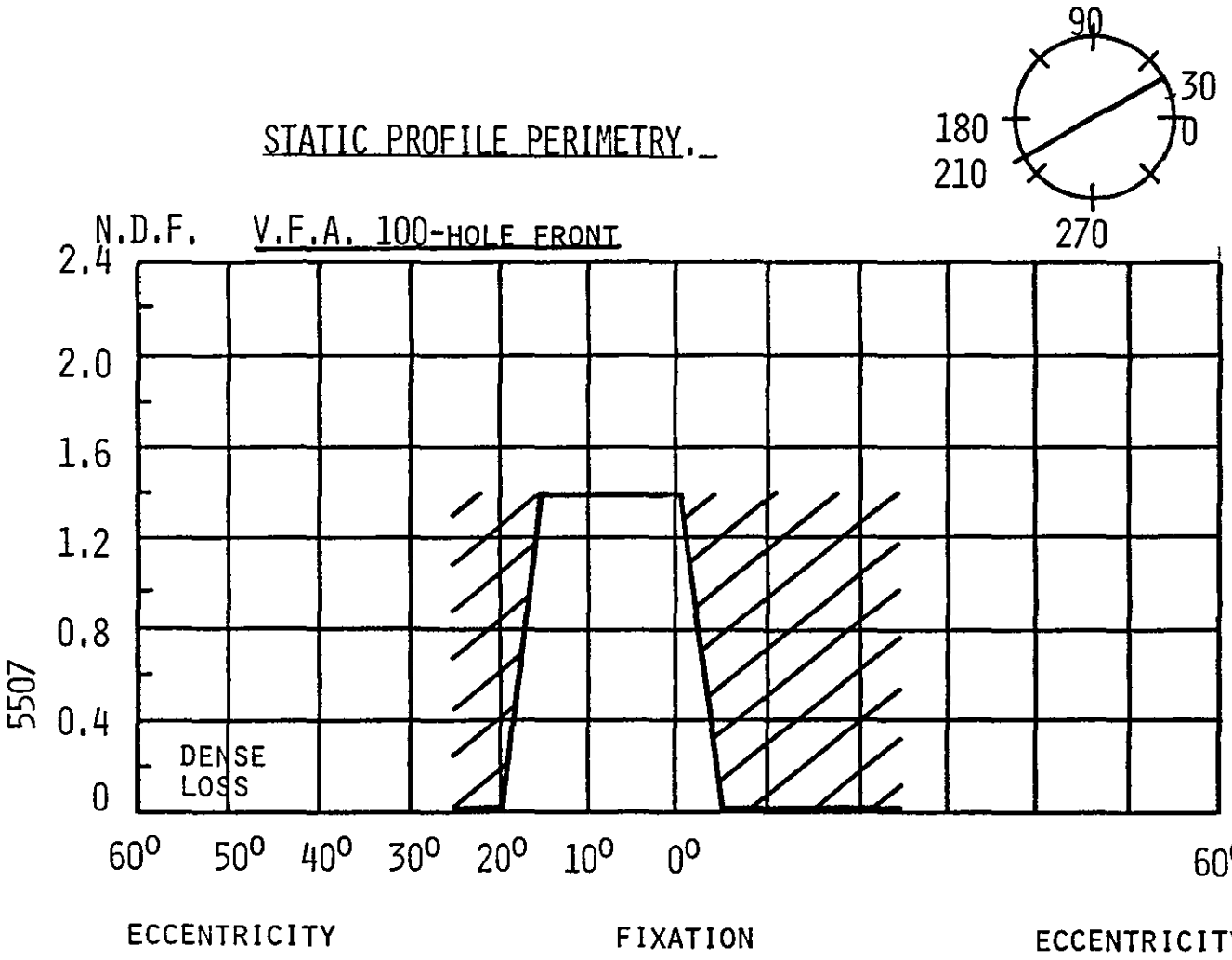


FIG 11. Illustration of sectional perimetry, where examination along a series of static points, to obtain threshold of visibility gave greater information on a local depression found by kinetic perimetry on a Goldmann Bowl Perimeter.

In later modifications of the Goldmann bowl perimeter and in such instruments as the Tubingen, single point static quantitative perimetry was made easier by using special attachments or built-in facilities. This method of static perimetry was, however, more time consuming than kinetic perimetry, and was mainly used to obtain additional local data about a visual field loss, and especially to give the gradient of a loss, as in sectional perimetry, (Fig 11). Although introduced by Sloan (1939), static perimetry largely received attention through the work of Harms (e.g. 1952,1954, 1969), and Harms and Aulhorn (1959). However, these more refined aspects of visual field investigation were only appreciated by the minority of practitioners, and perimetry in ordinary clinical practice was largely limited to simple kinetic methods.

The technique of static stimulus perimetry was a more suitable approach to screening for visual loss as it allowed investigation at various pre-determined points and selected areas. In consequence a number of visual field screening instruments were devised based on this principle. Unfortunately various very necessary physiological and photometric aspects, as will be discussed later,were not appreciated, and though praiseworthy, these early efforts were relatively crude in their approach, and likely to be unreliable clinically.

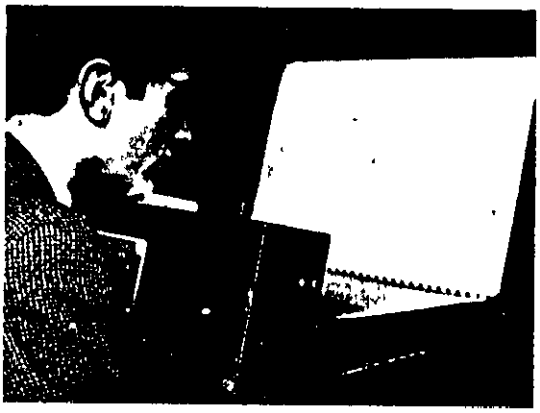


FIG 12. The Harrington-Flocks visual field screener.

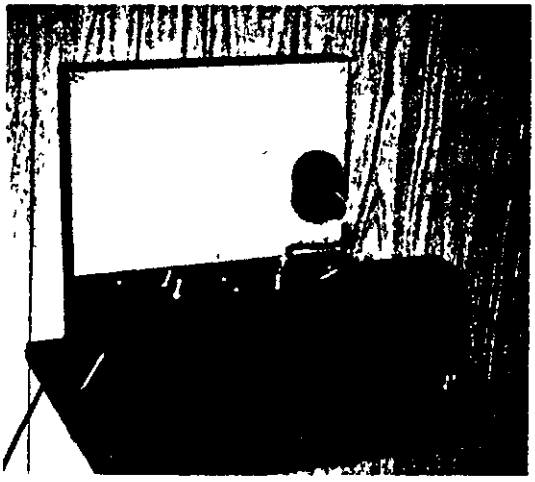


FIG 13. The Roberts visual field screener.

FIG 14. The Fincham-Sutcliffe visual field screener.

FIG 15. The Globuck visual field screener.

EARLY INSTRUMENTS FOR "SCREENING" THE VISUAL FIELDS.

Various aspects of instrumentation for visual field screening have been reviewed by the author, Bedwell (1967). The first visual field screener which was at all initially widely used, was the Harrington-Flocks (1954), (Fig 12). This instrument consisted of a series of ten test cards for each eye, made of white card, on each of which was printed, in fluorescent ink a series of patterns. These patterns were practically invisible under white light, but glowed green on exposure to long-wave ultra-violet light, this being provided by a flash of light of 0.25 seconds duration from a low pressure discharge tubular source with a U.V. filter surrounding it. There was no control over external illumination, and therefore of retinal light adaptation, or control of stimulus luminance,and individual patterns were relatively large. At that time, however, the instrument was a genuine attempt to encourage interest in visual field investigation, and to use the technique as part of a regular eye examination.

A different approach to the production of stimuli in a visual field screener was made by Roberts (1957), (Fig 13), though less widely used at the time than the Harrington-Flocks. In Roberts' instrument, a screen containing nine patterns of holes was used, each hole being illuminated from the rear by a small tungsten-filament lamp. The stimuli were relatively large, varying from 2mm to 7 mm in diameter. A multi-way switch was used to expose one pattern of stimuli at a time. Again no control of external

illumination or retinal adaptation was possible, though a crude control of stimulus luminance was possible by using a variable dimmer or rheostat. As will be discussed later a further disadvantage is that independent light sources, such as tungsten filament lamps, used as stimuli, allow far too much variation in individual stimulus luminance to be adequate for sensitive visual field investigations. The stimuli were exposed for 0.25 seconds.

A similar approach was employed in the Fincham-Sutcliffe instrument, Sutcliffe and Binstead (1961), (Fig 14). In this case a screen the size of the normal Bjerrum screen was used at one metre. The stimuli consisted of small translucent plugs subtending angles from between five to ten minutes at the eye according to position, with a tungsten filament lamp behind each. A series of eighteen patterns could be exposed, with up to four stimuli at a time, fifteen of which were common to both eyes, the stimuli being controlled by multi-way switches. The stimuli were exposed by a flash the duration of which could be varied from approximately one tenth to nine tenths of a second, and stimulus luminance could be arbitrarily adjusted by means of a variable rheostat. In use stimulus luminance was supposed to be set just above threshold, and if any loss was found, the visual fields could be examined in the usual kinetic manner. A small hand-held projector was provided for projecting the stimulus on to the grey surface of the screen. The Fincham-Sutcliffe visual field screener was undoubtedly an improvement on the

Harrington-Flocks, and the Roberts, but again suffered from the disadvantage that there was no control of ambient illumination and retinal adaptation. A far too wide a variation in stimulus luminance could result from using individual tungsten filament lamp sources. The control of the luminance of the multiple light stimuli by a single rheostat is inadequate because it is not individually quantitative. Again, however, it was a praiseworthy attempt to encourage more regular visual field investigation.

Another approach was the Globuck screener, (Fig 15), Buchannan & Gloster (1965), which was again a large screen for viewing at one metre, but in this case containing seventy-four apertures of 1 mm diameter, evenly spaced over the field, and each illuminated from behind by a small tungsten filament lamp. The luminance of each lamp could be pre-adjusted by using individual rheostats, in addition to overall arbitrary control of stimulus luminance by a main rheostat. By using relays, and a hundred-way uni-selector one stimulus was exposed at a time for 0.2 seconds, according to a pre-determined sequence. If the patient missed a flashed stimulus it's exposure was repeated, and if still not seen, the examiner pressed a button. This caused a small burn to be made on a scotoma chart in a spot corresponding to the position in the field, Areas in which stimuli were missed were subsequently examined on a Bjerrum screen.

V

A NEW APPROACH TO VISUAL FIELD SCREENING AND INVESTIGATION.

It can be gathered from the various aspects already considered, that there was a need to develop a method of visual field investigation which would both quickly and sensitively detect early loss in the visual field. The method should also be able to fully quantify any reduction of vision found, without subsequent resource to laborious classical techniques. Kinetic methods of visual field investigation are very variable in their adequacy according to the expertise of the investigator, and are not really suitable for detecting the more gradual gradients occurring across the mid-peripheral field of vision as compared with those found in the periphery. The early attempts at visual field screening were far too crude in their control of variables, photometric design, and allowance for physiological variations in perception, to be used for reliably detecting early visual loss.

Before considering the detailed design of any new instrument, it is essential to understand and to evaluate those factors which can be considered clinically as essential, and to decide what variables should be adequately controlled. It is desirable that the techniques of operating the instrument should have as little influence as possible on the recorded results, and that data obtained at different times should be readily comparable.

Methods for the clinical investigation of the visual field aim essentially at trying to assess whether there is any localised reduction, or loss, of visual function. The basis of a sound technique should be whether a stimulus, or stimuli, may be visually perceived at threshold at different positions over the visual field, when viewed against a certain background luminance. This threshold should be at just above what could be regarded as a normal physiological difference of contrast. If the luminance difference between background and stimulus is much higher than threshold, as it is so often in many approaches to visual field investigation, then only the grosser visual field losses will be detected, and the important early indications of pathology missed. The actual contrast required for perception for a given background luminance is influenced by the angle subtended by the stimulus at the eye, the luminance and duration of exposure of the stimulus, the shape of the stimulus, the position at which it falls on the retina, and the number and type of receptors that are stimulated. The degree of interconnection between neurones affecting summation is influenced by the adaptation of the eye, which can be influenced, not only by the background luminance of the screen or bowl and possibly the stimulus, but also by the luminance of any ambient light, for example, room lighting. The spectral quality of the stimulus light, as well as it's quantity is important, as this may influence the degree of the rod and/or cone stimulation.

The duration of exposure of the stimulus not only determines the total quantity of light incident on the eye, but can also affect the degree of summation that occurs. If the stimulus is moving, as in kinetic perimetry, the duration of exposure of the stimulus on any local retinal area will depend very much on the speed with which the individual investigator moves the stimulus. There is some advantage in limiting the duration of exposure of the stimulus to within that which will produce a variation of pupil size, and hence possibly a variation of retinal adaptation. The latter should be determined and controlled by the luminance of the adaptation field alone. The inability to hold steady central fixation can also introduce vagaries in the recorded data of differential threshold. With a constantly exposed stimulus, steady fixation is much more difficult, this difficulty decreasing as exposure time is reduced.

VI

VISUAL FIELD INVESTIGATION.

(A) The Application of Kinetic and Static Perimetry to Visual Field Investigation.

Visual field investigation, until recently, generally made use of a kinetic technique which records areas of visibility and of visual loss. Bair (1940), called this "topographic perimetry", since it furnished the shape of a field defect. However, with this method it is difficult to investigate field defects, where there is a relative or partial loss, without continually altering the size of the stimulus. Therefore, a technique facilitating the detection of relative defects was developed and designated "light-sense perimetry" by Sloan (1939. a,b,c). Bair (1940), suggested that this light-sense perimetry should be referred to as "quantitative perimetry", since it gave an indication of the density of the field defect. In the topographic technique, where only the stimulus size is altered, the visual field is represented by isopters, or contours of limits of the visibility of a certain size of stimulus, whereas in the quantitative technique, the field is represented in terms of the minimum luminance at which the stimulus can be seen. Harms (1950), distinguished between visual acuity perimetry, (which is a technique where stimulus size is altered,) and; light-sense perimetry, (in which thresholds of luminance sensitivity are determined).

There is now general agreement regarding the place of static and kinetic methods of perimetry, but prior to the 1950's there was some disagreement on the relative

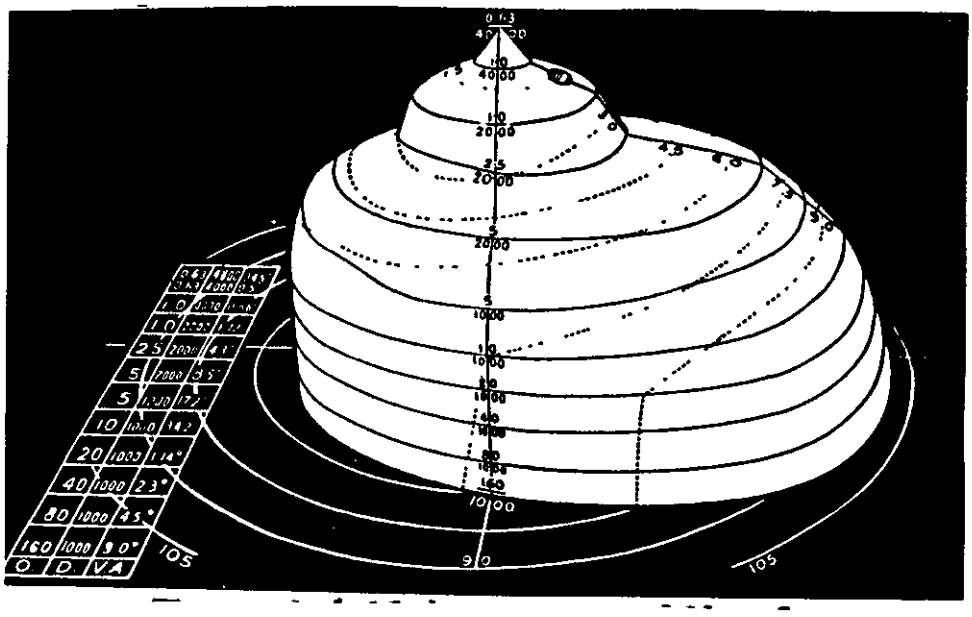


FIG 16. Traquair's "Island of Vision".

merits of the different techniques. Goldmann (1954 a) advocated using kinetic quantitative perimetry whereby a stimulus is exposed while it is being moved from the periphery to the centre of the visual field, until it is just perceived by the subject.

In kinetic perimetry the data is presented by means of isopters, or "islands of vision" Traquair (1927),(Fig 16). In static quantitative perimetry the differential sensitivity of adjacent localised points is determined, commonly along a meridian that shows a depression originally revealed by kinetic methods. This technique of profile perimetry, demonstrating variations in cross-sectional sensitivity, gives more clinical information regarding the condition, and the type of defect than is possible from a kinetic approach. This is very important when one is dealing with gradual gradients of changes in sensitivity, or very localised losses where isopter contour differences are less likely to give an adequate indication of abnormality.

During the period from about 1945, through to the early 1960's there was much active interest in visual field research, and it was understandable that there were some differences of approach and recommendations. Harms (1957) felt that results obtained from static and kinetic quantitative perimetry should not be used for direct comparison. In static perimetry a small group of retinal receptors is stimulated for a given period of time. The stimulus luminance is increased after each sub-threshold stimulation until the

stimulus is observed. In kinetic perimetry the stimulus is made to travel from a point in the periphery of the visual field towards the centre, producing a path of stimulated retinal receptors. The eventual threshold due to the effect of spatial summation and lateral inhibition is likely to have been produced in a very different manner from the threshold response in static perimetry. Results for the two methods will not therefore be comparable.

Aulhorn (1963) felt that neither topographic nor static perimetry in isolation, could produce sufficient information about scotomas in the visual field. Topographic perimetry could easily fail to detect a small scotoma, or to give information about possible changes of density occurring with time while the extent of the scotoma remains unaltered. Therefore a combination of the two methods was necessary to give the required information, especially in determining the effect of a certain course of treatment on the scotoma. Aulhorn's view was supported by Schmidt (1965), who showed by means of a photograph of a model, how the clinical data obtained from kinetic perimetry, and static perimetry, was complimentary.

Jayle (1960) defined "quantitative perimetry" as a method of exploring the visual field at certain levels of adaptation, and consequently, under different physiological conditions. In this technique of "static perimetry" the thresholds for points on the visual field are determined on patients at scotopic, mesopic, and photopic luminance levels, and compared with the physiological levels found

amongst normals. He also undertook kinetic perimetry, at different levels of adaptation, and found the effect of adaptation on the size of isopters for similar stimuli.

Sloan (1961) felt that static perimetry could give more precise data than the kinetic method. Threshold gradients with a very small slope are not desirable in kinetic perimetry, since slight changes in luminance of either stimulus or background, or minor fluctuations in retinal sensitivity, which are of no clinical significance, may result in marked variations in the limits of the field for a given stimulus. If such a gradient is steep, there will be a large differential sensitivity between adjacent retinal points, and it will not be difficult for a subject to recognise a threshold stimulus. If, however, the slope of the gradient is small there will be only a very small differential sensitivity between adjacent retinal points, and the subject will be more hesitant in making a decision. In addition the reaction time required by the subject to indicate the decision, and the reaction time of the operator, may cause the actual point of recording to be several degrees different from the point at which the stimulus was first noticed. Therefore, the speed of stimulus movement is an important factor in kinetic perimetry (Goldmann 1945 b Schmidt 1965). In static perimetry this complication does not arise, thus ensuring greater accuracy.

Harrington & Flocks, (1954, 1959), advocated the use of multiple-pattern stimuli as a better method of testing extra-foveal visual function, rather than conventional

perimetric methods, By this means it was possible to make use of the so-called "extinction phenomenon", Bender (1945 & 1952). In this approach, if two points on the visual field are stimulated simultaneously, one where visual response is felt to be normal, and the other where a depression of vision is suspected, simultaneous presentation of identical stimuli is supposed to enhance the likelihood of one being seen and the other missed, i.e. differential threshold contrast is increased. If this was so, it would be a very helpful method of indicating early visual field defects of a hemianopic or quadrantic nature, though at present there is a difference of clinical opinion as to the validity of this hypothesis.

Henderson (1955) emphasised that visual perception occurs at three successively higher levels; seeing, recognising, and comprehending what is seen. Seeing is essential for any test of visual function, and is involved in all the standard methods of visual field investigation. When using multiple patterns of stimuli recognition of the simultaneous presentation of 1, 2, 3 or 4 stimuli is necessary. Though identification of pattern shape is not involved, perception at a higher neural level than in ordinary perimetry may be occurring. From work undertaken by the author on the thresholds of perception of both single and multiple presented stimuli, it appears that there is no practical difference in the thresholds obtained. The need to recognise the number of stimuli presented in a multiple array does not therefore appear to alter the threshold compared to just seeing a single stimulus.

(B) Desirable conditions for Visual Field Investigation.

It is now necessary to summarise what has been recommended as desirable conditions under which visual fields should be investigated.

Goldmann (1945 a), who was one of the pioneer post-war workers on visual fields, stipulated that the following conditions should be observed for accurate perimetry;

1. Account must be taken of the level of adaptation.
2. The contrast between stimulus and background must remain constant while the background luminance should remain constant.

Where these conditions are fulfilled, he added that stimuli of different sizes may be quantitatively related. This facilitates a numerical indication of the sensitivity of each retinal point, when the visual field has been investigated with a number of stimuli. In this context he mentioned that a retinal point is characterised by different stimulus sizes needed to achieve threshold of visibility.

Harms (1950) was more specific when he laid down requirements for his idea of accurate and reliable quantitative perimetry:

1. The state of adaptation of the eye must be equal and constant for every point of the retina.
2. The stimulus should not alter the state of adaptation to any appreciable extent.
3. The background luminance (adaptation level) must be known: and
4. The stimulus luminance and size must be known.

The following section gives detailed consideration to the individual variables that are outlined above, for incorporation into the design of a new instrument.

(C) PHOTOMETRIC AND PHYSICAL CHARACTERISTICS OF THE STIMULUS FOR VISUAL FIELD INVESTIGATION.

(1) Background Luminance.

The luminance of the background determines retinal adaptation during the visual field investigation, and Bair (1940) seems to have been the first to have considered the importance of differential retinal sensitivity with respect to different levels of adaptation. He recommended a background luminance of 0.01 milli-lamberts for topographic investigations, since both rods and cones can be stimulated at this level, at approximately similar sensitivity. Goldmann (1945 b) mentioned that background luminance levels of practical value for kinetic perimetry varied between 1 to 6 milli-lamberts and his perimeter operated at levels between 4 and 4.5 milli-lamberts.

Cibis (1948) and Cibis and Muller (1948), investigated adaptation time for local stimulation. They felt that adequate control of stimulation may not be obtained as long as the general background could be affected by the stimulus, or from "side effects" derived from neighbouring areas not directly stimulated. It was therefore necessary that the whole of the visual field should be exposed to the same level of incident luminance , and that stimulus presentation should be so designed as to minimise any affect on this general adaptation. These recommendations would appear to have been taken into account

in the design of subsequent perimeters by Goldmann (1945 b), Harms (1950), and Jayle, Aubert & Vola (1961).

Considerable research has been undertaken by various workers regarding the changes in differential threshold of stimulus luminances for different sizes of stimulus, and for different levels of background luminance, and hence retinal adaptation. Both kinetic and static quantitative methods of perimetry have been used in these experiments. In the kinetic technique the stimulus is exposed constantly. In static perimetry the stimulus could be exposed constantly and luminance increased until just above threshold is reached, or controlled duration of exposure could be employed with stimulus luminance adjusted similarly.

For example, Sloan (1950), demonstrated the variation in the threshold gradients of the rods and the cones for a stimulus seen in different areas of the visual field in the dark-adapted eye, and the partially light-adapted eye. Harms (1952), showed that there was an increase in the sensitivity when the background luminance was reduced from 10 to 1 milli-lamberts. Marlow (1957), showed the value of examining the visual field under reduced illumination when detecting and investigating visual field defects in chronic simple glaucoma. Fankhauser and Schmidt (1960), investigated the effect on differential threshold for several sizes of stimulus at different background luminances. They found no significant differences in scatter for the different levels of adaptation used.

Jayle, Vola, Aubert, and Fantin, (1963), undertook an investigation to determine the physiological basis and the clinical significance of using various levels of adaptation in visual field investigation. They concluded that there was considerable advantage in using a mesopic level of adaptation to ensure a more or less linear sensitivity of examination across the field.

Since then further work has been undertaken on the effect of background luminance in relation to stimulus visibility, for short duration stimulus exposure, and on the relationship of variation of threshold to retinal physiology, Bedwell (1967, 1971, 1972, & 1974), Bedwell and Obstfeld (1972), and Obstfeld (1973). The conclusions from these studies are discussed in Section XII.

(2) Stimulus Duration.

In much of the earlier work on visual field research, the stimulus was constantly exposed during the investigation as kinetic perimetry was employed. In his work on quantitative static perimetry Harms (1950), took into account the significance of stimulus duration, and used a period of 0.5 to 0.75 seconds with an interval of two or three seconds between exposures. Harms (1952) suggested that the stimulus duration should never be more than one second, and that stimulus duration had no effect on the differential threshold when it is 0.1 second or longer. He, therefore, suggested standardising stimulus duration at 1 second, Harms (1957). Monjé (1954) said that a reduction in stimulus duration to 0.1 second does not change the sensitivity, adding that 0.04 second would probably be the most effective stimulus duration.

The rather long duration suggested by Harms (1957) for static perimetry would facilitate temporal summation, possibly even in cases of abnormally reduced neural activity. This might reduce the technique's sensitivity for revealing early defects. It would therefore, seem advisable to use a short stimulus duration with a 2 second interval. Jayle et al.(1965) used a stimulus duration of 1.33 sec.

Both Harrington and Flocks (1954), and Sutcliffe and Binstead (1962), employed a stimulus of 0.25 second duration in their multiple static stimuli instruments. They agreed that this was a sufficiently short duration for a clinical screening test, and added that shorter durations might be valuable. In the case of these instruments, however, as the light sources were operating from 50-cycle alternating current, a stimulus duration of less than 0.2 seconds produced problems, especially where simple electro-mechanical relays were used to provide the pulse, and the latter was not synchronised to the alternating current wave form. Because of these and other considerations discussed later, Friedmann (1966) and Bedwell (1967), used a much shorter stimulus duration of approximately 300 micro-seconds.

(3) Stimulus Size.

The earlier techniques of visual field investigation employed kinetic perimetry and simple painted round stimuli as targets, with arbitrarily chosen sizes of 1 mm.,2mm., 3mm., and 5 mm. etc. diameter. The classical "Hill of Vision" referred to by Traquair (1927) gave an island whose cross-sectional gradients gave a very sharp fall towards the periphery of the visual field, simply because the eye responds more to logarithmic changes of stimulus area than to linear changes. A much more gradual slope would have been found if the stimulus had been changed in equal intervals of the log of its area.

As the investigation of the visual fields may be undertaken at different distances, it is easier for purposes of comparison to give the angular subtense of the stimuli at the eye. Sloan (1939) used a stimulus of 1 degree, and Harms once used one of 1^{o} 40,' but later used a 10' stimulus Harms (1954), since the latter size is more sensitive in the detection of early defects. He also showed graphically the influence of stimulus size on the threshold luminance along the horizontal meridian, demonstrating that a stimulus subtending 1^{o} gave a much flatter response with eccentricity, than one subtending 10', largely because, in the former case, of the effects of summation.

Sloan (1961) determined the most suitable stimulus to be employed in static perimetry, using a modified Goldmann bowl perimeter at a background luminance of 3.16 milli-lamberts. From the isopters formed from records of responses obtained from one subject, she found that varying either the stimulus luminance or the stimulus size could be used to detect impaired sensitivity in any region. Along the horizontal meridian she found threshold luminances to increase regularly, from the centre to the periphery, for different stimulus sizes. The rate of increase was very gradual for the larger stimuli and decreased with increasing stimulus area. Gradients for the vertical and two oblique meridians showed similar results. Fankhauser and Schmidt (1960), showed the mean values of differential threshold for several stimulus sizes at different background luminances. No relationship was found between stimulus size and eccentricity, though in the outer periphery scatter proved to be greater for some cases. Matsuo et al. (1965) investigated static perimetry and found that for small stimuli to be seen at a static point stimulus size and luminance should both vary logarithmically but higher thresholds were obtained with increasing eccentricity, as in kinetic perimetry.

(4) Stimulus Luminance.

In static quantitative perimetry, if stimulus duration, stimulus size, and background luminance are controlled, the stimulus luminance required to provide threshold visibility for given points in the visual field can be found.

Sloan (1961) found the stimulus luminance increased with eccentricity, for different stimulus sizes. The rate of increase was more marked with decreasing stimulus area. Jayle et al. (1965) found an almost logarithmic increase in stimulus area for logarithmic changes in stimulus luminance with increasing eccentricity. Matsuo et al. (1965) came to a similar conclusion.

From previous investigations Cibis (1947), Harms (1952), Fankhauser and Schmidt (1960), it is clear that the ambient illumination should remain constant, and that a more or less arbitrary adjustment of the stimulus luminance with respect to the background luminance is not accurate enough for an instrument designed to provide a reliable indication of early reduction of vision in the visual field

Bedwell in section XII confirmed the need for a constant ambient illumination, and constant state of retinal adaptation. Differential threshold contrast for different sizes and retinal locations of a stimulus is influenced by background luminance and it's effect on

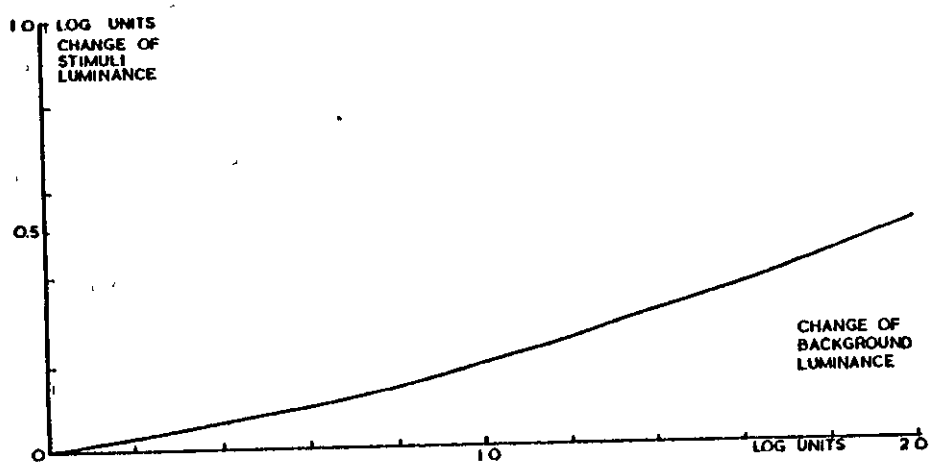


FIG 17.

The average gradient for change of stimulus luminance with change in retinal adaptation for a short-duration stimulus subtending 12', BEDWELL (1972).

summation. The average gradient for change of stimulus luminance with change in retinal adaptation for a short duration of exposure of stimulus subtending 12' is shown in Fig 17.

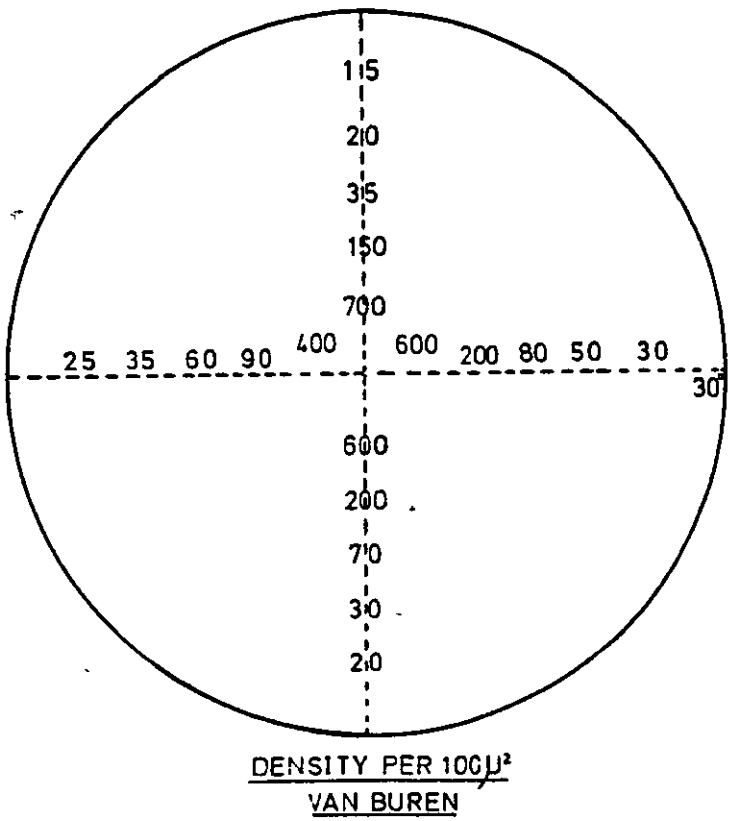
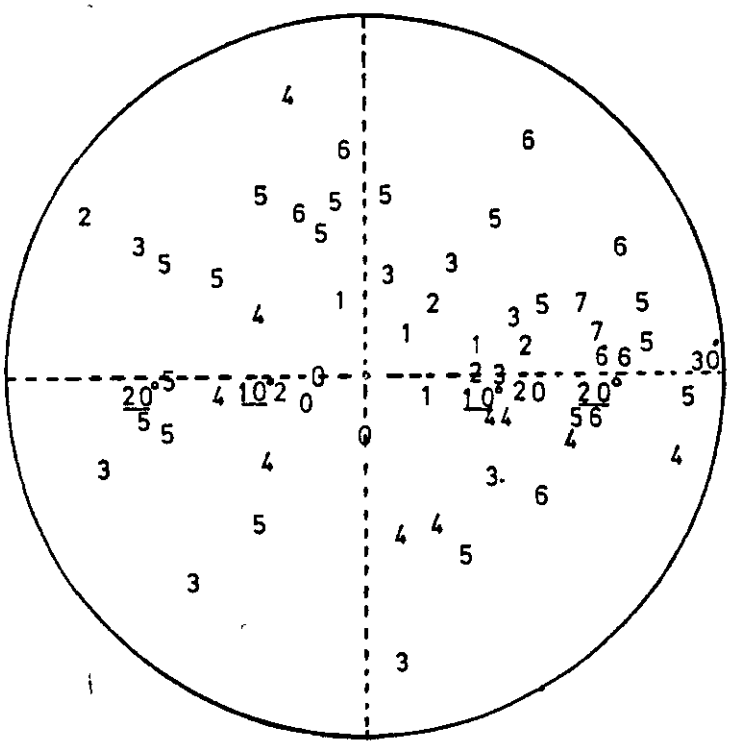


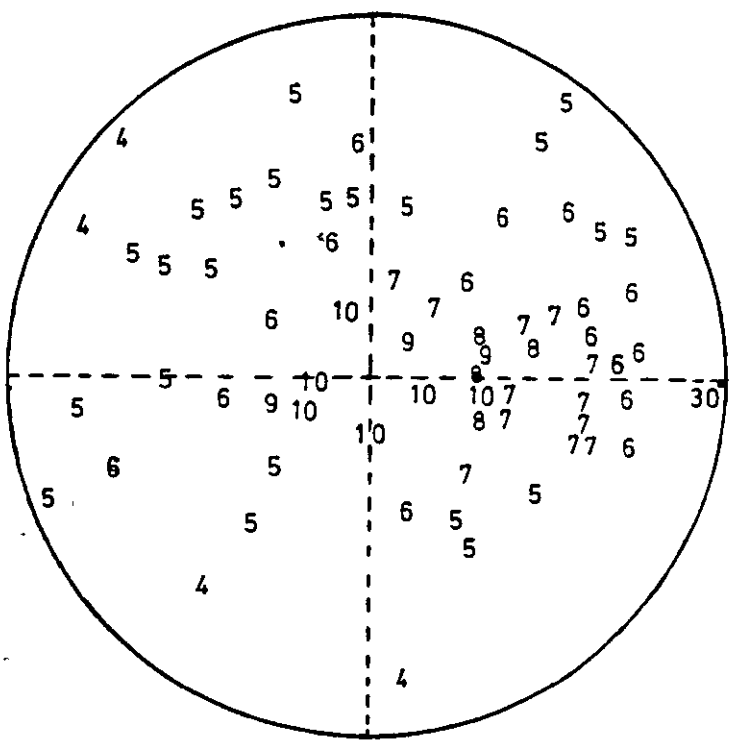
FIG 20. Ganglion cell population after Van Buren.



0 — TO 105000
1 - TO 115000
2 — 125000
3— 135000
4 — 145000
5- 155000
6 — 165000
7-OVER165000

AFTER ØSTERBERG

FIG 18. Rod population after Østerberg.



4— TO 4500
5— TO 5500
6— 6500
7- 7500
8— 8500
9— 9500
10-OVER 9500

AFTER ØSTERBERG

FIG 19. Cone population after Østerberg.

(D) PHYSIOLOGICAL FACTORS RELATED TO RETINAL SENSITIVITY.

(1) The distribution of rods, cones, and retinal ganglion cells.

The type and density of retinal receptor varies over the retinal area, and hence over the visual field. In addition, there is an inter-connection between receptors, particularly the rods, by a system of nerve cells, so that visual detection can be optimum under any given conditions. This mechanism operates through summation of sub-threshold stimuli. It is therefore necessary, when considering methods of visual field investigation, to take into account retinal physiology, so that adequate allowance can be made for these summation effects which may be influenced by various factors.

Østerberg (1935) investigated the rod and cone population distribution (Fig 18 & 19) over the human retina. He suggested that his distribution data could prove to be of interest when they were related to physiological phenomena. For example, there might be a connection between the ring-shaped zone of densest rod population, and the ring-shaped zone of maximum perception in the dark-adapted eye; or between the difference in cone distribution in the nasal and temporal quadrant, and the difference in colour perception in the two parts of the field. Van Buren (1963), (Fig 20), showed the histiological picture of the general distribution of ganglion cells over the retina, and Oppel (1967), showed their distribution for each point along the horizontal meridian, in the human eye.

Comparing this data one notices great differences in the distribution levels of density of the rods, cones, and ganglion cells over the retinal area. Oppel (1967) encountered the greatest density of rods at $5\frac{1}{2}^{o}$ nasally and 4^{o} temporally. This was followed by a steep drop to a low level, which then gradually decreased further with increasing eccentricity. However, a considerable increase was found at $21\frac{1}{2}^{o}$ nasally, and $29\frac{1}{2}^{o}$ temporally. This is the area of about densest rod population found by Østerberg (1935).

Glaser (1967) wrote that it was interesting to see from Østerberg's (1935) observation that the rod and cone population diminishes less per unit area in the upper nasal quadrant as the periphery is approached. Also of note was that Van Buren (1963) demonstrated an ovoid pattern of ganglion cells skewed nasally. Both these findings have functional counter-parts in the visual field. Work by Bedwell and Obstfeld (1972), also confirmed this correlation between retinal physiology and visual field isopters.

(2) <u>The sensitivity of the receptor population</u>.

Sloan (1939 c) reported a large central scotoma, and a ring of highest sensitivity, at about 10^{o} from the fovea in the normal, dark-adapted eye. This finding was confirmed by Bair (1940).

Cibis and Muller (1948) reported having encountered an area of equal sensitivity for faint stimuli situated as an annulus around the fovea, and extending to 10^{o} to 15^{o} outwards. They used a perimeter arc luminance of 0.224 milli-lamberts. The area indicated by Sloan (1939 c), Bair (1940), and Cibis and Muller (1948), where there is heightened visual sensitivity, coincides with the area of densest rod population of Østerberg (1935).

The idea that rods would function "only in the dark" is now considered to be incorrect, Mandelbaum and Sloan, (1947), Brooke (1951). It is known that the rods are mainly responsible for vision below 0.01 milli-lamberts, and cones for vision at higher luminance. Photopic vision shows some activity at luminances as low as 0.00014 milli-lamberts, though at these luminances scotopic vision is dominant. There is no active division between rod and cone functioning, Lythgoe (1940). Mandelbaum and Sloan (1947), came to the conclusion that there are sufficient rods present at 4^{o} and 5^{o} eccentric, to dominate discrimination at background luminances up to 0.1 milli-lamberts. They concluded from their investigation that the foveal light threshold of the cones, as well as the threshold for para-central and peripheral cones, occurs at a luminance of approximately 0.0004 milli-lamberts. At 25^{o} to 30^{o} eccentric the contribution made by cones to visual acuity would seem to be so poor that they fail to exceed the efficiency of rods, at a background luminance of 1 milli-lambert.

Sloan (1950) concluded from her investigations using a background luminance of 0.7 milli-lamberts with a 1^{o} white stimulus on the Ferree-Rand perimeter, that there is no simple relationship between rod density and rod threshold. She suggested that light-adapted rods might be a third type of retinal receptor. When the eye was adapted to a luminance used in clinical studies, the threshold of the hypothesised rods would differ only slightly from that of cones. No evidence for this suggestion has been forthcoming.

Mandelbaum and Nelson (1960) found an "equal contribution" by rods and cones at a background luminance of 1 milli-lambert, but at 10 milli-lamberts cones were clearly dominant. Blackwell and Moldauer (1958) found that the visual field is relatively homogenous in sensitivity at a background luminance of about 0.008 milli-lamberts and that this is in close agreement with similar findings by Bair (1940), and Jayle (1960).

Data obtained by these workers and the author, (e.g. Figs 52 a and b) from investigations of visual fields near the photopic/mesopic border of adaptation, does appear to give a flatter gradient of receptor sensitivity with eccentricity, than the higher photopic values of adaptation that have tended to be used in the past.

(3) Variation of retinal sensitivity with age.

It has long been realised that beyond middle-age, higher levels of illumination are necessary to ensure a somewhat similar visual performance to that of a younger age. It is generally assummed that the reason for this is largely due to reductions in transmission of the optical media of the eye, and possibly to an average smaller pupil size effectively reducing the entrance pupil to the eye, like a camera. Transmission loss is the sole cause of the higher threshold of luminance required with increasing age may be too simple a solution, because, though the transmission of signals along the visual pathway is based on the "all or none" system, it may well be that there are other factors due to an aging process that may be producing transmission losses.

Until the advent of the more sophisticated type of bowl perimeter introduced by Goldmann, a single arbitrary allowance of a slightly larger target was the only provision that was made for the effect of age on vision during a visual field investigation. From his investigations Goldmann (1945 a) concluded that the mean value of the differential sensitivity for subjects between the ages of 60 and 70 was only half that of subjects of 20 to 30 years of age, in the periphery of the field. Jayle (1960) found that for normal subjects of age 20, an isopter could vary in position by 2.5^{o}, and for older subjects by more than 2.5^{o}, from the standard isopter.

(4) The effects of refractive error and a spectacle correction in visual field investigations.

If the image of the stimulus used for the visual field investigation is blurred, the differences of contrast across the retinal image will not be the same as a sharp image, and the threshold for perception may not be similar. For example, though the blurred image may be larger than the original sharp image, because of diffraction and other effects, the gradients of luminance across the image will be very different from that of the sharp image. In consequence the retinal receptor system may only be able to be stimulated effectively by a much smaller area of the blurred image on the retina than if the image had been sharp, and it may require a higher threshold luminance for perception. To avoid significantly affecting the threshold for a stimulus response when examining the mid-peripheral fields of vision, an appropriate refractive correction for viewing distance employed should be worn. When the peripheral fields are being investigated vision will now be outside that area covered by a spectacle lens, the refractive error will be different, and the examination will have to be done without a spectacle correction. In this case, however, there may not be quite so much disadvantage as larger targets have to be used, because of the lower acuity in the periphery. Sharp imagery is not so important an aspect in the functioning of the peripheral retina in everyday life, and possibly not so much allowance need be made for it when investigating peripheral vision.

Harms (1950) and Sloan (1961) showed the specific effect of a refractive error on threshold measurements in static perimetry. The main effect is that a significant increase in luminance is required to attain threshold visibility, with a very marked increase required over the central 10^{o} area containing the fovea. When considering the effect of refractive error, it must be remembered that the correction is usually made to provide maximum foveal visual acuity, and that for oblique rays of incidence to the visual axis, there is likely to be an appreciable increase of hyperopia. For example, Ferree and Rand (1935), found that 0.50 D of hyperopia at 10^{o} eccentric, and therefore possibly of minor significance here, could well increase to 2.00 D of hyperopia at 30^{o} eccentric.

The possible refractive effect produced by a spectacle frame, or deeply-set orbit in relation to an over-hanging upper orbit margin, a protruding nose, or a drooping upper lid, can naturally affect any visual field investigation, particularly the peripheral field. Even for the mid-peripheral or central field of vision care needs to be taken that spectacle frames, or anatomical features, are not giving artifically restricted limits. If they do cause restrictions they must be displaced, or suitable postural adjustments made.

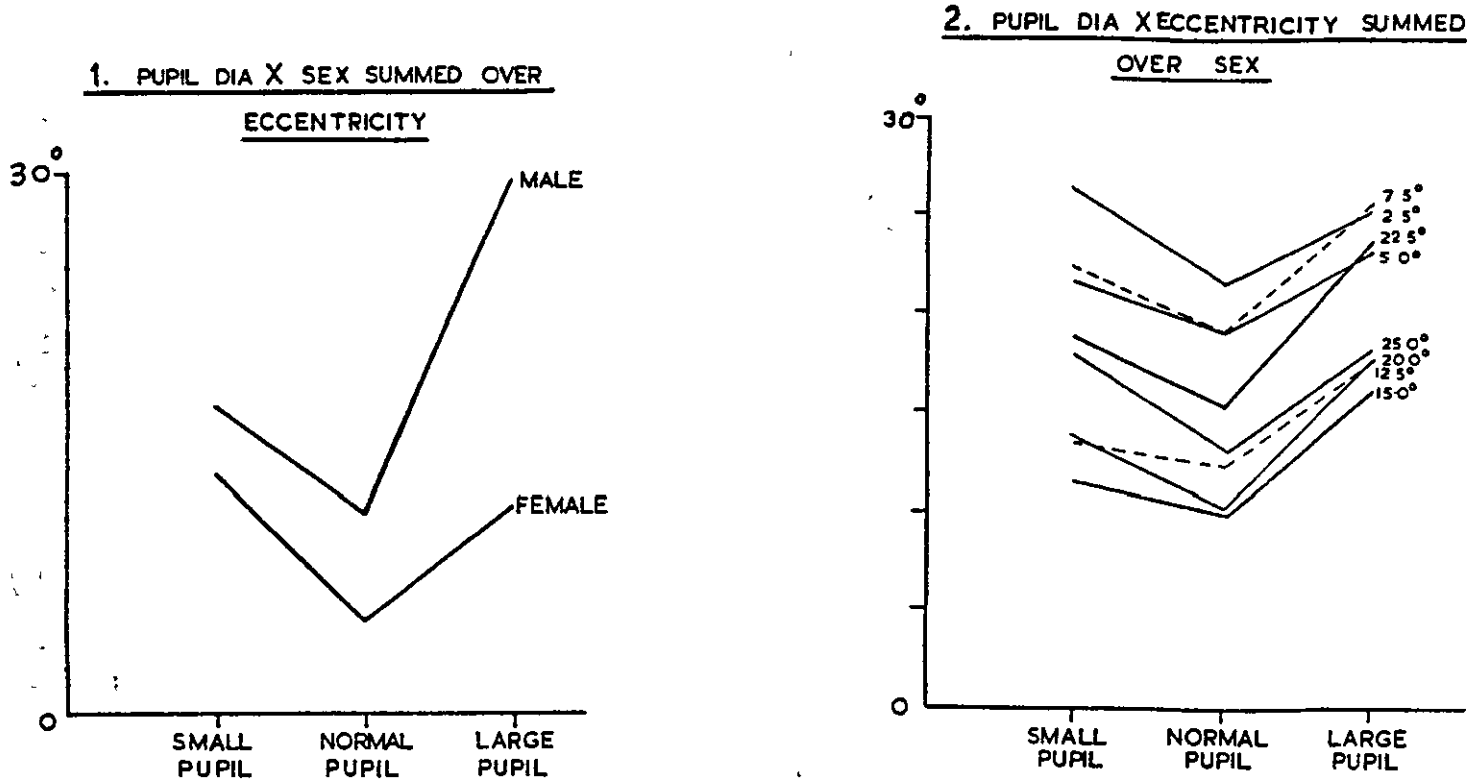


FIG 21. Threshold contrast and pupil size.

(5) The Effect of Pupil Size on Visual Field Investigation.

Ferree and Rand, and Sloan, (1934), Engel (1942), Dubois -Poulsen (1952), and Aspinall (1967) found that changes in pupil diameter between 2 and 6 mm diameter tend to have a negligible effect on visual field threshold. Bedwell and Davies (1976), found that there was an approximate maximum variation of 0.14 NDF units in threshold for changes in pupil size between approximately 3.5 mm to 0.5 mm diameter, and that therefore, these changes could be accepted as being within normal limits. They found however, that in the case of the dilated pupil with young males there is a lower threshold than for females with a dilated pupil. Therefore, under certain circumstances, when the very earliest indications of visual field reductions are being sought, it may be pertinent to take the effects of pupil size into consideration. (Fig 21).

(NDF units = Neutral Density Filter units)

(6) Miscellaneous Factors Affecting Visual Field Investigation.

As well as the various main factors discussed already, there are some extraneous factors which should be considered as being relevant to visual field investigation, particularly when working near the threshold of perception.

Weinstein and Arnulf (1946), found that the physical state of the subject played an important role, and in some cases produced a larger scatter of results. Examples of these particular states are the ingestion of alcohol and effects of fatigue

The allowance of adequate time for the subject to become adapted to the ambient illumination used in a visual field investigation can be significant, and is shortened if the room illumination is dimmed prior to sitting in front of the instrument. It is also important to note if the subject is reliable and whether he or she is familiar with the particular type of visual field investigation technique. In static quantitative perimetry the author has found that less allowance need be made for "a learning factor" if stimuli near the fixation point are examined first rather than the stimuli in the periphery. Certain subjects, too, are more indefinite regarding any decision that they may make. The form and manner in which even simple questioning requiring a decision are posed can also be significant and a consistent approach should be maintained.

In general it is easier for both the patient and the investigator if visual fields can be examined under quiet conditions as extraneous noises can be distracting, and produce an unnecessary scatter of results.

VII

FACTORS TO BE CONSIDERED IN THE DEVELOPMENT OF A NEW TECHNIQUE FOR INVESTIGATION OF THE VISUAL FIELDS.

(A) Viewing Distance.

Assuming that the essential aspects of stimulus design have been correctly specified, there are other aspects also to consider in relation to viewing distance, in addition to the latter's effect on angular subtense of the stimulus. It is important that the average observer can see a reasonably sharp image of the exposed stimulus, otherwise blur circles will be imaged on the retina. The effect of blurring of the stimulus image is to increase differential threshold contrast, and this effect should be minimised.

Another aspect is that the closer the working distance of the eye from the stimulus, the smaller are the tolerances of the viewing position to avoid an out-of-focus image. For the individual stimulus to be seen at a desired obliquity the eye should be directly in front of the central fixation target. A different eye position alters the effective solid angle of the stimulus at the eye. If it is necessary to view the stimulus through a small aperture, a tunnelling effect will be introduced, depending on the plate thickness and this effect will both alter the effective area and the solid angle of the stimuli presented to the eye.

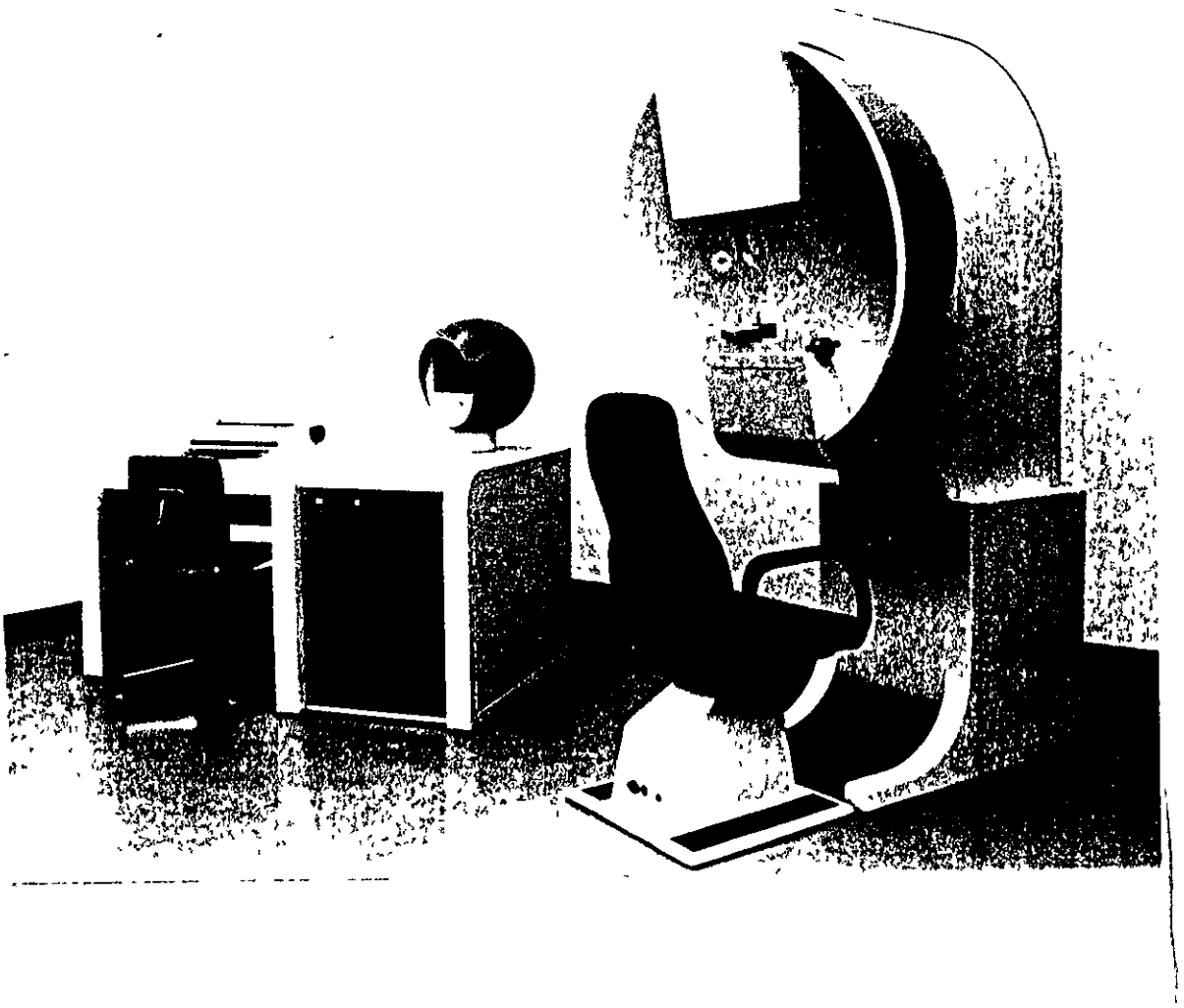


FIG. 22. The Octopus automated Bowl Perimeter.

The most important age group of patients who may have visual defects, where such conditions as simple chronic glaucoma need to be looked for, are those in the 40+ age group. Unless the patient is suitably myopic at this age, reading spectacles are necessary. If an examination can be undertaken within the working distance for which reading glasses are usually prescribed, the patient has a readily available optical correction for seeing thestimuli sharply at $^{1}/_{3}$ metre. For the younger patient, the stimuli placed at this distance can readily be seen by accommodating. If much shorter working distances than a $^{1}/_{3}$ metre are used, special correcting lenses are necessary to view the stimuli. Problems of aberrations are then introduced which tend to degrade the optical image, particularly of the more peripheral stimuli.

With modern bowl perimeters one third of a metre has been largely accepted as the most useful standard viewing distance. This ensures a reasonable sensitivity of examination without requiring an excessively large instrument. Only recently developed large computer-controlled automated perimeters, such as Octopus, (Fig 22) described by Spahar, Bebie, Fankhauser, (1977) is a 50 cm viewing distance used.

In the case of a new instrument for investigating the visual fields a working distance of a third of a metre was regarded as a sensible choice affording a compact and yet readily useable and accurate method of perimetry.

This approach allowed ready compatability with investigations on a standard bowl perimeter. A compact design makes for easier use with standard single and multiple instrument tables, and with adjustable arms on refractor columns; transport is also easier.

(B) Adaptation Level.

There is some difference of opinion regarding the most desirable level of adaptation at which to investigate visual fields. Classically, they have been investigated under the level of photopic illumination that would have been provided in a clinic originally using gas lamps, and then incandescent electric lamps. For example, Traquair (1927), recommended about 70 lux falling on a black screen, which assuming a reflection factor of about 10%, would have given a background luminance and adaptation level of approximately 7 milli-lamberts. In the case of the Goldmann bowl perimeter, which is coated with a high-reflection matt white surface inside, a higher reflected luminance to the eye of approximately 3.15 milli-lamberts, is recommended.

It is important to realise that because of their distribution, even in the mid-peripheral field, the differential threshold contrast for rod receptors is really being examined rather than that of cone receptors. The rods are mainly responsible for vision below .01 milli-lamberts, although photopic vision is active down to 0.0001 milli-lamberts, even if scotopic vision is dominant in this range. At a certain somewhat ill-defined range of adaptation around these values of photopic/scotopic vision there is a band, the mesopic range, where the cones and rods are approximately equally active. Different workers give a somewhat different

value of luminance to allow working in the region of the scotopic/photopic border, but Yves le Grand (1957) suggests that this is about 1.2 milli-lamberts.

If the visual fields are examined hear the mesopic range, a flatter sensitivity gradient can be obtained with eccentricity. The investigation of rod receptor threshold is then likely to be more adequate, particularly in conditions such as simple chronic glaucoma, where rod receptors are especially likely to be involved. The investigation of different thresholds when the normal gradient is approximately flat, makes it easier to determine when there are abnormal variations from the gradient.

In everyday clinical practice the ambient illumination is likely to be around the mid-to-low photopic range, probably of the order of 50 to 100 lux, as most ophthalmic examinations have to be undertaken in rooms with the blinds drawn, and in artificial illumination. The use of fluorescent discharge lighting, when such sources are used in clinical areas, has tended to increase these values. Like most aspects of clinical examination, visual field investigation has to be undertaken under pressure of time, As a good ten minutes or more is required to adapt to the mesopic state, investigation of the visual fields under this level takes a longer time. By working near the photopic/mesopic border, the time for adaptation can be reduced, and yet a reasonable overall sensitivity of examination of the mid-peripheral field obtained.

In the final design it was decided to standardise on a level of 10 lux falling on the black screen containing the stimuli apertures, so that with a reflectance factor of 8%, this would allow an adaptation level of approximately 0.8 milli-lamberts at the eye, near the mesopic/photopic border.

Threshold contrast difference varies with adaptation level, so it is important that having once decided on a certain level of adaptation it should be kept, and not be affected by extraneous ambient lighting. As will be discussed later, a method was devised for providing a constant and even adaptation field, with sufficient light spill from the illuminator to enable the investigator to work without extraneous illumination.

(C) Choice of Stimulus Light Source.

The significant contribution of Mr Friedmann's idea of providing all the stimuli from one fixed plate, and a rotating rear shutter plate, was that one source of illumination could be used. There are three main types of light sources readily available, tungsten filament lamps, fluorescent discharge lamps, and electronic discharge tubes, (normally Xenon arc).

Tungsten light sources have the advantage that they are inexpensive, and require minimum electrical control gear. They suffer, however, from the disadvantage of a limited life and also darkening of the lens envelope, unless they are of the halogen type. Only a small proportion of the electrical power input to the lamp is radiated as visible light energy, the rest being radiated as heat. There is the very considerable disadvantage with tungsten lamps that changes of light output occur with small changes in voltage resulting in about a 4% change in light output from a 1% change in voltage. If a compact source is chosen, such as is necessary for adequate optical control, the tungsten lamp, possessing considerable thermal lag cannot be turned quickly on and off with a sharp wave form to the light pulse peak. If, therefore, a tungsten filament lamp is to be used, it must be left on all the time the instrument is in use, causing problems of reduced life, and the need to eliminate heat. An electro-mechanically

operated shutter mechanism is then required to provide a pulsed light source.

If fluorescent discharge lamps are to be considered, these of necessity have to be large, making optical control more difficult. They can be flashed or pulsed but this is undesirable in the normal low mains-voltage type usually used, as the consequent electrode bombardment would considerably shorten the life. The type of phosphors normally employed tend to have a fairly long time constant to provide non-fluctuating illumination from the normal 50 cycle mains supply. Pulsed flashes could be more readily obtained from a high voltage cold-cathode type of tube, but here again, the problem of lamp size makes optical control more difficult. Furthermore when a patient is in physical contact with an instrument in which supplies of several thousand volts are required, safety is of paramount importance, and additional design and cost considerations are imposed.

The final alternative was the Xenon discharge source, of which there are two main types. One produces a high intensity flash of very short duration and is operated by a power supply of several thousand volts from a paper dielectric capacitor. The other type is the low voltage Xenon tube, having a somewhat longer flash duration and powered at some 300 to 500 volts from a compact electrolytic capacitor, as commonly used in electronic flash guns for photography.

These small electronic flash tubes are compact, making optical control much easier, and they possess a very long life. As they are in operation only when a pulse of light is required, there is little problem from heat dissipation, and the reasonably low operating voltage reduces the problem of electrical safety.

These electronic discharge tubes have the advantage that the light output is very similar to daylight in spectral quality.

Another major asset is that output varies only according to half the square of the applied voltage, producing far less problems from mains voltage fluctuations than would occur with tungsten filament lamps. For mobile use, operation from a small battery-fed supply would be quite feasible. It was, therefore, decided to standardise on a small Xenon discharge lamp for the new instrument. Some under-running of a Xenon lamp to prolong life produces very little change in colour quality of the light emitted, compared to even small changes of applied voltage on the emission from tungsten lamps.

(D) The Stimulus.

For given duration of exposure a stimulus can be made visible against its background by using various combinations of luminance and solid angle. In classical perimetry the stimulus is exposed constantly, and to improve the sensitivity of investigation a white stimulus of 1 mm. diameter viewed at 1 metre was commonly used, i.e. subtending approximately 5 minutes at the eye. Visibility of stimuli of this small size is significantly influenced by variations of uncorrected refractive error, and the effect of aberrations of the eye's optical system in oblique viewing. Blurred margins to the retinal image are produced, with a smaller bright centre which influences the differential threshold contrast between background and stimulus.

Too small a stimulus tends not to be seen when it's image falls on a retinal blood vessel as in the case of angioscotoma. Too large a stimulus may bridge a small field defect.

It is generally felt that pathological conditions producing visual field changes, particularly involving the retina, may affect summation co-efficients. A stimulus that is too small does not allow sufficient of the retinal area to be investigated to detect the effect of summation anomalies. Also, too large a stimulus tends to make investigation of the effect of these anomalies more difficult.

When stimuli are viewed through apertures, the effect of diffraction increases as the apertures become smaller, tending to degrade image quality.

There has been some difference of opinion regarding preferred stimulus size, but an angular subtense of between 10 to 15 minutes at the eye, or 1.4 mm diameter at 33 cms, appears to be a reasonable compromise. In terms of letter chart acuity, this would be equivalent to a vision of between 6/12 to 6/18, and would make some allowances for the deviations from normal visual acuity commonly encountered in everyday clinical practice.

(E) Determination of Stimuli Positions and Combinations.

The greater number of stimuli that can be exposed at any instant, the larger the area of the visual field that can be examined in a given time. However, there is a limit to the normal span of comprehension which is possible when a subject is asked to assess a number of multiple stimuli in a visual display. Though many observers could perceive, say five stimuli, it is sensible to limit the number of stimuli that can be exposed at any one time to not more than four, to avoid visual overloading. Where possible the number and positions of the stimuli should be varied to minimise the effect of guessing, which can be fairly easily detected as a random response by the investigator who possesses a little experience.

The effect of variations in fixation on the perception of stimuli is less when stimuli are flashed, than it is in kinetic perimetry, when central fixation has to be maintained for a long time.

The choice by Friedmann of the various positions for the stimuli had to be determined largely by an appreciation of the areas in the visual field where defects were most likely to be expected and of the characteristics of the defects likely to occur in each case. This meant that a careful survey had to be undertaken of the type and incidence of visual field defects found both from personal clinical experience and

in the published work by others using the results of the then existing techniques of visual field examination. For example, glaucoma is a common condition demonstrating at an early stage small areas of loss in the field represented by the arcuate nerve fibre bundles above and below fixation, 10 to 20° eccentric from the fovea. Harms and Aulhorn (1958), and subsequently Aulhorn and Harms (1967), found that on analysing some fifteen hundred glaucoma early field defects, about 50% of the defects occurred in this arcuate area, and approximately half of these arcuate defects were initially isolated from the blind spot. In view of the greater density of rod receptors in this area, and therefore the greater the visual sensitivity, careful specification of stimuli is necessary to ensure that visual field defects in this area are detected.

Changes of visual threshold contrast on either side of the vertical mid-line of the retinal fixation area are particularly important in revealing lesions beyond the retina, for example, hemianopic and quadranopic field defects. When employing multiple pattern stimuli it is possible to make use of the so called "phenomenon of extinction", whereby any possible difference of threshold contrast existing between adjacent areas in the visual field is intensified if stimuli are simultaneously exposed on an area of retina with normal response, and on an adjacent area where there may be reduced sensitivity.

In some cases the toxic effect of certain systemic drugs causes reduction in vision around the macula area, and between the macula area and the disc, and therefore, it is necessary to ensure that stimuli are placed to cover these areas.

In addition to these specialised areas which must receive attention, a reasonable number of stimuli should be applied to the mid-peripheral field to give general coverage.

A number of physiological factors have to be allowed for in determining the positions of the stimuli. Precautions should be taken against slight differences of size and position of the physiological blind spot, and also against any slight displacement caused by any small variations in central fixation. By carefully placing the stimuli so that they are just outside the average area covered by the blind spot, the incidence of false positives is reduced. Enlargement of the blind spot, as an early indication of visual field loss in glaucoma, is now discounted, and for this purpose there is no need to place stimuli critically near the blind spot margin. Also it is possible to have difficulty during visual field investigation in the region of the projection of the arcuate nerve fibre bundles, (due to angioscotoma), because of the presence of retinal blood vessels in this region. When a stimulus falls over one of these vessels on the retina it may not be seen. This effect can be minimised by the

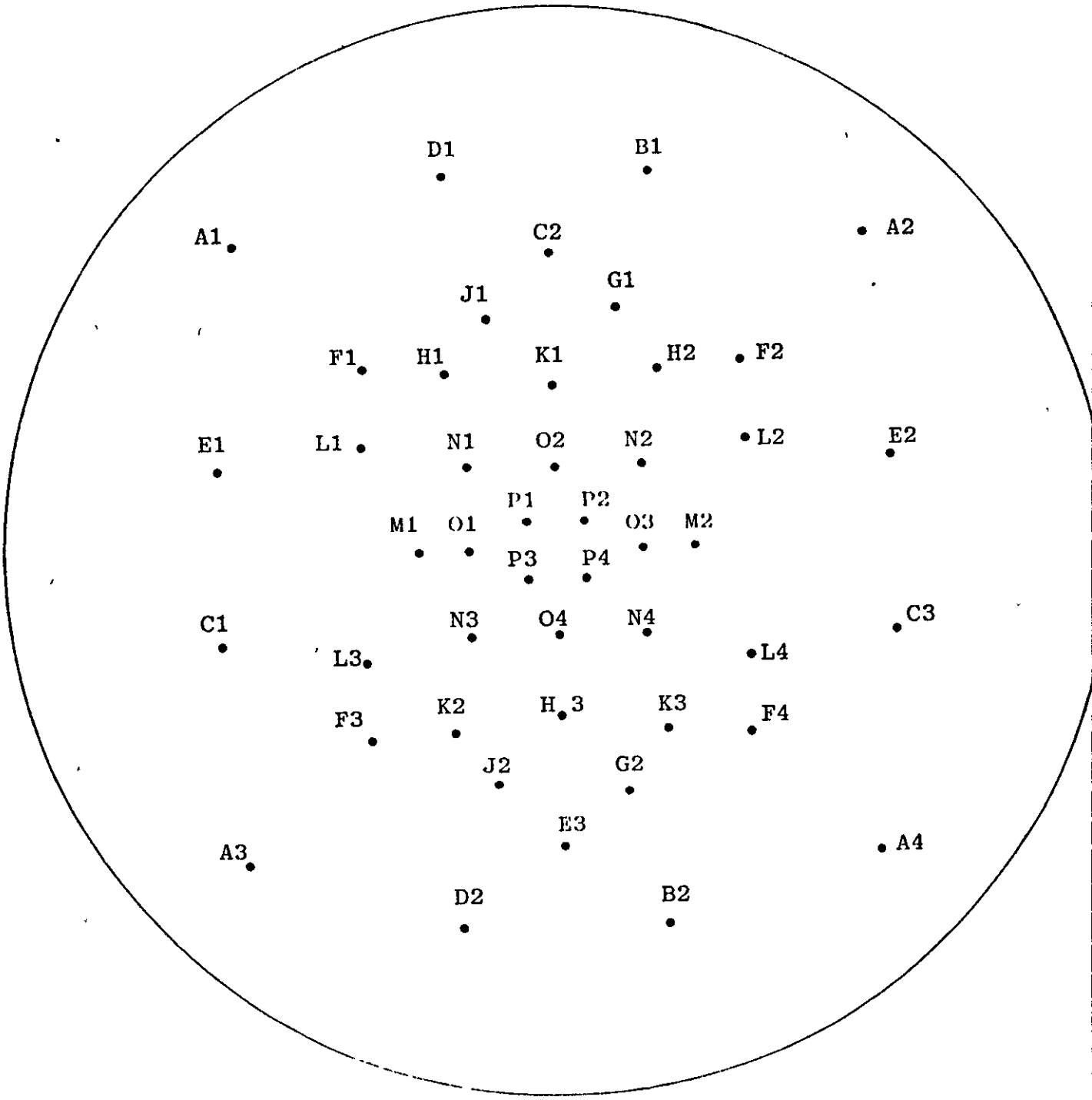


FIG 24. Composite diagram showing all stimuli positions used in the 46-hole front.

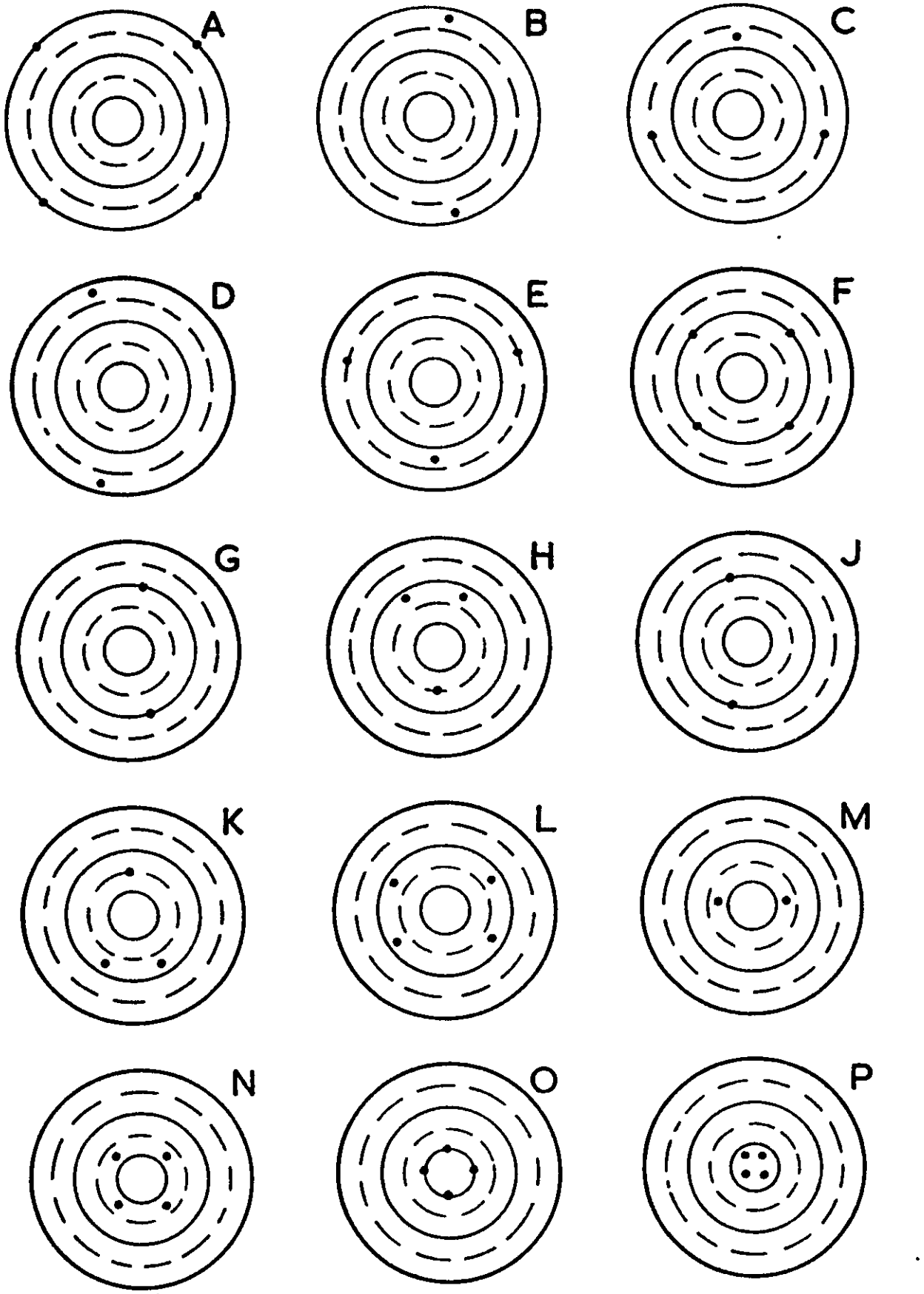


FIG 23. The 15 individual patterns of stimuli on the 46-hole front of the Visual Field Analyser.

choice of suitable sizes of stimuli, and also by reasonable distribution of their positions. Provision is made to readily isolate such a situation by making a slight change of fixation position, when the stimulus will be seen normally. When determining stimulus positions and sizes, it is also important to allow for the shape of the projected area on the visual field from retinal nerve fibre bundles.

To avoid the complexity of two different sets of stimuli for right and left eye, and to obviate the necessity of separate charts, the stimuli positions were very carefully chosen so that one series of patterns could be used for either eye.

The disposition of the individual patterns of stimuli finally decided upon for the 46-hole front are shown in Fig 23, making 15 sets of stimuli to be exposed in sequence. The stimuli arranged as a composite diagram are shown in Fig 24.

(F) Assessment of Foveal and Macula Light Function.

It is common in clinical practice to find differences in visual acuity which cannot always be accounted for by fundus anomalies, differences in refractive error, or known history of amblyopia exanopsia. Therefore, incorporated into this new instrument is a method for assessing foveal and macula area light sensitivity, to determine whether any differences of visual acuity are due to a suppression amblyopia, or to a defect somewhere along the visual pathway, which would be demonstrated as a reduction of local light threshold.

(G) Control of Threshold by Variation of Stimulus Luminance.

Clinical investigation and interpretation is made easier if any loss detected can be in terms of degree of one variable. It was felt desirable that not only should the state of adaptation be kept constant, but that the stimulus luminance should be uniform over the mid-peripheral field being examined, so that variations in retinal sensitivity could be allowed for by differences in stimuli sizes. Once an average physiological threshold had been obtained over the retinal area, for that level of adaptation, by using appropriate stimuli sizes the overall variable to be adjusted could be that of stimulus luminance. The shape of any area where there was loss would indicate the type of pathological condition. The luminance of the

stimulus required to achieve visibility, unless vision is completely absent, would give the localised density of that loss.

No adequate data was available on visibility of these short-duration stimuli so it was decided to obtain the required data in two main phases.

The first phase established, by fairly simple experimental means, the variation in size of stimuli required to achieve differential threshold contrast for different areas of the retina. Stimuli of angular subtense of 11 minutes were used as the initial starting point, with a particular level of adaptation.

The second phase, was to institute a more basic and long-term research programme on the visibility of this type of short duration stimulus for different sizes of stimulus for different levels of adaptation.

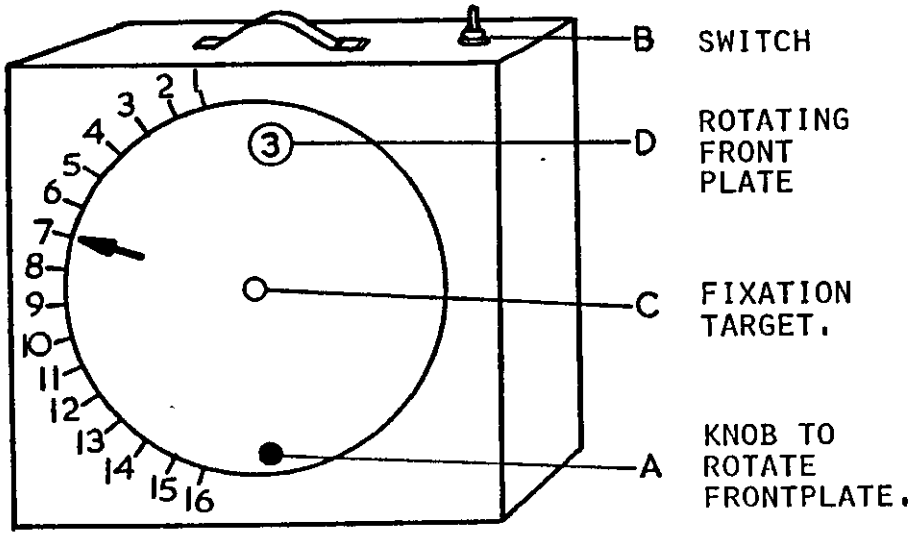


FIG 25. Early design of Visual Field Analyser before joint development.

VIII

INSTRUMENTAL DESIGN AND DEVELOPMENT.

The development of a safe and viable clinical instrument from a basic idea usually involves difficult design problems, much experimental research, and the production of a series of gradually improved proto-types. The difficulties are increased when, in the case of visual field investigation, it is necessary to differentiate effectively and efficiently between normal variations in differential threshold contrast response, and the beginnings of an abnormal response indicative of pathology.

In the case of the Visual Field Analyser before joint development, the original device for displaying multiple stimuli from a rotating shutter plate assembly, took the form of a simple box,(Fig 25,)coated white inside, with light from a flash-tube source entering at the bottom. With this arrangement there was a considerable variation in stimuli luminances over the front plate. There was also a variation in the solid angle of the apertures contained in the front plate when viewing them obliquely from the line of sight. In addition this effect was increased by "tunnelling" due to the finite thickness of the plate.

In the new instrument all the multiple stimuli are illuminated from a single source, are exposed by means of the shutter-plate assembly, and need to be presented to the eye near the threshold of visibility

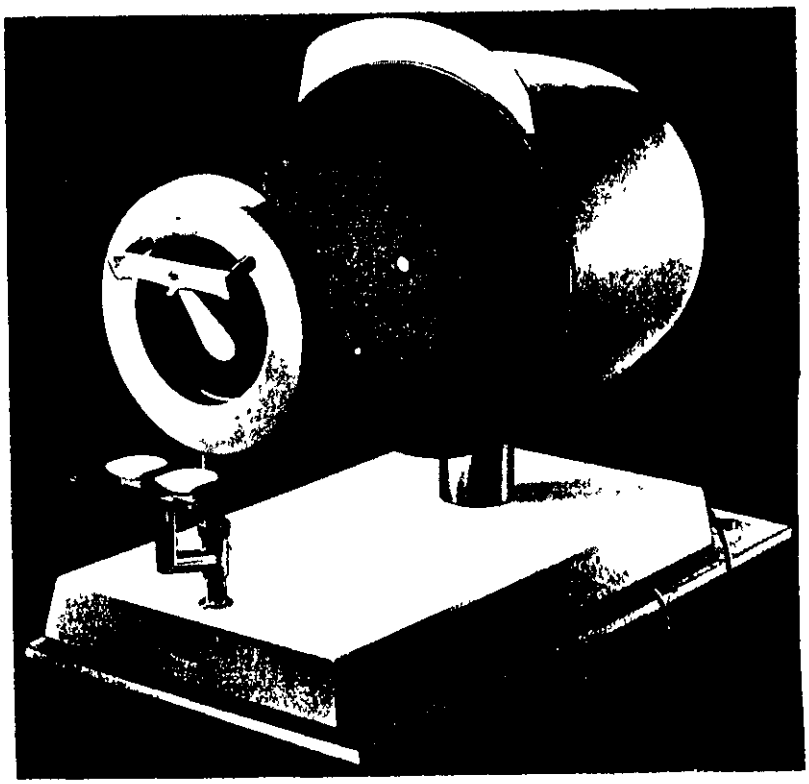


FIG 28. Early production model of the Visual Field Analyser.

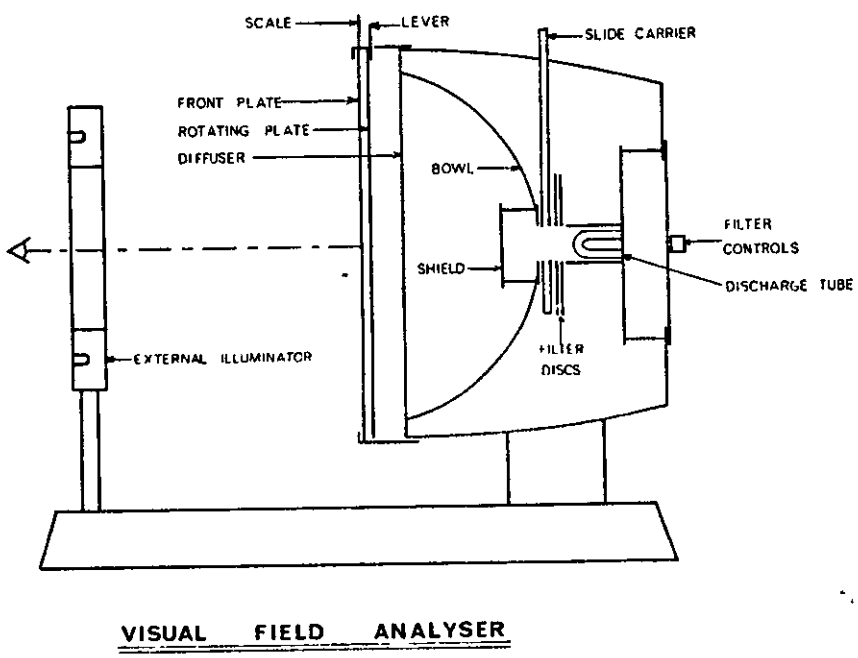


FIG 29 Cross-section of design of early production model of the Visual Field Analyser.

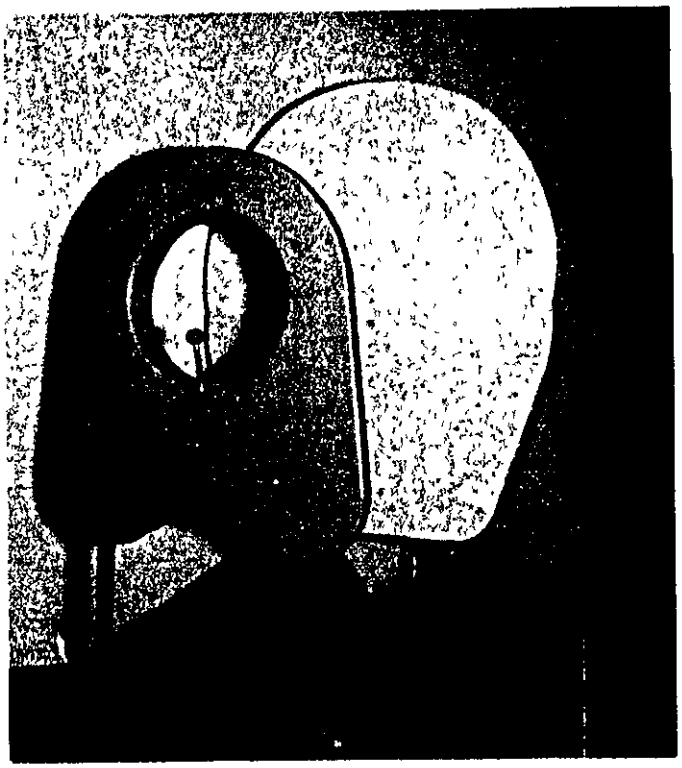


FIG 26 Early prototype Visual Field Analyser.

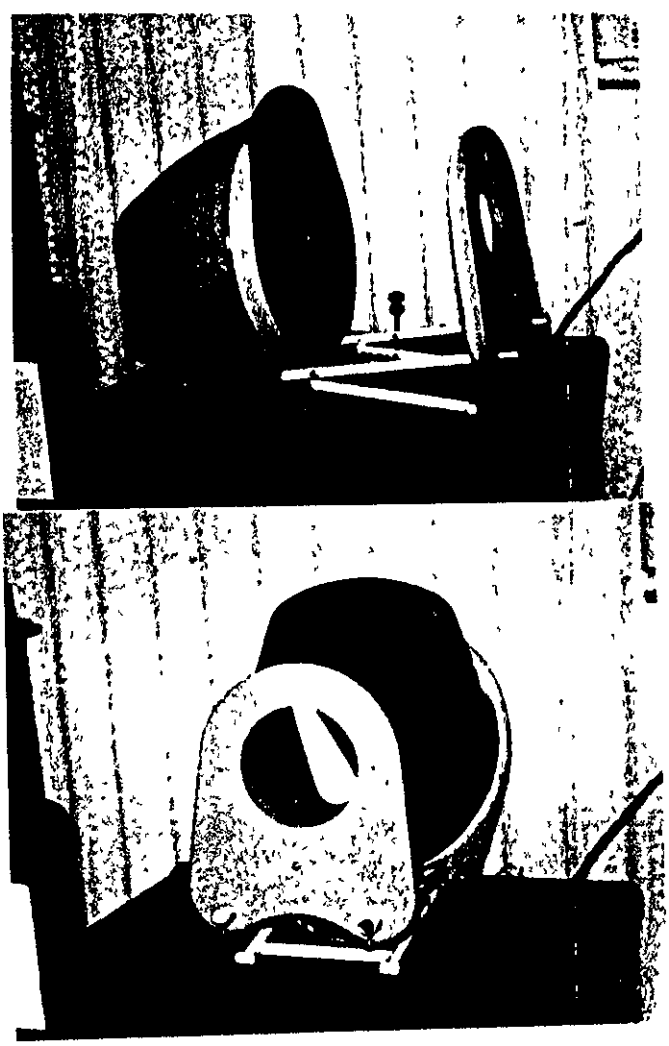


FIG 27. Later prototype Visual Field Analyser.

for the level of adaptation specified. Stimuli luminance should be under variable quantitative control to allow for both individual general variations of threshold contrast, and for an abnormally low visual response.

It was also necessary to provide, preferably from the instrument itself, control of light adaptation so that the investigation could always be undertaken at the same level, in this case near the photopic/mesopic border.

To achieve these requirements the various aspects of instrumental design and development that followed will now be considered in detail. Two of the earlier proto-types involved in this process are illustrated in Fig.26 & 27. Originally it was proposed to construct the instrument from a small number of inter-fitting plastic vacuum formings to minimise production costs, as will be seen from the last two illustrations. Later, to give greater rigidity and flexibility of design, a glass-fibre construction was used for the main casing. An early production model is shown in Fig.28, with a cross-section view in Fig 29, illustrating the principle aspects of the internal physical design.

In this instrument an equal luminance for all stimuli was provided by using a hemispherical bowl integrator. Then, to achieve a similar visual threshold over the area covered by the stimuli, a pre-adjustment was made of stimulus size, to give an averaged response. Neutral density filters were used to vary the light intensity from a constant Xenon source. A ring illuminator was used to provide controlled adaptation.

(A) The Provision of a Constant Stimulus Luminance.

A number of methods for producing a similar luminance over the mid-peripheral field to be covered by the front plate assembly were considered. For reasons mentioned previously a 33 cm viewing distance from the eye to the front-plate assembly was to be used. This meant that an even luminance had to be provided from a single source over an area, of which the diameter is approximately 35 cm.

The decision was made, after experimenting with a number of different methods, to use an integrating bowl hemisphere, coated white inside, with an aperture at the rear for entry of the light from the source, and to cover the open diameter of the bowl with an opal translucent diffusing plastic sheet. By correctly positioning a white shield in front of the aperture at the rear of the bowl,

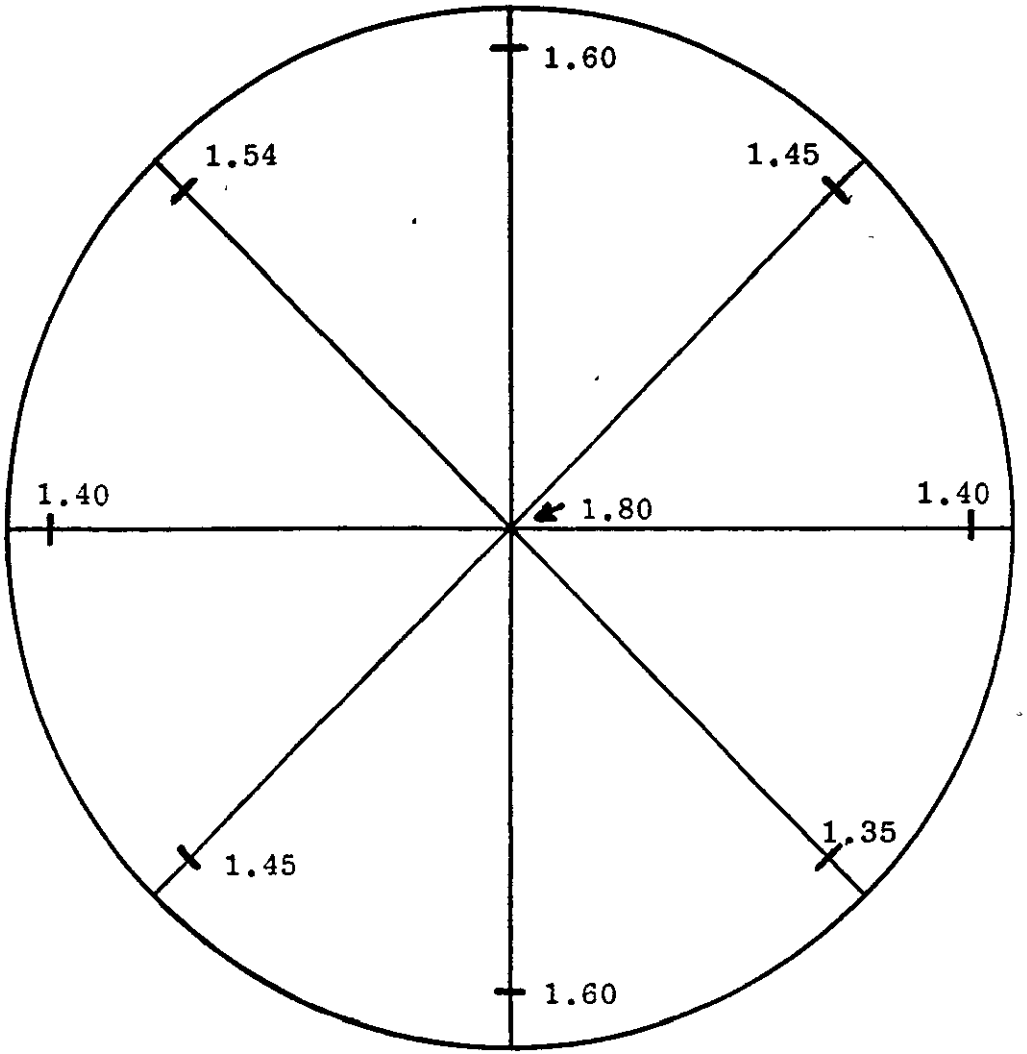


FIG 30. Initial photometric measurement across the diffuser of the bowl integrator using a constantly exposed source entering the bowl measured with a selenium-cell photometer in lumen/sq.ft.

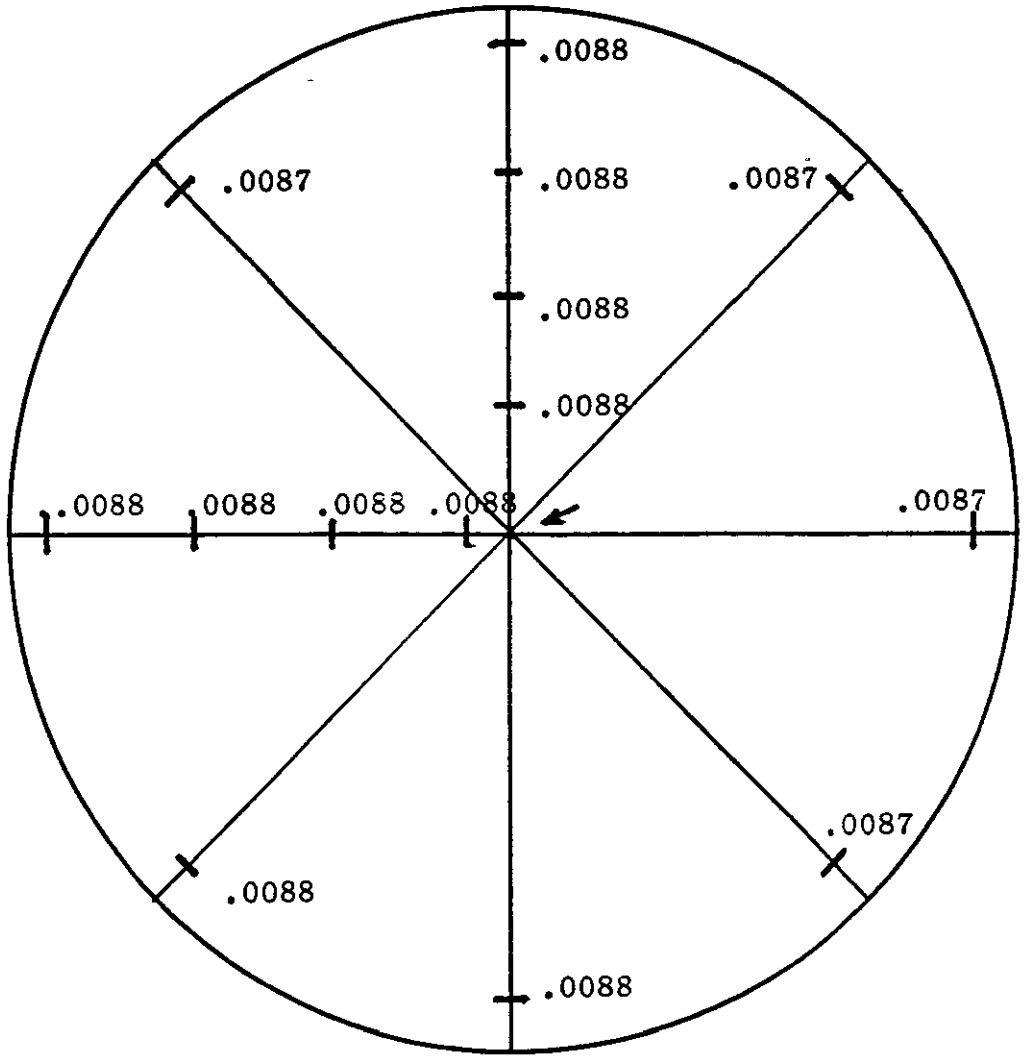


FIG 31. Photometric measurement of relative light output at the eye taken across the diffuser of the bowl integrator measured with an integrating spot photometer in lumen/secs.

direct incident light on the front diffuser surface of the bowl was prevented, and maximum light integration made possible. By carefully designing the position and site of the shield in front of the light source, it was possible to produce an even illumination across the bowl diffuser surface. In early tests a constant emmitting tungsten source was projected through the rear of the bowl so that initial trials could be undertaken. Photometric measurements were made over the diffuser surface to check the design, Fig 30. These early results obtained indicated a maximum decrease in luminance from centre to periphery of about 22%. Further modifications were then made in the shield design to minimise this decrease of luminance to within 5%

At this period, in early 1965, there was not the same availability of photometers as there is now for working with flashed-light sources. Using, however, an American micro-spot photometer, employing a photo-multiplier tube and integrator, and placed at the position that would be occupied by a subject's eye using the analyser, the light output difference over the front surface of the diffuser was observed, using a flashed Xenon discharge lamp as the source. The differences were found to be between 0.085 to 0.081 lumen/sec, i.e. approximately 5% flux difference, Fig 31.

This relatively small change resulted in only a slight increase of luminance from the centre to the periphery.

A satisfactory photometric design for the bowl integrator having been achieved, it was then necessary to consider how the luminous input into the rear of the bowl integrator should be controlled. To provide sufficient facilities for clinical investigation of both the mid-peripheral field, and the dark-adaptation function, it was desirable that the luminance of the front diffuser of the bowl integrator should be variable over a range of 5.0 log units.

(B) VARIABLE CONTROL OF LAMP LUMINANCE.

(1) Limitations of Electrical Methods.

The output in Joules of a small low-voltage electronic discharge source such as the U-shaped F A 10 tube, operated near maximum, varies approximately as $J = \frac{1}{2} CV^2$ (where C is the capacitance in farads of the storage capacitor used, and V is the applied voltage to the capacitor). The nominal light output is about 40 lumens per watt for a normal rated input of 100 joules, reducing to approximately $5\sqrt{J}$ for a lower energy input. The output of the tube may be changed by varying the capacitance value, but this is difficult when a large change in output is required. The output may also be varied by reducing the applied voltage but inconsistancies in tube firing occur at low voltages.

As it is necessary to think in terms of a logarithmic response of the eye to luminance changes, a minimum variation of 2.3 log units would be expected, which would require a change of capacitor value from approximately 20 micro-farads to 200 micro-farads. At these very low levels of capacitance there is a difference in the spectral quality of light output; there is considerable variation in shape of the light output curve in relation to time; operation of the tube is unstable, and it is also very difficult to find a suitable range of lower-value capacitors for this type of discharge application.

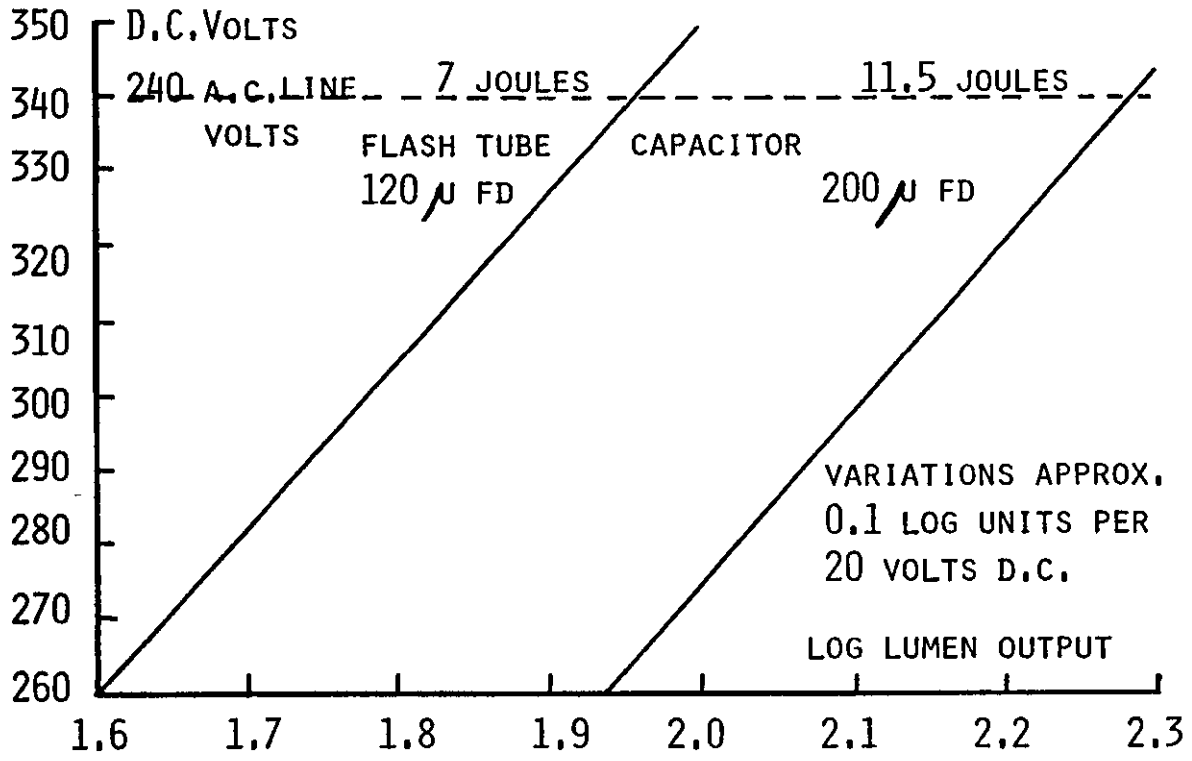


FIG 32. Luminous output for variations in voltage for 120 μFD and 200 μFD electrolytic capacitors.

Capacitors for electronic discharge lamps have to be specially constructed to handle high discharge currents and stresses, compared with the normal capacitor used in electronic smoothing and de-coupling circuits. An electrical method of controlling light output over such a wide range was therefore felt to be impractical. Even now with more recent developments in semi-conductor techniques, control over such a large range of light output would be difficult, and not as satisfactory as optical filter techniques.

It was therefore decided to operate the Xenon tube so that it would provide the maximum luminance needed, and to control luminance output, optically. Suitable quality electrolytic flash capacitors of 120 micro-farads, and later 200 micro-farads were chosen to provide the required output. It was possible to operate the flash tube with either of these capacitors at less than their rated output by employing slightly less than the maximum rated applied voltage. By this means neither capacitor nor tube was stressed, and long life could be assured. Initially the capacitor of 120 micro-farads was used, but later it was found desirable to change to the 200 micro-farads capacitor to achieve a slightly higher light output, (Fig 32).

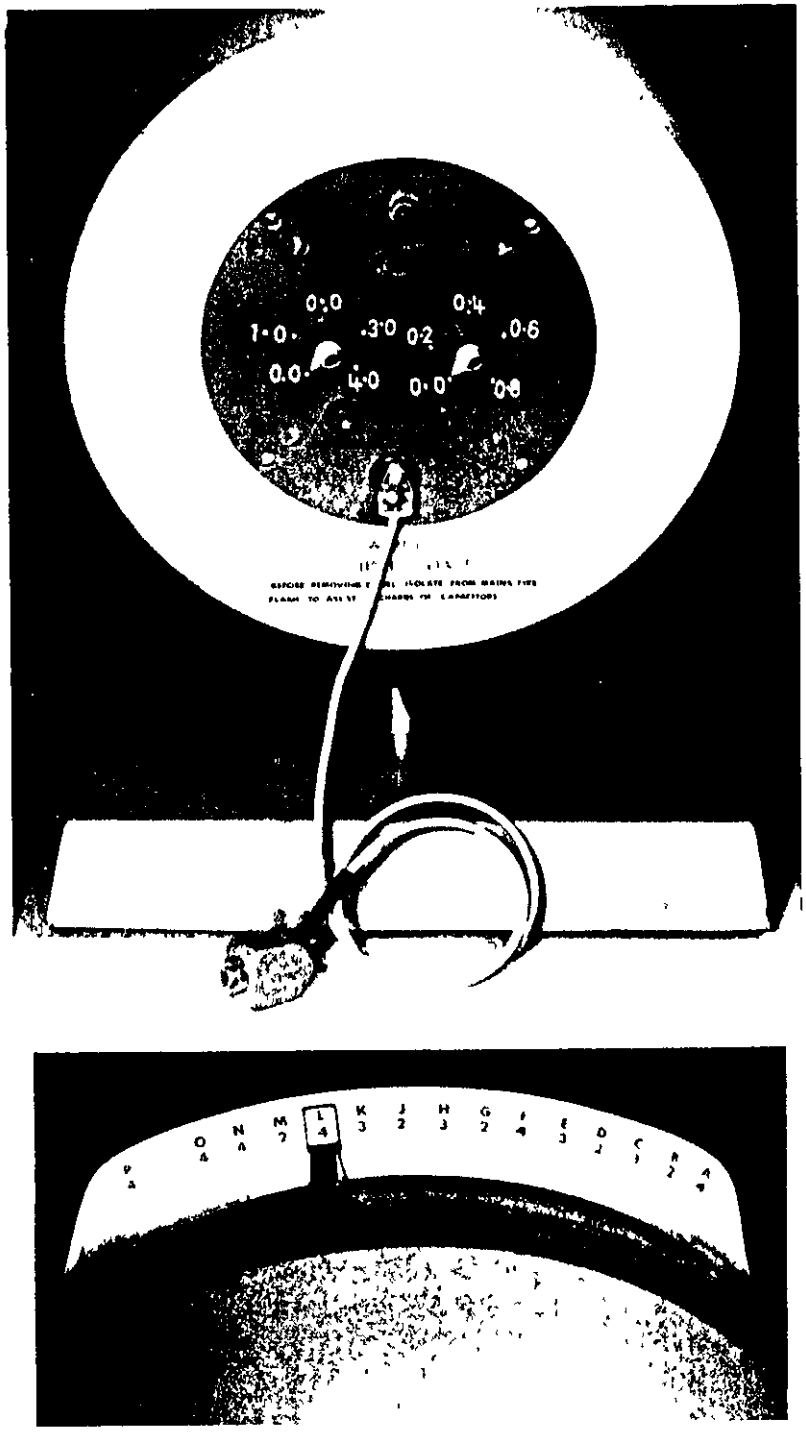


FIG 33. Rear view of Visual Field Analyser showing knobs for controlling neutral density filters and indexing of stimuli patterns.

(2) Luminance Control by Optical Methods.

Luminance control was achieved by using two sets of neutral density filters mounted in discs, and controlled by knobs at the rear of the instrument, one set operating over a range of 0 to 5.0 log units, in steps of 1.0 log units, and the other from 0 to 0.8 log units, in steps of 0.2 log units, (Fig 33). From other work, decsribed later in this paper, it was found that variations in light threshold difference of 0.2 log units were within physiological limits, and that therefore, this variation in luminance output was thought to be adequately sensitive.

When large reductions in luminance were required, such as for example, in dark adaptation tests, additional filters could be inserted in the light path using a slide carrier. Coloured filters coudd be used for clinical work requiring light of special spectral quality, e.g. red light for investigation of cone-function over the macula area.

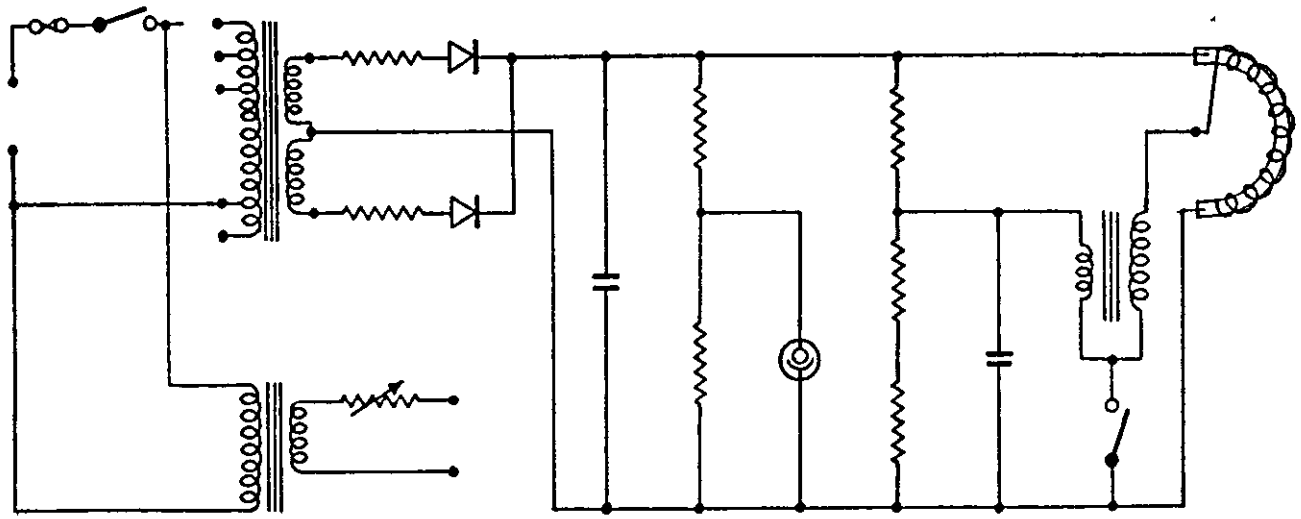


FIG 34. Basic electronic circuit used in operating the electronic flash tube in the Visual Field Analyser.

(C) Electrical Circuit for the Xenon Flash Tube.

At the time of the development of this instrument, semi-conductor units and control methods had not advanced to their present state. Therefore a fairly straight-forward basic electrical circuit,(Fig 34), was designed, using a double-wound mains transformer with a centre-tapped high-tension winding, and outputs taken via two silicon rectifiers to charge the electrolytic flash capacitor. A resistance bridge was placed across the D.C. high-tension supply with a neon tube connected at a suitable point to indicate when the capacitor was adequately charged. The Xenon flash tube was fired by a conventional high-voltage pulse coil. The low voltage winding of this coil was pulsed by a trigger switch discharging a condenser which was fed from a potentiometer supply placed across the D.C. high-tension circuit.

It was anticipated that for clinical use the interval between the flashing of successive stimuli patterns was unlikely to be less than four seconds. The circuit was therefore designed with a time-constant that permitted the capacitor to be almost fully charged in three seconds. After this period the condenser would have been charged to 85% of the maximum D.C.line voltage, and be able to discharge within 0.1 log units of maximum output. Initially it was felt that to reduce the charge time would necessitate using a higher output mains transformer, and therefore a heavier, costlier and bulkier unit, an approach which was felt to be undesirable. In the final production instrument it was

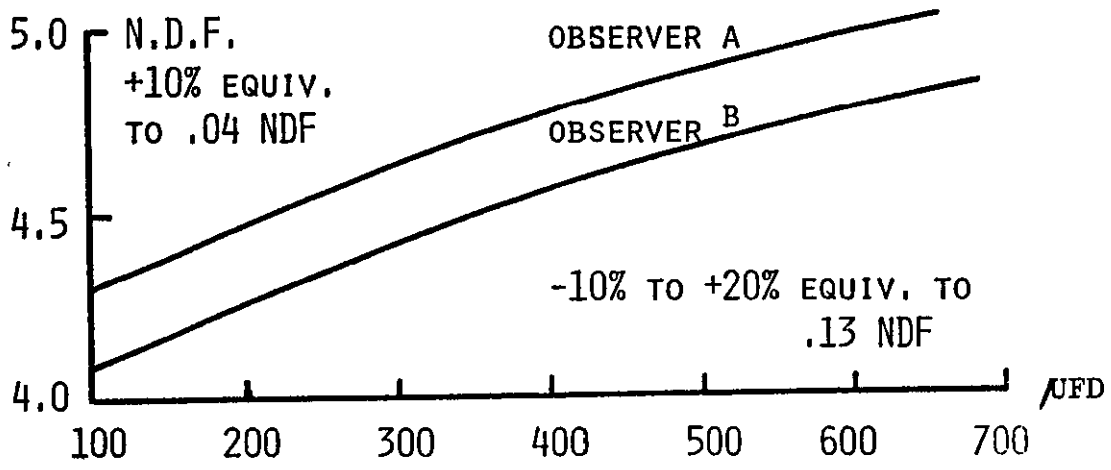


FIG 35. The effect of variation in condenser capacity on differential threshold contrast.

found possible to decrease this charge time still further and remain within the capacity of the transformer being used. The advantage achieved was that the chance of a false negative answer was reduced if the patient's response was unusually fast, or the operator very quick in re-triggering the flash.

Even good quality electrolytic flash capacitors demonstrated appreciable variations in actual capacitance compared to their nominal rated value. In the specially selected type of capacitor used in this instrument, the tolerance could be up to 20% increase of capacitance on a capacitor normally rated at 200 micro-farads, though in ordinary electrolytics the tolerance can be up to -20% to +50% of normal capacity. In terms of light output from the flash tube, a 20% increase on the rated value of capacitance was found to give up to a maximum of 0.07 log units increase in light output, and therefore within physiological tolerance limits,(Fig 35). The instrument, is in fact, so designed that the light output is always slightly in excess of that minimum which may be required. Small fixed elements of neutral density filter can be incorporated in the light path to ensure that the light output of each instrument is within acceptable limits of approximately $\pm$ .05 log units.

When the capacitor is fully charged, the effective duration of a light pulse is approximately of the order of 300 micro-seconds, (Fig 36).

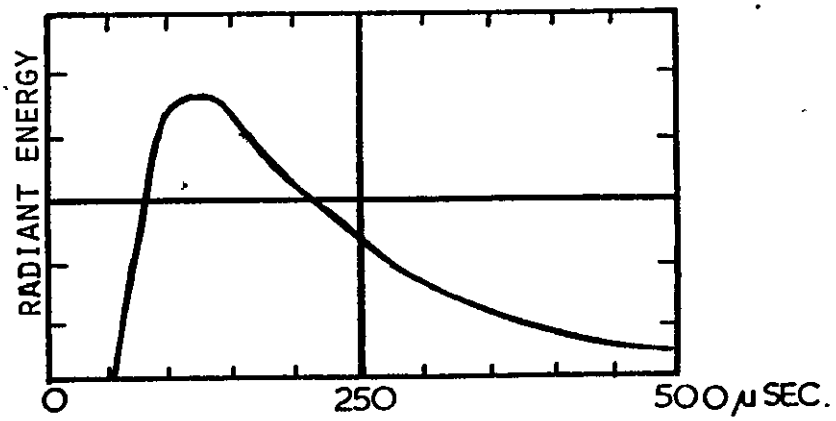


FIG 36. Light discharge pulse through xenon flash tube.

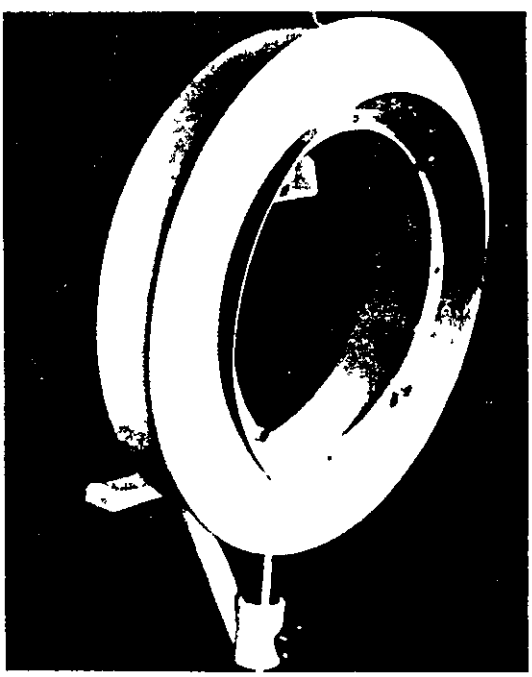


FIG 37. External ring illuminator.

With more recent developments in semi-conductor electronics some improvement in automatic control of light output would now be possible. The simplest would be automatic control of the D.C. line voltage with a circuit preventing the tube from being fired until a set voltage had been reached. A further sophistication would be the actual integration of light output during discharge from the Xenon flash tube, and a cut-off of the power supply to the tube by thyristor control, when the correct light value had been reached. From considerable clinical experience now obtained in using this instrument, it is probably debatable how much real value there is in making the circuitry more complex and expensive. It may also be unwise to alter the light-pulse wave form.

(D) The External Illuminator.

It is essential that retinal light adaptation be controlled during a visual field examination otherwise there will be arbitrary variations in differential threshold contrast. There can be considerable variations in consulting room illumination, producing differences of illumination across the screen of the instrument containing the stimuli. A special ring illuminator was designed, (Fig 37), through which the patient could view the whole of the evenly illuminated front-plate, which, by reflecting light back, maintained a constant level of retinal adaptation. A grey surface was at one time tried for the front-plate, but a matt black rigid vinyl was finally chosen, because a black surface introduces less

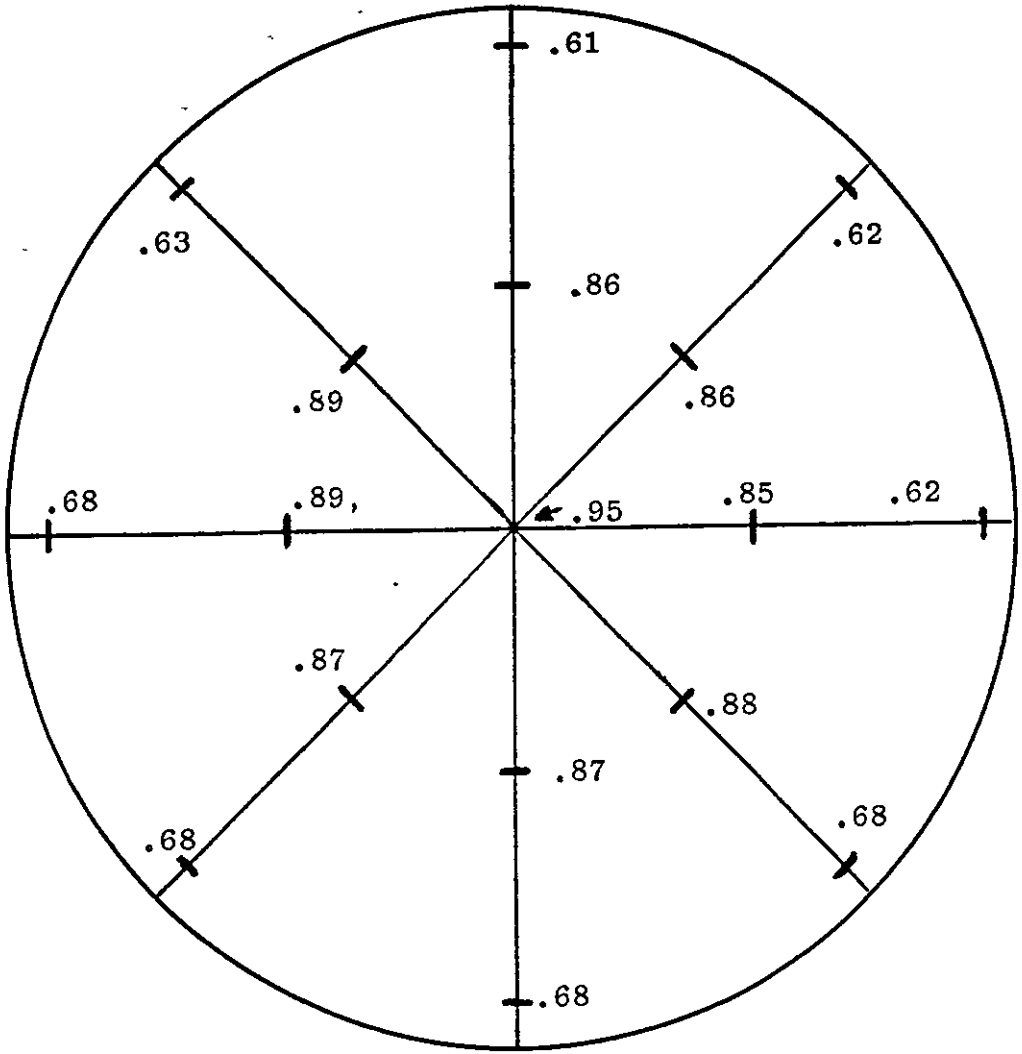


FIG 38 (a). Initial variation of illuminance across the front plate produced by the external illuminator in lumens/sq.ft.

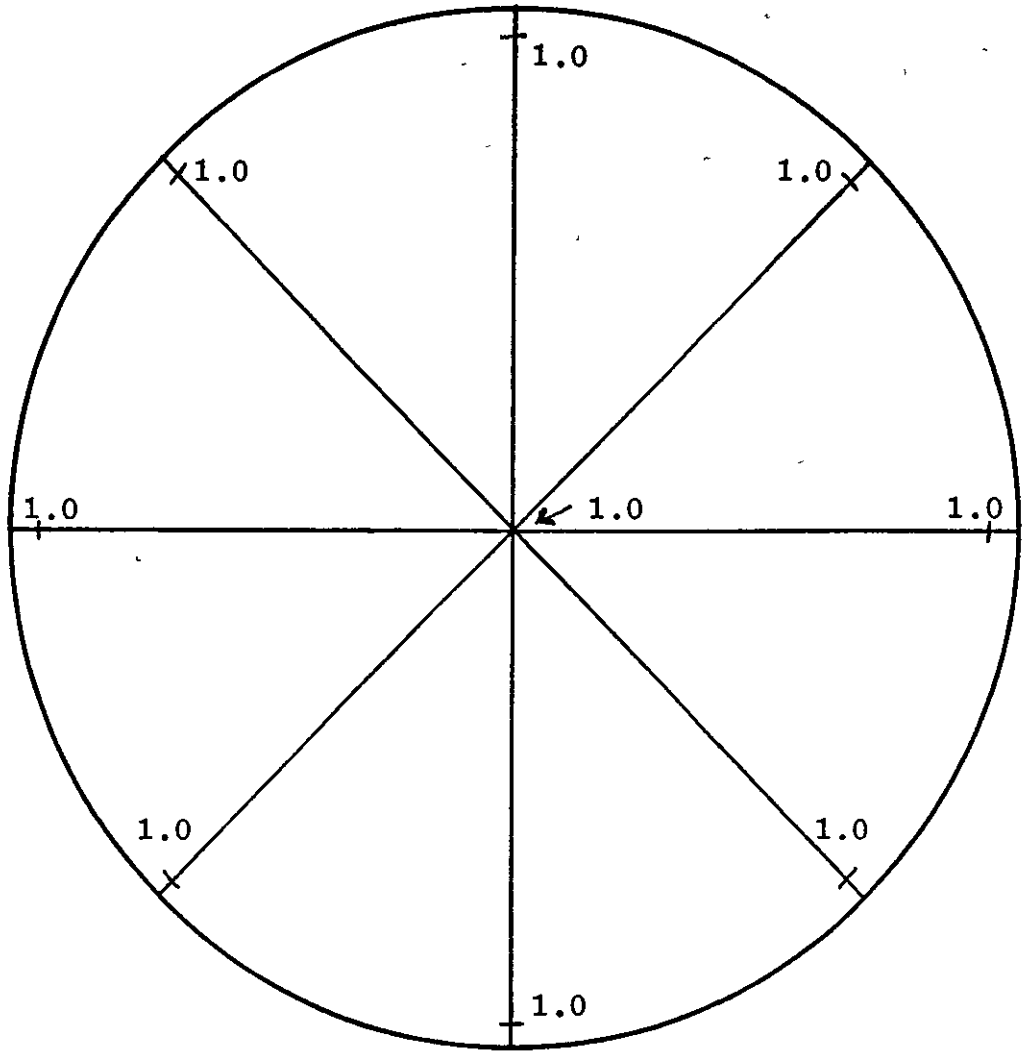


FIG 38 (b). Variation of illuminance across front plate in final design.

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problems with any stray light that happens to fall on the instrument.

To allow investigation around the photopic/mesopic border of retinal adaptation, the ring illuminator was designed to give 1 lumen/ft^2 on the front plate. The matt black vinyl of the front plate had an approximate reflection factor of 0.08, and this gave a mean front plate surface luminance of approximately 0.08 foot-lamberts or 0.08 milli-lamberts. On the initial prototype the actual measured value of illumination across the front plate assembly given by the ring illuminator varied from 0.95 lumens/sq.ft. at the centre to 0.61 lumens/sq.ft. at the periphery, (Fig 38 a). The maximum increase in differential threshold contrast that this variation could produce was of the order of 0.05 log units, and therefore could be taken as being within adequate physiological limits. In later designs this variation of luminance across the front plate was further minimised, (Fig 38 b). Any small residual local variation in adaptation could be allowed for when the final values of the apertures in the front-plate assembly had been determined from extensive clinical trials.

To provide an even light flux six low-voltage tungsten filament lamps were used as sources for the external illuminator, and they had to operate to within 10% of their nominal rated light output. To maintain

adequate tolerances of illumination they were also intentionally under-run, both to prolong life, and to help compensate for the effect of mains voltage fluctuations.

The ring illuminator was designed so that the configuration of the inner part of the ring and shield, in relation to the eye, provided a visual cut-off of objects in the subject's field of view beyond the external dimensions of the front of the instrument, The ring illuminator was also designed so that an overall side-spill of light provided low-level illumination around the instrument and enabled the operator to work and make recordings on the chart, without having to use any external illumination.

(E) Compensation for the Effects of Mains Supply Voltage Variations.

The public mains supply voltage is usually controlled to within defined limits but often greater variations can occur or be evident at the end of supply lines.

The light output of a Xenon discharge lamp will vary with half the square of the applied voltage. If for a nominal 240 volts standard alternating current supply, the voltage varies by plus and minus 10%,

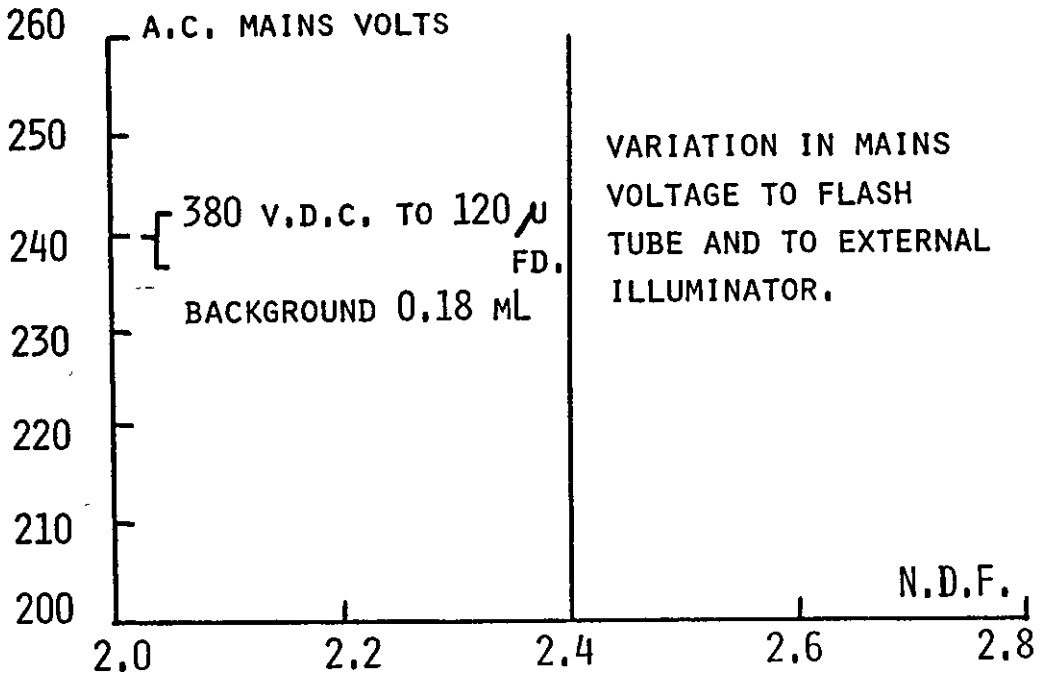


FIG 41. The total effect of mains voltage variation on differential threshold contrast.

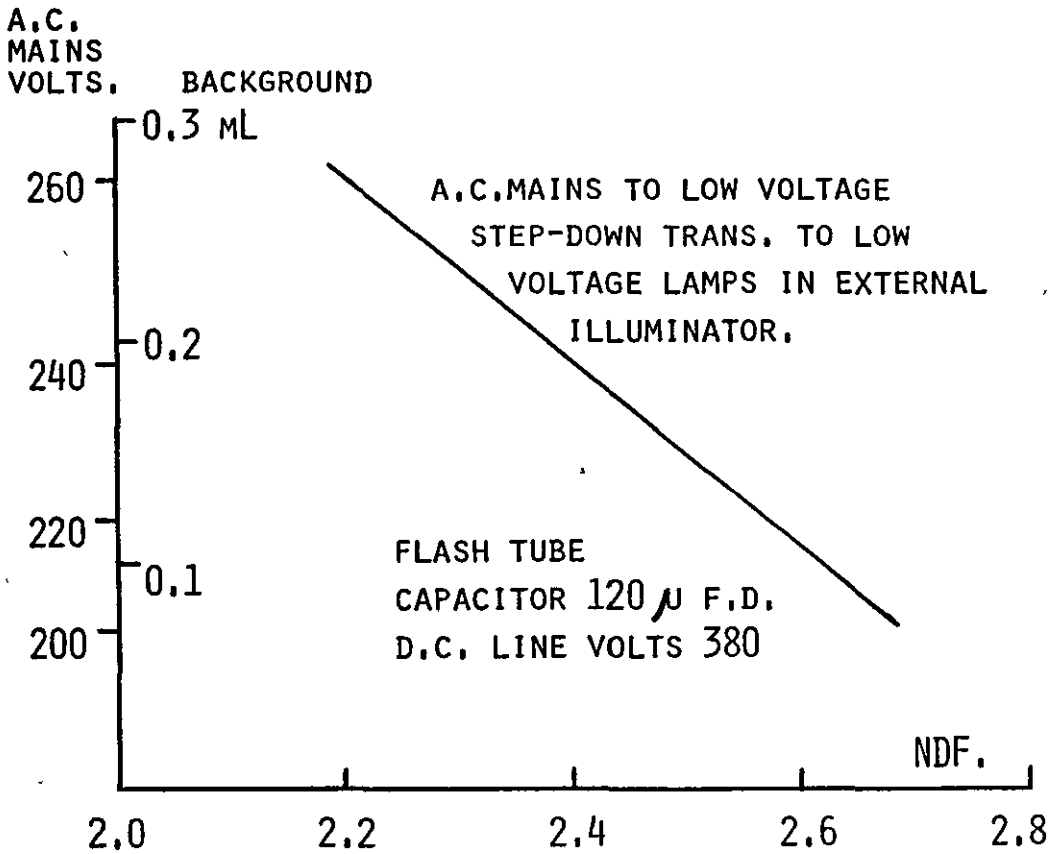


FIG 40. Effect of variations in voltage and illumination from external illuminator alone on differential threshold contrast.

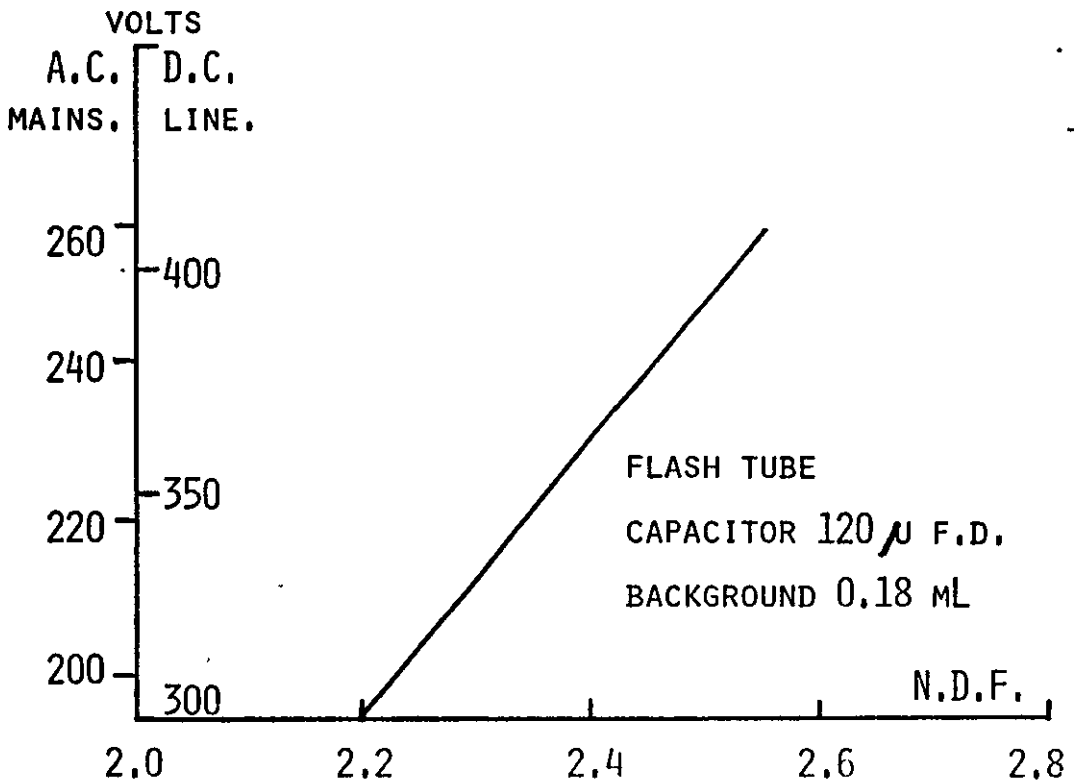


FIG 39. Effect of voltage variation on stimuli luminance alone on differential threshold contrast.

(a very considerable swing), there could be a variation of stimulus luminance, and resulting in a change in differential threshold contrast by about 0.3 log.units, (Fig 39). This amount is slightly greater than the 0.2 log units variation accepted as being within physiological limits, and would therefore be unacceptable.

The operating conditions for the light source in the ring illuminator were therefore arranged such that any change in retinal adaptation produced by mains voltage variations would be compensated for by changes in luminance of stimuli,(Fig 40). In the final design there was practically complete compensation for the effect of mains voltage fluctuations on visual thresholds, (Fig 41). By this means the considerable expense and extra weight that a constant voltage supply unit would involve was avoided.

IX

(A) THE DETERMINATION OF APERTURES FOR THE STIMULI ARRAY.

It was stated in section VI that a stimulus subtending between 10 and 15 minutes at the eye was a reasonable choice, as this size avoided the problem of requiring a 5 minutes angular subtense for the classical standard of 6/6 acuity. Using a larger stimulus size decreased the problems due to angioscotoma from retinal vessels, and also allowed a better assessment of deterioration of summation co-efficients commonly occurring in ocular pathology. In this instrument stimuli were initially employed that subtended 11 minutes at the eye, and then variations in size were superimposed to obtain a similar differential threshold contrast over the mid-peripheral field to be examined. The various stages involved in arriving at a correct specification for these apertures are now considered.

Geometric Considerations.

In the original concept it was intended to employ a front plate which contained all the 46 apertures needed to examine the different parts of the mid-peripheral field eccentric to 25 degrees from central fixation, and to expose the individual patterns of stimuli, of two, three or four at a time. A total of fifteen patterns, contained

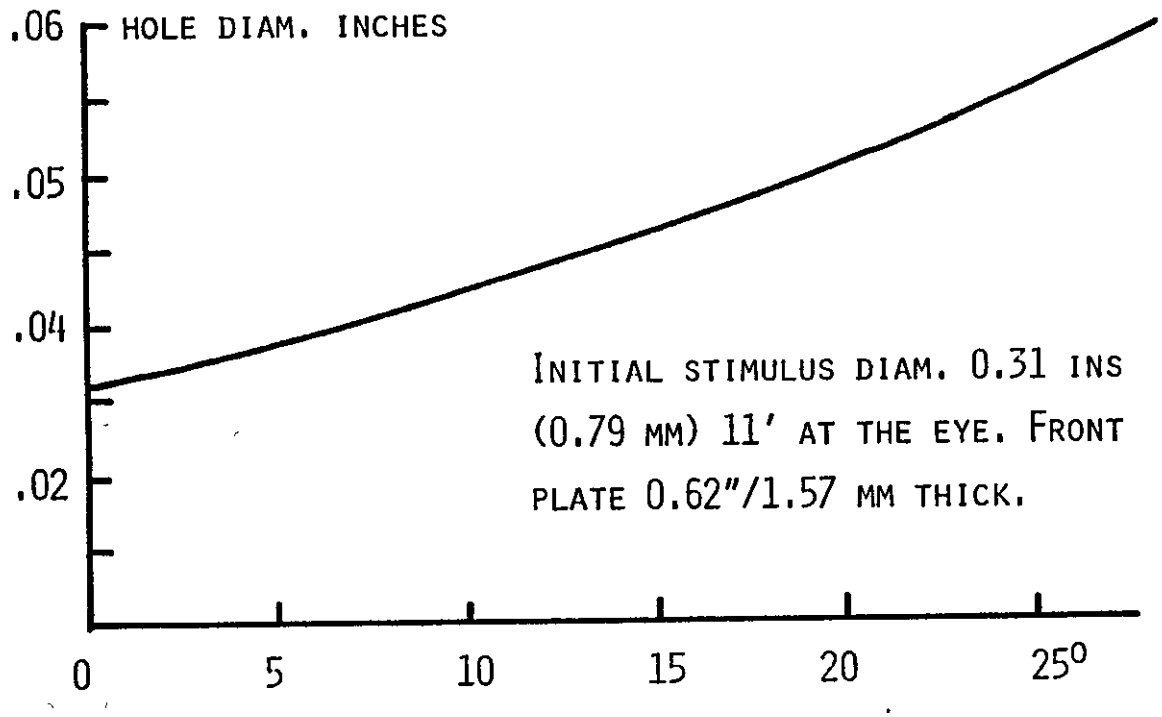


FIG 42. The diameter of stimuli subtending the same solid angle at the eye for increasing eccentricity and allowing for tunnelling.

in a rear shutter plate which could be rotated to indexed positions, allowed the appropriate apertures in the front plate to be opened for each indexed pattern setting. The front plate was to be constructed out of rigid black vinyl sheet 1.59 mm thick. With the eye placed 33 cm in front of the centre of the front plate, any aperture placed away from the centre would be viewed obliquely. If, therefore, any of these eccentric apertures were to subtend the same angular subtense of area at the eye as that of the stimulus seen centrally, they would need to be drilled at varying angles to the front plate according to the deviation from viewing axis. As such a method of manufacture would be very complex and expensive, it was decided that all the apertures in the front plate and rear plate should be drilled at right angles to the plate surface. This meant that "tunnelled" apertures would be seen, and that allowance would need to be made in the actual diameter of the hole if the effect of tunnelling and obliquity of viewing was to be allowed for, so that each aperture presented to the eye the same area of solid angle subtending 11 minutes at the eye.

To allow for this geometric effect of obliquity of viewing, the diameters of the holes for increasing degrees of eccentricity were calculated for the plate thickness being used, for the stimuli positions already determined. These are indicated in Fig 42, for an initial stimulus subtending 11 minutes at the eye. The proceedure employed is illustrated in Appendix A.

(B) ALLOWANCES FOR THE EFFECT OF PHYSIOLOGICAL FACTORS ON DIFFERENTIAL THRESHOLD CONTRAST IN THE MID-PERIPHERAL FIELD OF VISION.

(1) Differential Threshold Contrast and its Determination.

When stimuli of the same luminance and of the same angular subtense at the eye are exposed on the front plate over the range 0 - 25 degrees, it is necessary to adjust the angular subtense of the stimuli so that they can all be seen at just above the threshold of visibility against the background luminance provided by the external illuminator on the front plate. In other words allowance must be made for the effects of retinal physiology to achieve the same differential threshold contrast for all angular displacements of the stimuli. The term absolute threshold is not used in this context as it would mean threshold visibility at negligible background luminance, i.e.for very low scotopic adaptation.

Localised variations of differential threshold contrast for a stimulus at different background luminances are assessed in terms of the different neutral density filter settings that would allow perception at threshold. Luminance difference is expressed on a logarithmic scale.

It will be noted from the above that the differential threshold contrast is the value at which the perception of a luminance difference occurs between the front plate stimuli and the background luminance of the plate. This is the differential threshold referred to throughout the following discussion.

In actual clinical practice it would be necessary to determine the neutral density filter value at which the stimuli should be seen at just above threshold and to compare this value with that obtained for the same positions where there was a reduction of threshold. The area over which this loss occurred, and the shape of the area, together with the degree of loss at the different points, would indicate the type of abnormality, or pathology, that might be involved. Like most areas of clinical diagnosis, however, the visual field data has to be taken into consideration with other clinical signs, symptoms, and data, before a final conclusion can be reached.

In determining what should be the criteria for a stimulus to be just visible, a number of approaches are possible. Criteria for perception at threshold of a stimulus has been discussed extensively, e.g. WOODWORTH and SCHLOSSBERG (1954). A classical approach is to accept a response at threshold when a positive response is recorded 50% of the time. However for the type of clinical work with which this thesis is concerned a 50% response would bring the threshold recorded so near the border of normal physiological variation that far too many false negatives would result.

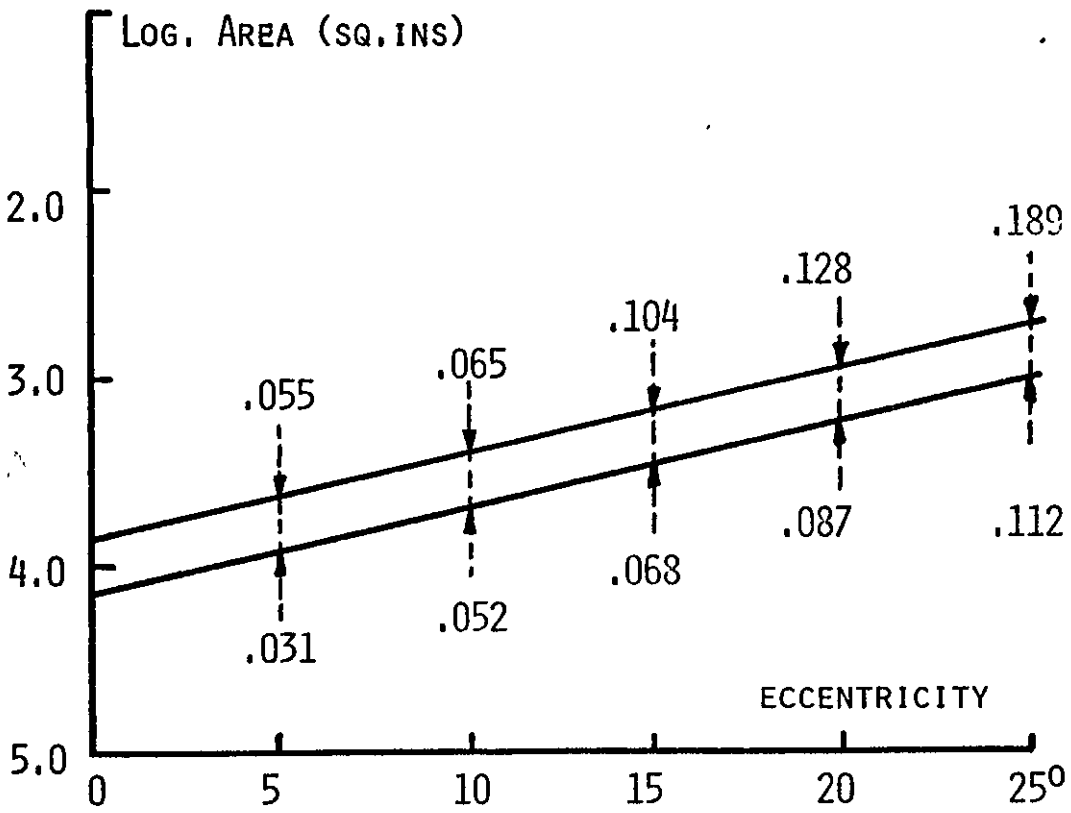


FIG 43. Approximate effect of retinal location on stimuli size for similar differential threshold contrast with increasing eccentricity for two series of basic stimuli sizes.

Clinically three correct responses out of four stimulus presentations is taken as the threshold setting. When the flash tube discharges, a slight click is heard, therefore the subject is told that this click would accompany any flash of light. If one stimulus was being exposed the response requested was yes or no. If more than one stimulus is presented the number of flashes of light seen are recorded. In the latter case the subject had to point to those light stimuli that he could see, the one not seen then being taken as below threshold.

(2) The Determination of Physiologically Adjusted Stimuli Apertures.

No adequate research data was available which would enable calculations to be made for the effect of physiological variations on threshold contrast. In an initial trial, a special front was made for the instrument containing a slide incorporating apertures of increasing size. This slide could be positioned at the centre of the plate, with provision for eccentric viewing every 2½ degrees out as far as 25 degrees from central fixation. Initially a central aperture subtending 11 minutes at the eye was used, and variations in the aperture for each 2½ degrees of eccentricity along the nasal meridian were determined, Fig 43. The nasal meridian was used as previous work had indicated that the gradient was reasonably regular over this portion of the visual field.

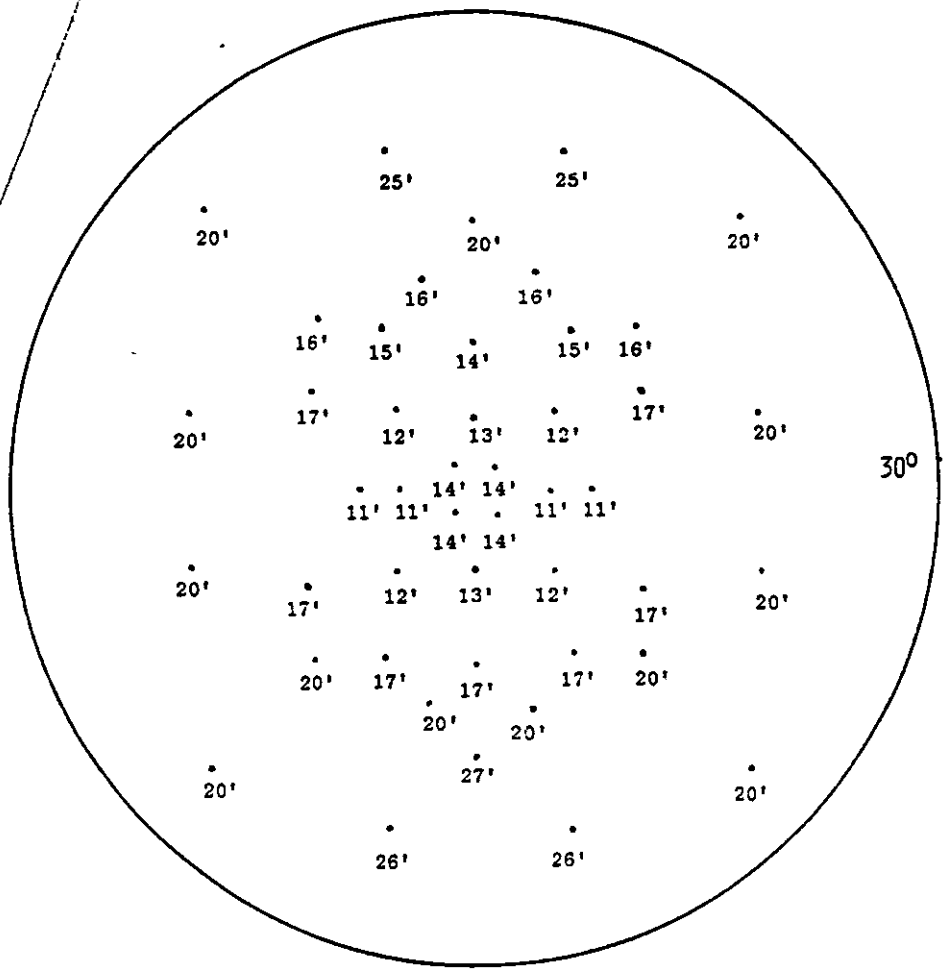


FIG 44. Initially determined angular subtense of the stimuli over the area of the front plate.

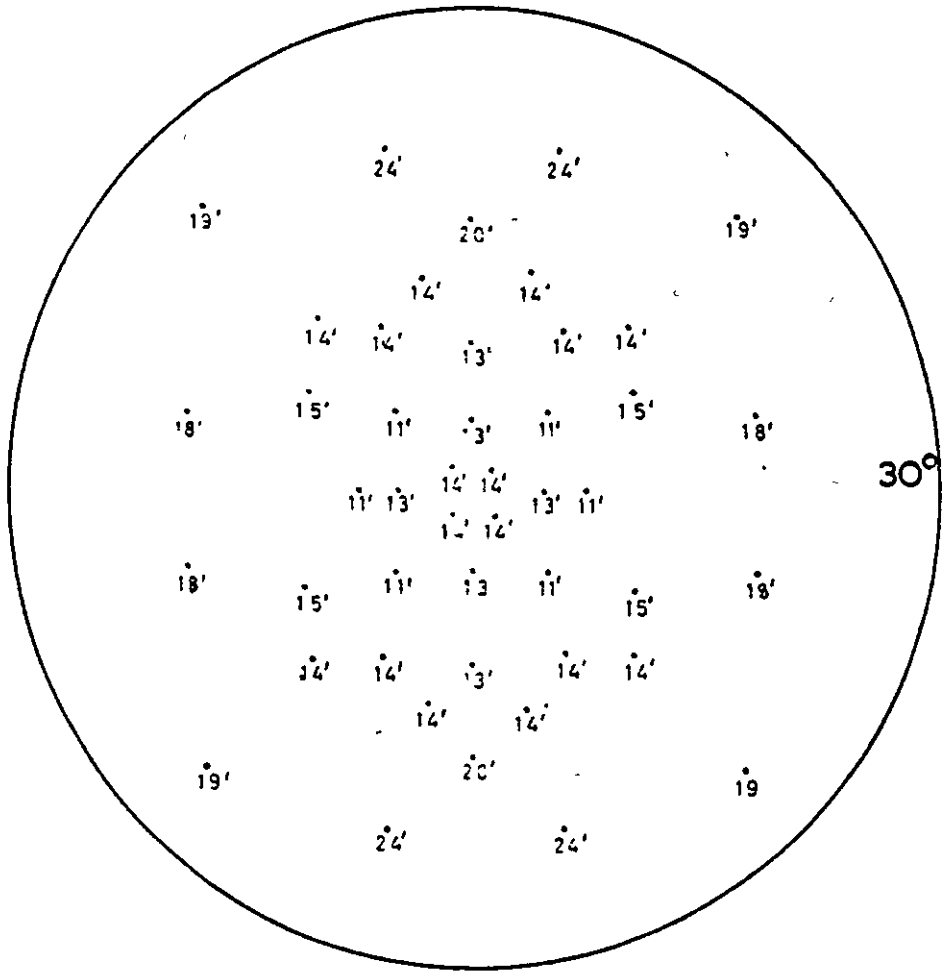


FIG 45. Final angular subtense of the stimuli over the front plate for the 46-hole front to give a similar differential threshold response.

Calculations were then made,(Stage A of Appendix A,) of the diameter of the apertures that would need to be drilled along the line of sight at the various stimuli positions that would allow for the effect of local physiological variations of threshold perception, as indicated by data based on Fig 43.

Subsequently,(Stage B1 of Appendix A,) hole sizes were calculated to allow for oblique viewing and "tunnelling" in order to give the same solid angle at the eye as in Stage A. This front plate was based on an initial central stimulus of 11 minutes subtense.

It was then necessary to determine experimentally for each stimulus position the diameter of the hole required for the average observer to perceive the stimulus at threshold, (as indicated in Stage B4.) The effective angular subtense at the eye of each stimulus in this initial front plate is indicated in Fig 44.

At the time of the development of the instrument data on differential threshold contrast was not available for the viewing conditions and positions being employed. Mr Friedmann decided to take as safe a clinical approach as possible to determine thresholds. An initial setting of overall stimulus luminance was made that would allow a number of the stimuli to be just visible. At this

stage of development of the frontplate, and at this level of neutral density filter setting, some of the stimuli would be below threshold, and be missed, others may be just visible, and the remainder may be too bright. Thirty normal observers were used as subjects for these experiments, and stimuli that were missed or seen at this setting recorded, and a scattergram made. Stimuli that were missed regularly were then enlarged slightly, usually to the next available drill size. Stimuli that appeared too bright were reduced.

An adequate average response over all the stimulus positions had not quite been achieved at this stage but it was felt that some of the peripheral stimuli, (as indicated in Stage B4 of Appendix A), were becoming too large. Therefore a new series of stimulus apertures was calculated from initial principles as at Stage B1, but based on a stimulus with a diameter of aperture of .031 ins at position P, (indicated in Stage C 1), instead of.033 ins (as in Stage B4). The above proceedure was then repeated using a scattergram approach again to determine which stimuli should be reduced or enlarged. The final diameter of aperture that gave a response nearthreshold for all the different stimuli positions were recorded, (as shown in Stage C 6) together with the effective angular subtense at the eye of each stimulus. These aperture positions and sizes are illustrated diagramatically in Fig 45, for the 46-hole front plate.

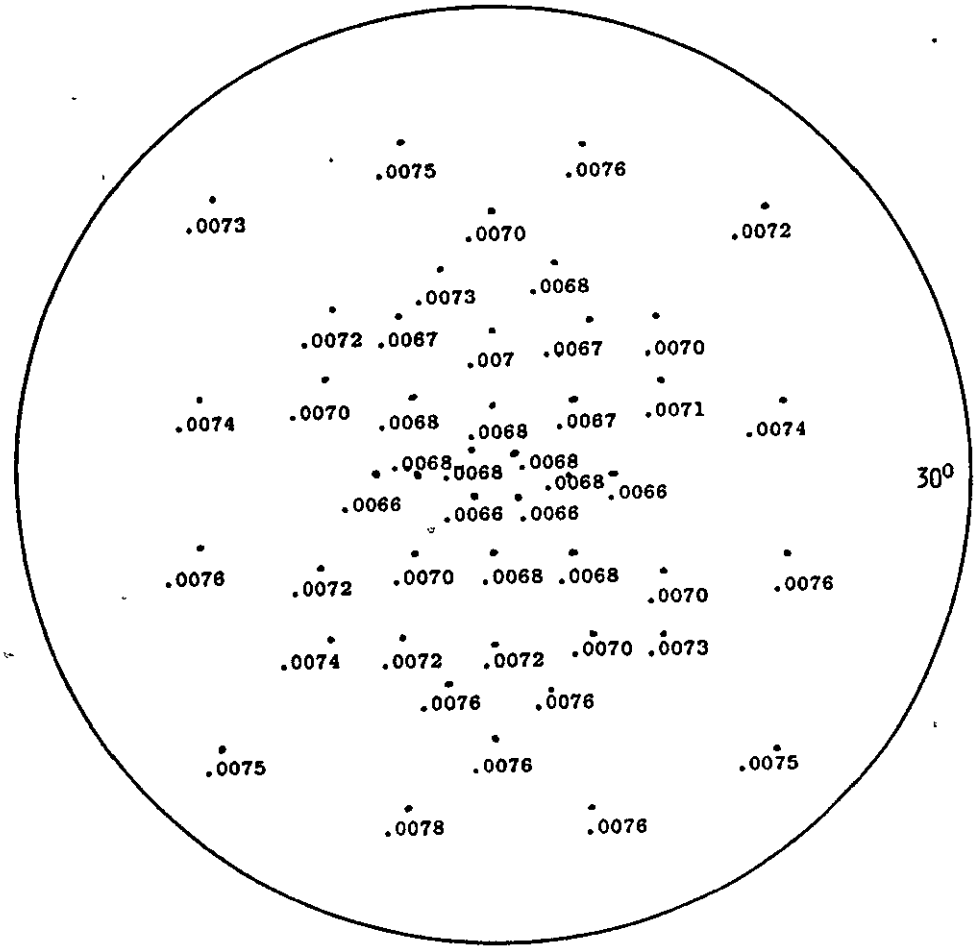


FIG. 46

Integrated relative light output measured with a flash photometer at the eye position for the different stimuli lumen/secs.

When the stimuli sizes for the final front plate had been specified the integrated light output at the eye for each of the different stimuli positions was measured with a flash photometer, (as shown in Fig 46). The difference between these values of light output indicates the allowance that needs to be made for variation of differential threshold contrast across the retina.

Individual variations in differential threshold contrast amongst normals, together with means and standard deviations for the different stimuli positions, obtained using this array of stimuli contained in the front plate are discussed in Section XIII.

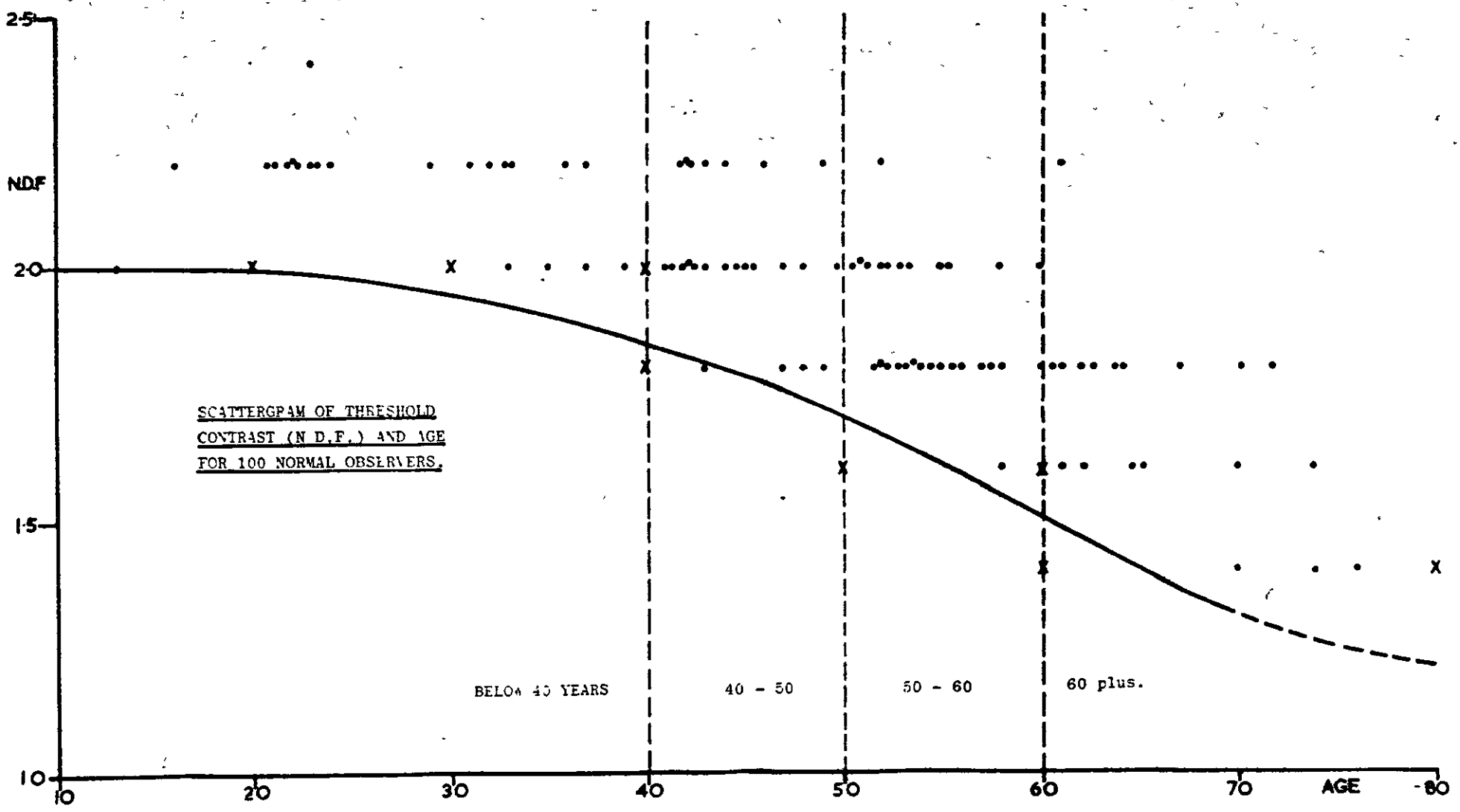


Fig. 47.

Scattergram of the effect of age on the neutral density filter setting needed to obtain differential threshold contrast.

(X's = NDF guide settings)

X

VARIATION OF DIFFERENTIAL THRESHOLD CONTRAST.

(A) The Effect of Age.

Differential threshold contrast varies somewhat between different individuals, and also shows a general deterioration with age. Having designed a front plate containing apertures that could demonstrate an approximately even differential threshold contrast for both eyes of a normal observer when the stimuli luminance was correctly set, it was then necessary to determine the average effect of age on threshold contrast. An analysis was therefore made of the individual thresholds of a hundred observers of different ages, all of whom could see all the 46 stimuli in the different pattern combinations.

Initially a scattergram was drawn, in which age was plotted against the neutral density filter setting needed to obtain differential threshold contrast, based on data tabulated in Appendix B, and illustrated in Fig 47. To avoid unnecessary referral of clinical cases due to false positives, a curve was then drawn just below the maximum N.D.F. setting for threshold at which the majority of subjects of different ages could see all the stimuli. Suggested neutral density filter settings based on this data that could be recommended for different age groups are indicated below.

FILTER SETTING AND AGE.

Up to 40	41-50	51-60	Over 60
2.0	1.8	1.6	1.4

These figures for the setting of the neutral density filter are to serve as a guide only, It generally being recommended that a setting of 0.2 NDF units dimmer than the recommended age setting be used, or 0.2 NDF units brighter than the approximate individual threshold, where extra sensitivity of investigation was required. The latter would be required, for example, when attempting to detect field defects which may be caused by neurological lesions, or for the detection of very early indications of field loss in glaucoma.

The table below shows the mean neutral density filter settings to allow perception at threshold of all the stimuli, and the standard deviations of these settings for each of the four age groups.

Mean or Average Age.		Average Neutral Density Filter Setting	Standard Deviation.
Up to 40 yrs	27.5 yrs	2.2	0.1
41 - 50 yrs	45.2 yrs	2.0	0.13
51 - 60 yrs	53.5 yrs	1.9	0.12
61 plus	67.1 yrs	1.6	0.17

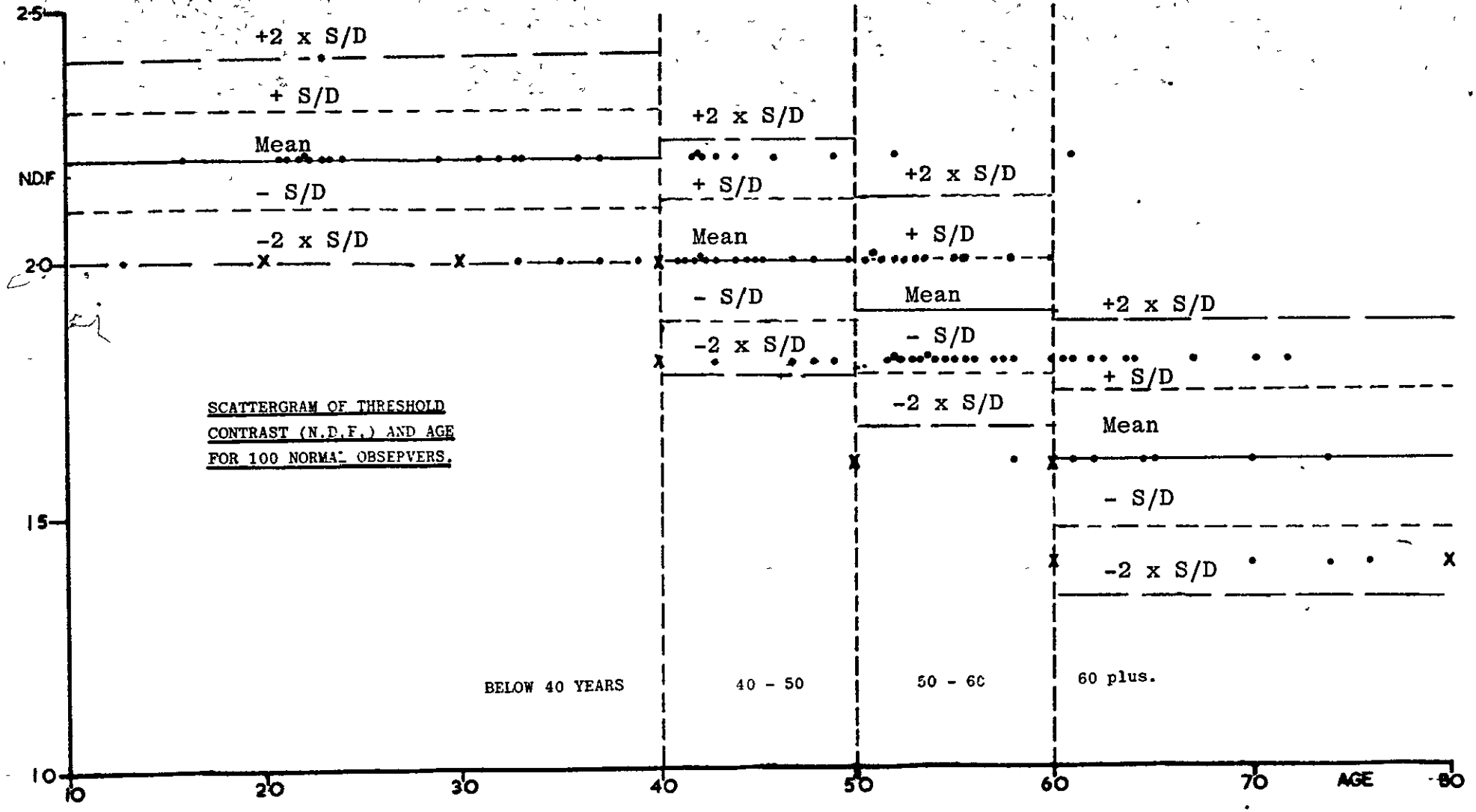


Fig. 48. Means and standard deviations of neutral density filter for age superimposed on the initially recommended settings for age. (Marked X X).

The same scattergram is shown in Fig 48, but superimposed on it is the mean neutral density filter setting calculated for each age group, together with plus and minus one standard deviation, which would allow for visibility for 65% of the sample, and plus and minus twice the standard deviation, which would allow for 95% of the sample.

It will be seen that for the below 40 year group a neutral density filter (NDF) setting of 2.0 NDF units would occur at approximately the mean threshold for that age group less 2 times the standard deviation. For the majority of the subjects in this group a 2.0 NDF setting would be within the 0.2 NDF units regarded as within normal physiological limits. The upper limit for a small majority would be at 2.4 NDF units. In this case an initial NDF setting of 2.0 could contain a 0.4 NDF unit difference of threshold contrast i.e. just beginning of possible abnormality. A more sensitive NDF setting of 0.2 higher than the 2.0 NDF initial setting, i.e. 2.2, would enable any abnormality in this small group to be detected, and put a somewhat greater number of people nearer to threshold.

For the 41 to 50 year age group, an initial NDF setting of 1.8 occurs at a value approximately 1½ times the standard deviation less than the mean of 2.0 NDF units for that age group. On the scattergram the upper limit of sensitivity of this age group occurs at

approximately 2.2 NDF units, i.e. about 1½ times the standard deviation above the mean NDF unit setting, and therefore 0.4 NDF units above the initial recommended neutral density filter setting for age. Here again a more sensitive neutral density filter setting of 0.2 log units higher than the initial setting, i.e. 2.0 NDF, would then bring the more sensitive individual in this age group within the 0.2 limits of physiological variation, and place the less sensitive at the border line of differential/contrast threshold.

For the 51 to 60 year age group, an initial 1.6 NDF setting occurs at a value approximately twice the standard deviation less than the mean of 1.9 NDF units for that age group. The upper limit of threshold if taken as 2 times the standard deviation higher than the mean of 1.9 NDF, would be about 2.1 NDF units, and would allow a significant proportion to have a threshold contrast reduction of 0.4 NDF units that may be at the border line of being detectable. There would be a very small minority who would have a sensitivity of 0.6 NDF units better than the initial NDF setting of 1.6 NDF units. Therefore an NDF setting of 0.2 NDF units higher than the initial 1.6 NDF, i.e. 1.8 would be adequately sensitive for those falling within plus one standard deviation, but may not be adequate for the smaller number who have a higher sensitivity than this, and for whom a setting of 2.0 NDF units may be necessary.

For the 61 + age group, an initial setting of 1.4 NDF would occur at 0.2 NDF units less than the mean of 1.6 NDF units for that age group, and therefore would be adequately sensitive for those with a mean threshold of one standard deviation higher than this mean. The remainder of the group with a higher sensitivity would mostly be contained within twice the standard deviation above this mean value of 1.6 NDF units. A NDF setting of 0.2 NDF units higher than the initial setting, i.e. 1.6 NDF would then be adequately sensitive. For the small number with a high sensitivity for their age, an initial setting of 1.8 NDF might be needed.

Summarising, the initial neutral density filter setting recommended as a guide for the different age groups would allow investigation with adequate sensitivity of the majority in any age group to within 0.2 - 0.3 log units. There would be a minority of slightly higher sensitivity who would be better investigated at 0.2 lρg units higher than thisrecommended initial guide setting.

Particularly in the 51 - 60 and the 61 + age group there would be a small number of about 2½% in each group in the range of the mean plus twice the standard deviation, where it would be advisable to use a setting of 0.4 NDF units higher than the initial neutral density filter setting to achieve maximum sensitivity.

The initial neutral density filter setting for age suggested as a guide would appear therefore to eliminate most false positive responses for the majority of subjects investigated. The recommendation that a further 0.2 NDF units higher setting than the initial guide for age should be used for greater sensitivity would appear to be adequately sensitive for nearly all the subjects examined. Where the utmost assurance of the detection of potential clinical conditions is desired, the neutral density filter setting of 0.2 NDF units lower than the threshold for a few selected stimuli positions appears to be a very accurate and simple approach.

(B) The Effect of Pathology on Differential Threshold Contrast.

When a new instrument has been devised, and it is being used to detect possible pathology, it is most important that it be as reliable as possible in clinical use. To this end initial trials were undertaken by Mr Friedmann at the Royal Eye Hospital, comparing visual field data obtained by multiple static quantitative perimetry with that obtained using the Goldmann bowl perimeter, and the Bjerrum screen, both of the latter being clinically accepted methods of visual field investigation.

The various aspects of validation will be discussed in a later section, but at this stage the evidence was that not only was the instrument able to detect visual field defects found by these commonly used clinical techniques, but it also appeared to detect significant defects at an early stage which appeared to be missed by these other methods(Friedmann, 1966).

(C) The Clinical Recording of Threshold Responses.

For the clinical use of the instrument, two charts were designed, Figs. 23 and 24. With experience it was, possible later to enter response data directly on to the composite chart.

The neutral density filter controls were first set at an appropriate level of stimuli luminance, using say an NDF setting 0.2 higher than the initial suggested setting for age. The neutral density filter setting was then recorded on the chart as that level at which stimuli could just be seen, and where response was within normal limits. Positions where stimuli could be seen were left unmarked, and any position at which no stimulus could be seen was underlined so $\underline{\cdot}$.

The neutral filter setting was then reduced, usually by 0.4 NDF units, and if any of the previously missed stimuli were now seen, this value was put against the stimulus position. The process was then repeated by using reducing steps of 0.4 NDF units up to the brightest setting for any stimulus that could not be seen. The recording was marked ⊙ , indicating a very dense loss.

In general, it was found that variations of differential threshold contrast of the order of 0.2 NDF units were within physiological limits, but where there was a reduction of 0.4 NDF units or more, particularly over a number of points in the field, then an abnormality was likely to be present. The shape of the area over which the visual loss occurred would then give an indication of the type of pathological condition that might be present. The quantitative recording of the degree of loss indicated how long the condition had been established.

By the end of March 1965, it was felt that the design and validation had progressed sufficiently for a prototype instrument to be exhibited at the 1965 United Kingdom Society of Ophthalmology Congress.

XI

INDEPENDENT NON-CLINICAL INVESTIGATION OF THE VISUAL FIELD ANALYSER.

During the development of the instrument the author and those involved in the project undertook measurement of the instrumental variables involved in the various design parameters, in particular their effect on differential threshold contrast discussed in sections VIII and IX. In addition to this work, The British Scientific Instrument Research Association was commissioned by Clement Clarke (in 1969) to undertake an independent photometric assessment. When the instrument became more readily available, various workers also undertook their own evaluation of different aspects.

The Photometric Effect of Instrumental Variables.

The British Scientific Instrument Research Association considered the effects on the photometric characteristics of variations in all the main electrical and mechanical parameters involved in the instrument, including critical components, the effect of variation in mains voltage of the permitted plus and minus 6% of normal value, and the effect of calibration drift with time.

Summarising, they found as would be expected, that the greatest variation could be the radiant energy transfer, from the Xenon tube. This could be of the order of 0.31 NDF units at maximum and arose from

variations in output of the electrolytic flash capacitor. Factors affecting the external illuminator could produce up to 0.1 NDF units difference, the flash tube 0.02 NDF units, tolerances in stimuli apertures 0.02 NDF units, and from the neutral density filters, 0.01 NDF units.

In practice it was thought by the BSRA that all the parameters were very unlikely to be at their extreme values at the same time, and a realistic tolerance range was half of the total value of approximately 0.4 NDF units, giving a likely tolerance on overall resolution of approximately 0.2 NDF units, i.e. within the range of variation of response thought by the developers to be within physiological limits.

The most comprehensive technical investigation on the Visual Field Analyser published so far has been by Greve (1973). In a part of this work he discusses basic research undertaken on the effect of variation in design parameters on photometric characteristics and their effects on the perception of stimuli. In his technical investigation he took three early models of different ages, and found that the light energy content of the flash in the different instruments was in the ratio of 2.6 to 1.9 to 1.3 lumens, for a presentation time of 380 micro-seconds. The developers though that the reason for these differences was that in the early instruments there was a problem in obtaining similar electrolytic flash capacitors from one

supplier, the older instruments having a lower capacitor value. Since then the developers have ensured that every instrument is standardised photometrically and against the thresholds for a number of normal individuals, precautions being taken that no response was included for a stimulus that happened to be imaged on an angioscotoma. Any small residual variation in light output between different instruments of recent make is insignificant in clinical investigation as output would be a constant factor affecting all the stimuli positions in any one instrument.

The light flux from the Xenon tube was found by Greve to vary within plus and minus 5% on repeated presentation, and therefore was of negligible magnitude for clinical examination.

If the interval within flashes is kept to not less than 3 seconds, the decrease in light flux is negligible, but is found to be about 0.1 NDF units lower for a re-charging time of 1 second.

Greve felt that it is necessary to have a good method of standardising light output from the instrument if there is likely to be a significant difference of luminance when used over a length of time. The author has found that for one of the original instruments in regular use over ten years, with the same Xenon tube, the clinical difference obtained on patients examined on recent instruments is less than 0.2 NDF units.

In general Greve found that the Xenon flash tube was a good source of light for multiple stimulus static visual field examination. The provision of the external illuminator to provide control of retinal light adaptation was a definite advantage. The level of luminance on the black screen of approximately 0.5 lux was in the low photopic range. As examination at mesopic level has not proved to be vital, a photopic level reduces delay in adaptation before undertaking the examination and also reduces the effect of changes in surrounding ambient illumination. The ability to examine central or macula light sensitivity was also an advantage.

Ripley (1974) investigated possible errors due to the incorrect positioning of the eye in relation to the central axis of the instrument and to variations in position from the fixation target. The conclusion was that errors in eccentricity of stimuli due to mis-alignment of the eye are negligible in practice, unless miniature apparatus is being employed. The design was felt to be satisfactory in this respect, though naturally in use, the patient's eye should be reasonably centred by correct positioning.

Ripley (1974) investigated the cumulative errors of the apparatus arising from possible deviations in mechanical and photometric performance. He found that the variation of the effective area of the holes was not a smooth function of eccentricity, and that there was a variation of the order of 0.1 NDF units due to mechanical tolerances of the apparatus. The author has found from research undertaken on the perception of short-duration flashed stimuli that a smooth relationship between stimulus size and eccentricity does not occur, and a study of receptor density over the retina would not indicate this. Though a variation of 0.1 NDF units due to mechanical tolerances is well within normal physiological variations, this amount is much higher than that found by the British Scientific Research Association.

Measurements with a flash-photometer showed that the luminance of the white translucent screen placed over the face of the hemispherical bowl integrator and behind the front plate assembly, gave a random variation of approximately 0.1 NDF units between various point on the screen. Previous photometric measurements by the author would indicate a similar luminance variation.

The conclusion was that in the worst case cumulative error from the causes discussed would be approximately 0.2 NDF units. Variations in sensitivity should not therefore be considered to have occurred in a patient's

field until a change of 0.4 NDF units had been recorded. This possible 0.2 NDF units degree of error was confirmed in the British Scientific Association's report. Reductions of differential threshold contrast of only 0.4 NDF units or over are taken as being possibly abnormal for clinical purposes.

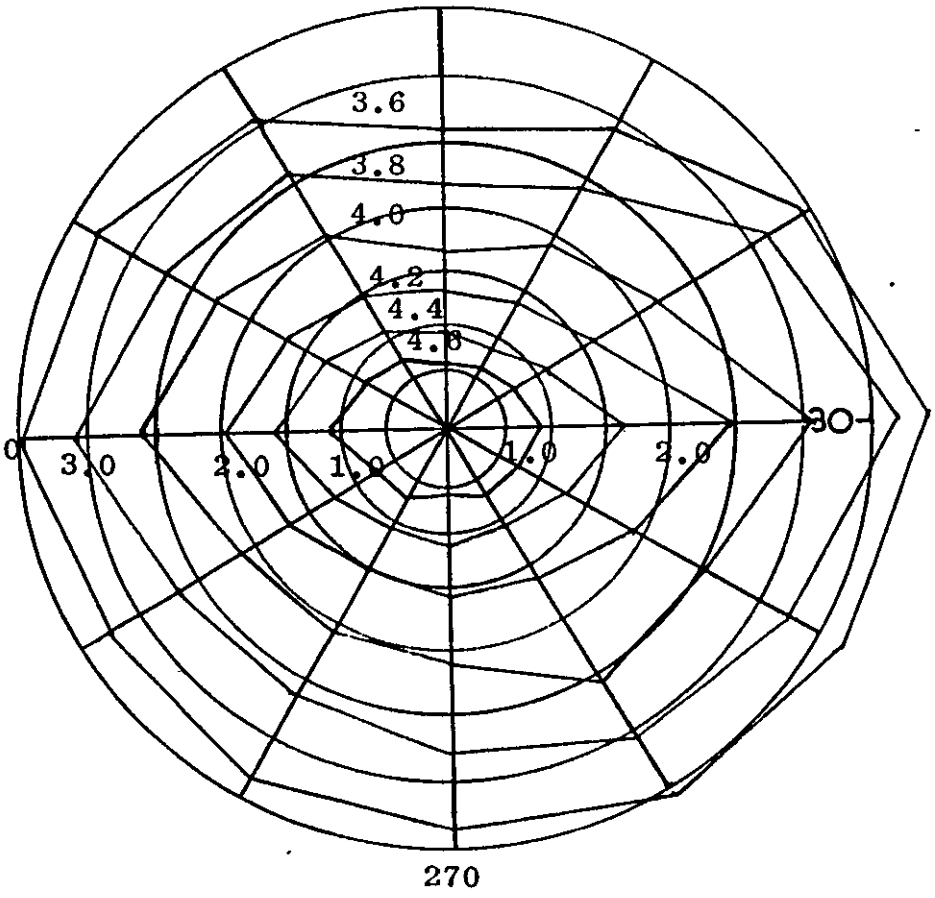
It is felt that the work of independent investigators confirms that of the author on the photometric effect of variations in tolerances, and the variations in normal perceptual response of the stimulus associated with them.

XII

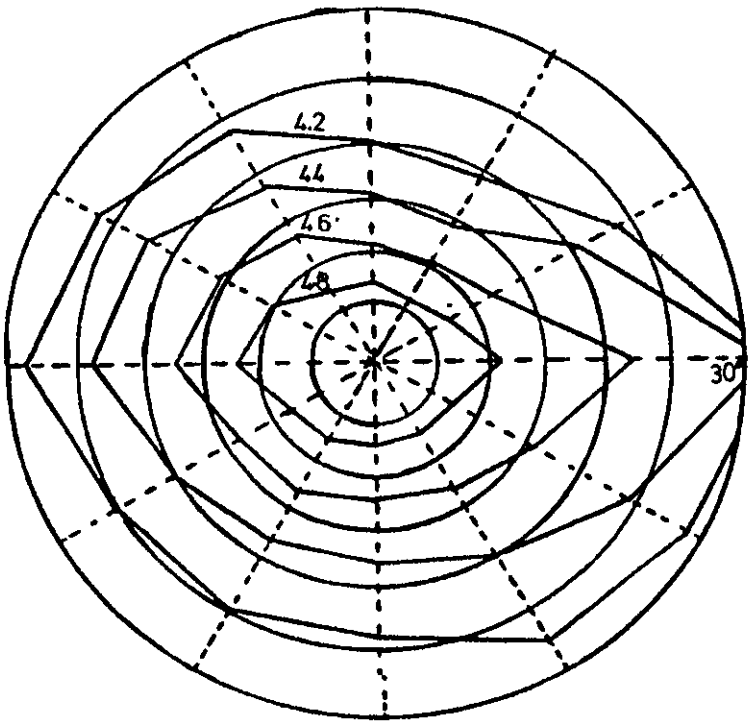
BASIC RESEARCH ON THE PERCEPTION OF SHORT-DURATION FLASHED STIMULI.

It was found that very little useful data had been published on the perception of short-duration flashed stimuli, which could be applied to visual field investigation. To enable a clinical assessment to be made of what might be an early abnormal reduction of differential threshold contrast over the mid-peripheral field of vision, an initial assessment of normal variations of threshold contrast with eccentricity was made when first designing the apertures for stimuli on the front plate of the instrument. Here a series of carefully undertaken trials were made to determine what variations of angular subtense of stimuli were required to obtain an average even physiological threshold of response for a given stimuli luminance, and state of retinal adaptation,(see Section IX).

In addition to the above, a programme of basic research on the perception of flashed light stimuli was conducted by Bedwell together with Obstfeld, to add to the experimental data previously obtained during the initial trials, (Bedwell 1967, 1971, 1972, and 1974, Bedwell and Obstfeld 1972, and Obstfeld 1968, 1971, and 1974). An increased range of adaptation luminances of 0.1., 0.5., 1.0., and 1.5 milli-lamberts were employed with two different sizes of stimuli, subtending 12 minutes and 24 minutes at the eye. By this means data could be obtained on the perception of stimuli up to 30^{o} eccentric, at, and



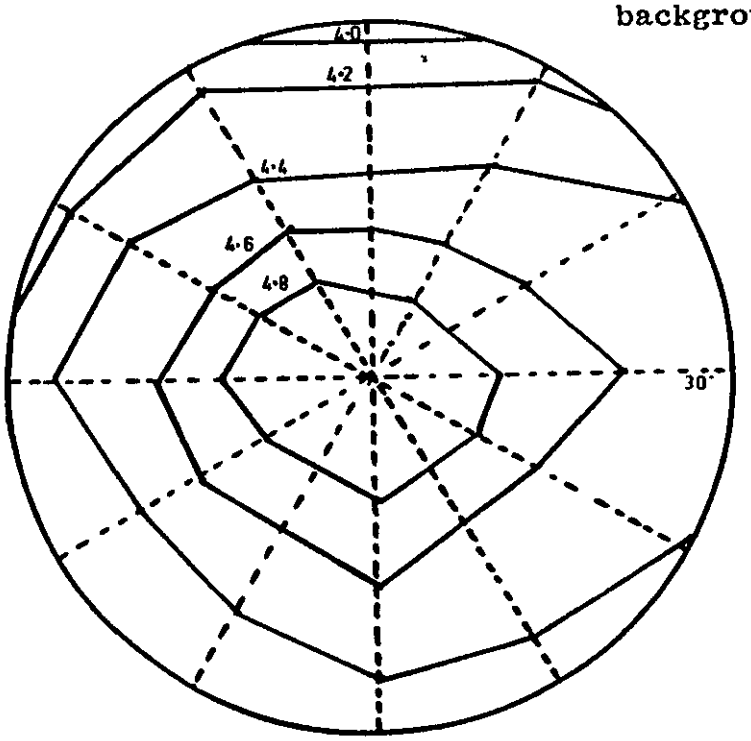
(c) 12' at 1.5 milli-lamberts adaptation.



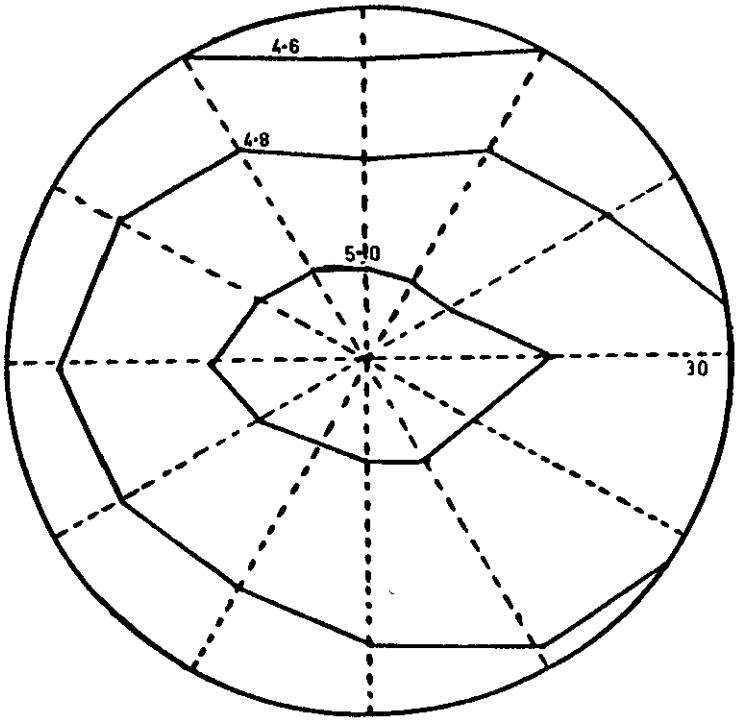
(d) 12' at 0.5 milli-lamberts adaptation.

Fig 49.

Typical isopters for differential threshold contrast for stimuli of 24' and 12' for 1.5 and 0.5 milli-lamberts background luminance.



(a) 24' at 1.5 milli-lamberts adaptation.



(b) 24' at 0.5 milli-lamberts adaptation.

somewhat above the level of retinal adaptation, and within the limits of the stimulus size, employed in the new instrument.

For this research a single central stimulus, (Obstefld 1968 and 1974), was exposed at the centre of a black screen, retinal adaptation was controlled by a visual field screen illuminator designed by the author, and varying eccentricity/by requesting the subject to fixate obtained at pre-determined positions on the screen indicated by a projector. The right eyes of 20 young adults were examined for each of the background luminances and stimuli sizes. The neutral density filter required to obtain threshold visibility at a certain point of eccentricity was recorded. The criteria for threshold response was as previously discussed, 3 out of 4 responses to be positive. Contours or isopters were then drawn indicating the neutral density filter required over the field for that particular stimulus size and background luminance. Typical isopters of threshold contrast are shown in Fig 49, and fully in Appendix C.

For these various combinations of stimuli sizes and levels of retinal adaptation, the average threshold gradients and standard deviations were calculated for different sections

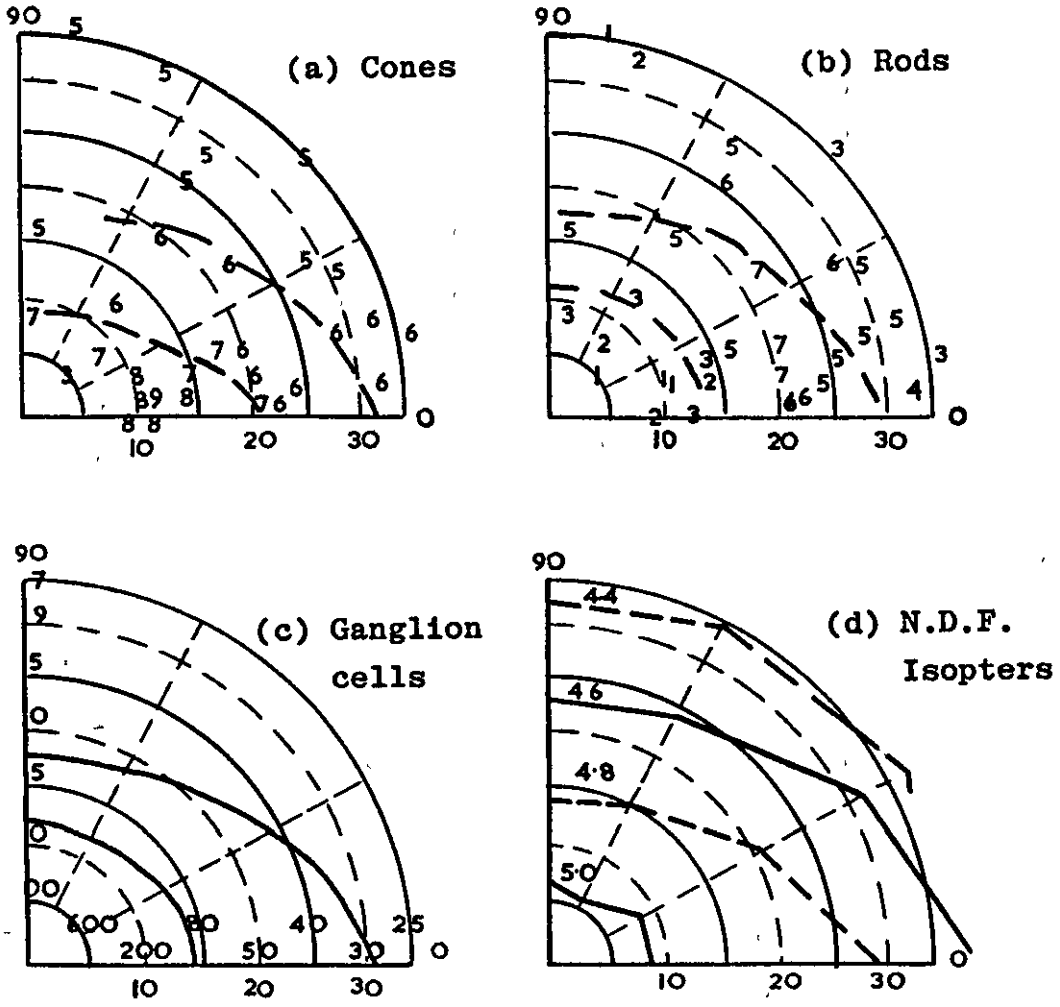


Fig 51.

The relation of retinal receptor and ganglion cell population to contours of similar differential threshold contrast for the upper right temporal field.

(a) Cones x 1,000

(b) Rods x 10,000 + 100,000

(c) Ganglion cells per 100 u^2

(d) Isopters for a stimulus of 12' and a background luminance of 0.5 milli-lamberts.

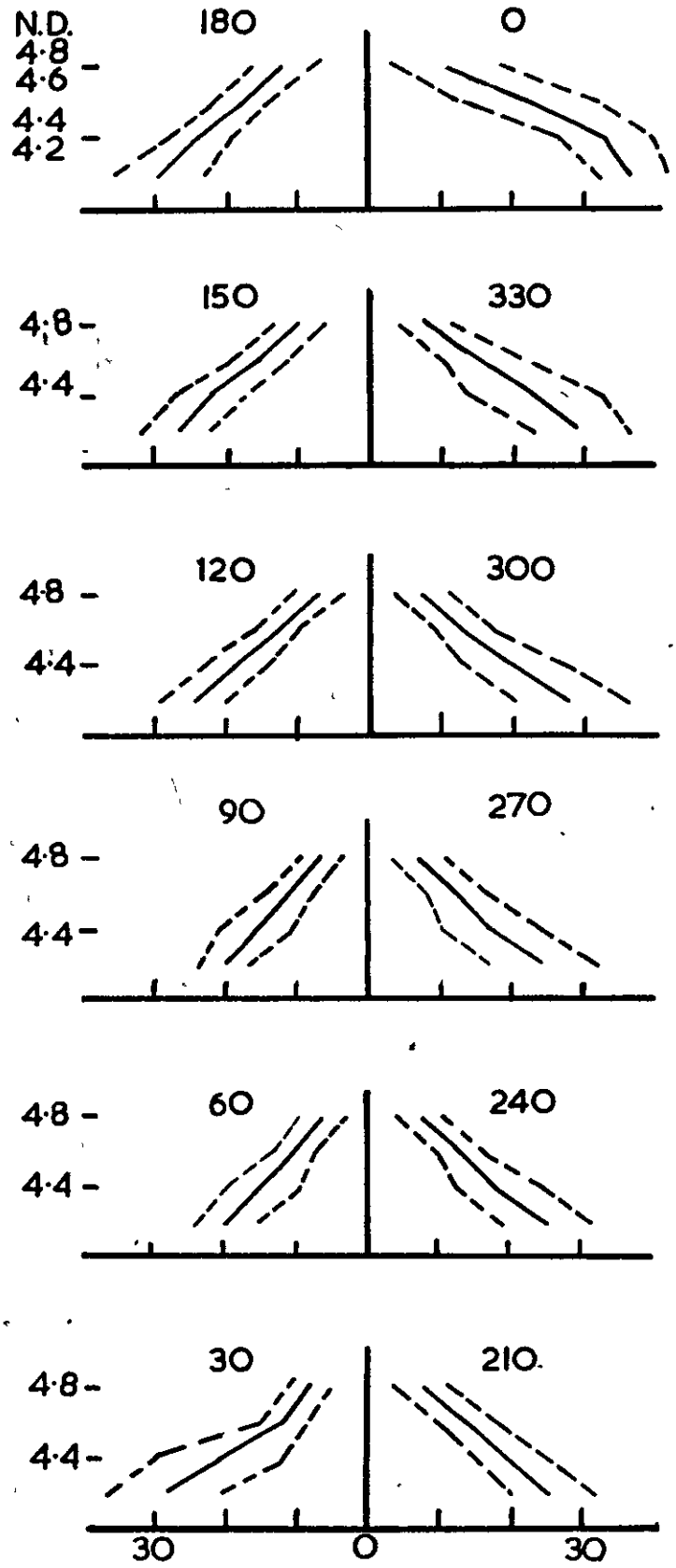


Fig 50.

Typical mean threshold gradients and standard deviations of differential threshold contrast for different sections through the visual field for 12' stimulus at 0.5 millilamberts background luminance.

through the field as shown in Fig 50 and illustrated fully in Appendix. C.

The Effect of Change in Adaptation and Stimulus Size on Differential Threshold Contrast.

The shapes of the isopters tended to be oval, and followed the contour that one would expect on consideration of the distribution of retinal receptors and ganglion cells, (Bedwell and Obstfeld, 1972), and illustrated in Fig 51. The shape of the isopters found for this type of stimulus was in keeping with that found for constantly exposed, and long duration stimuli, used in visual field investigation by other researchers, e.g. Goldmann, 1946.

It was found that the spacing between successive isopters tended to decrease with increasing background luminance, and the slope of the threshold gradients tended to increase in sympathy, as one would expect from consideration of retinal physiology. From examination of these gradients it was found that for a linear increase in stimulus eccentricity there was a straight line characteristic to the curve for N.D.F. units to obtain threshold,indicating a logarithmic relationship between eccentricity and stimulus luminance. As background luminance increased, differences in sensitivity between different parts of the visual field tended to show up more decisively.

The shape of the successive isopters varied from oval in the centre, to egg-shaped in the periphery,

because of the influence of the blind-spot in the temporal field. The upper half of the field was smaller than the lower half, and the isopters were straight at the top. The nasal half of the field was smaller than the temporal, and the upper temporal quadrant was smaller than the lower quadrant.

Accuracy in determination of thresholds tends to decrease with increasing eccentricity of viewing. For a given stimulus and luminance condition, as angular displacement from fixation increased so did the standard deviation of displacement, as detailed in Appendix C. This standard deviation varied from approximately 2.5^{o} near the centre of the field to between 5^{o} to 7^{o} at the periphery. In the periphery of the visual field, along the 60^{o}, 30^{o}, 0^{o}, and 330^{o} meridians, the threshold gradients were at their most linear. Over these areas the standard deviation was greatest because of the greater variations of retinal physiology in the periphery, and because of greater difficulties in subjective perception.

Jayle, Vola, Aubert and Braccini (1965) also found an increase of standard deviation with increasing eccentricity using a longer duration of stimulus exposure. As well as the above authors, Bedwell and Obstfeld (1972) found for their short duration stimuli that to achieve threshold, an approximately logarithmic increase in stimulus luminance was accompanied by an approximately linear increase in stimulus eccentricity.

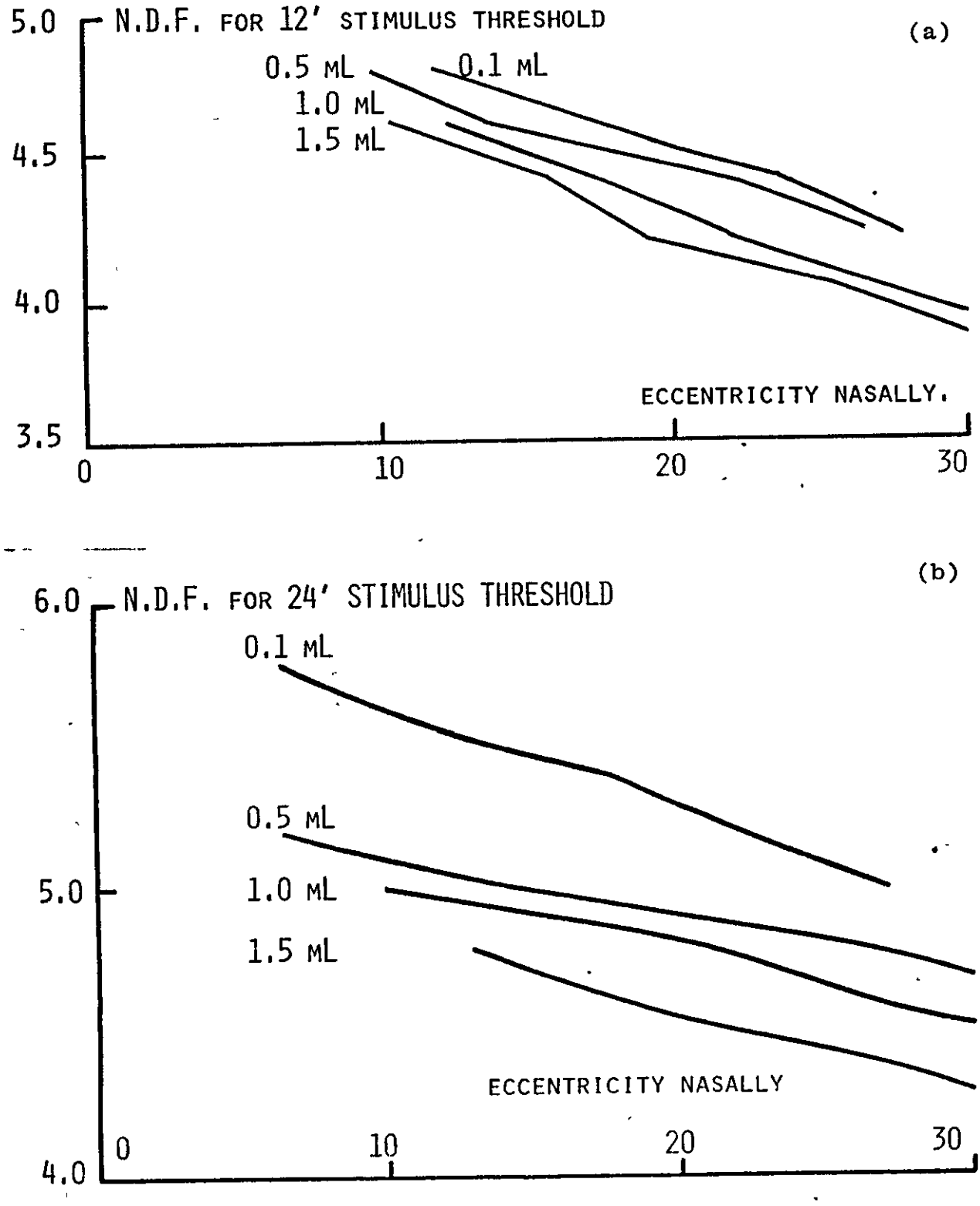


Fig. 52 Average relation along the nasal meridian between differential threshold contrast and eccentricity for background luminance of 0.1,0.5,1.0, and 1.5 milli-lamberts.

Michon and Kirk (1963) and Fankhauser and Schmidt, (1960), found a similar relationship between stimulus luminance and eccentricity.

An interesting finding by Bedwell and Obstfeld in this research was the larger separation of isopters over a large part of the 10^{o} to 20^{o} part of the visual field, where rod receptor is at its densest, and a related high ganglion cell population is present. This feature was particularly evident for the larger stimulus subtending 24 minutes at the eye. This aspect of the research confirmed findings by other workers such as Sloan (1961), Cibis and Muller (1948), and Mandelbaum and Sloan (1947).

The relationship between stimulus luminance and eccentricity tends to be more regular between observers along the horizontal nasal meridian of the field than for the other meridians. The effect of retinal adaptation on stimulus luminance and eccentricity for stimuli subtending 12 minutes and 24 minutes at the eye is therefore shown in this meridian for background luminances of 1.5, 1.0, 0.5, and 0.1 milli-lamberts, in Fig 52 (a) and (b), based on research discussed in Bedwell, (1972). In both cases the gradient of the curve of eccentricity plotted against stimulus luminance tends to be fairly flat, indicating that the levels of adaptation used are near the photopic/mesopic border. For a marked photopic state of adaptation the curve would rise more steeply towards central fixation whereas for a scotopic state the curve would decline from central fixation.

The standard deviationsof eccentricity for differential threshold contrast for each of the curves shown in Fig 52 (a) and (b) for eachof the combinations of background luminances and stimuli sizes are tabulated in Appendix C. These standard deviatıons are shown superimposed on the individual curves. The standard deviations for threshold (obtained graphically) are also shown superimposed on these curves. Fig 53 (a) and (b) show the two curves for the 12 minute and the 24 minute stimulus at 0.1 milli-lamberts background luminance. In these two cases there is a clinically significant separation of approximately 0.5 N.D.F. units bewteen the means. There was also a separation of 0.2 N.D.F. units (the average limits due to phsyiology) between the mean less the standard deviation for the 24 minute stimulus and the mean plus the standard deviation for the 12 minute stimulus. A background luminance of 0.1 milli-lamberts is of course the level of adaptation used in the Visual Field Analyser and therefore of particular interest.

At 0.5 and 1.0 milli-lamberts there is still a clinically significant separation between the curves and standard deviations, but the separation, though still likely to be clinically significant, decreases slightly at 1.5 milli-lamberts. This data illustrates the importance of standardisation and control of background luminance in the clinical investigation of thresholds.

SPATIAL SUMMATION.

Spatial summation was found to increase with eccentricity, to decrease with background luminance, and tended to vary along different meridians. For spatial summation to occur, the retinal area covered by the image of the stimulus must contain sufficient receptor units with appropriate neural interconnections to achieve stimulation.

The average co-efficients of summation for stimuli exposed for 300 micro-seconds and subtending 12 minutes and 24 minutes at the eye for 4 levels of background luminance are shown in the table below, from Bedwell (1974).

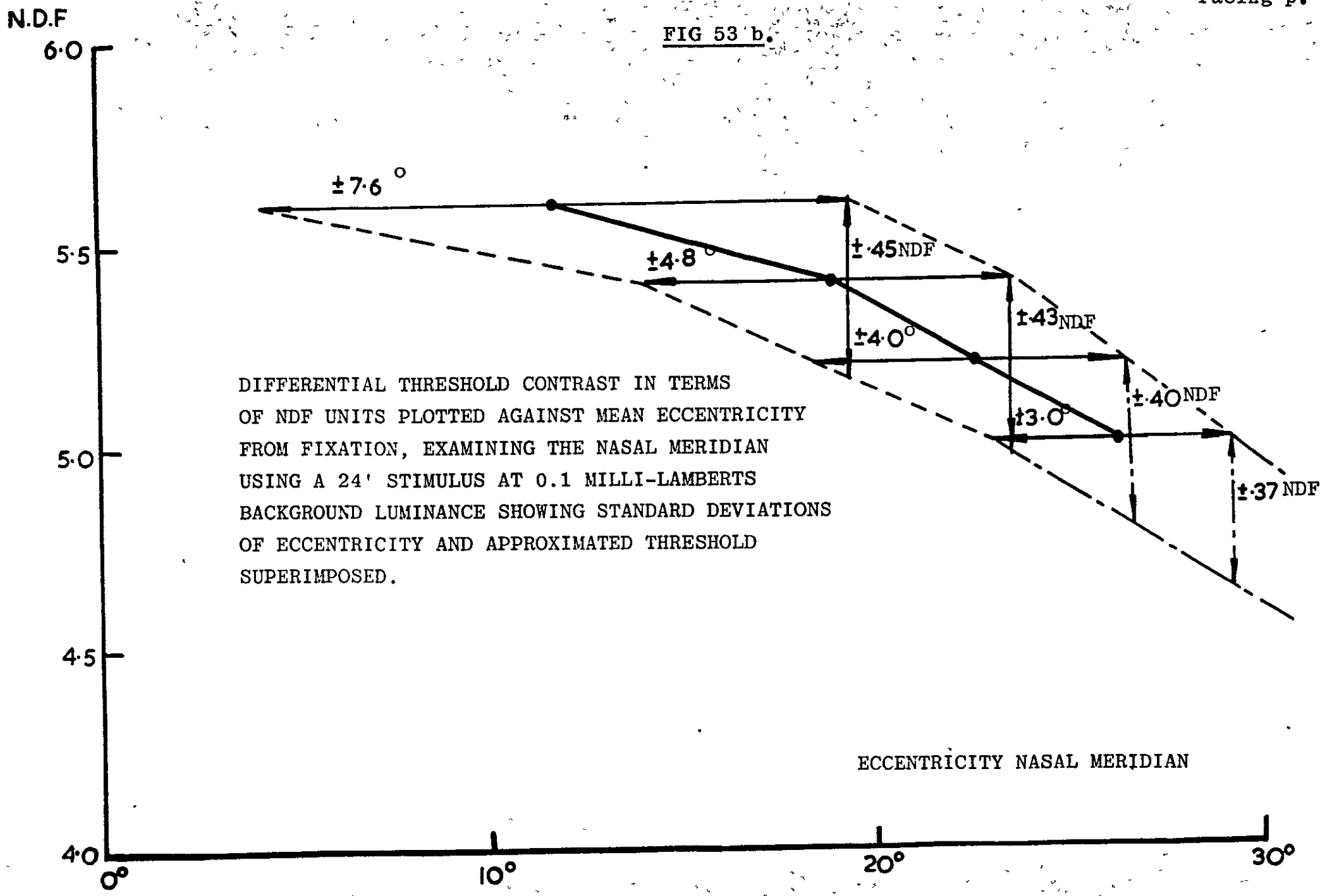
SUMMATION CO-EFFICIENTS.

BACKGROUND LUMINANCE.	ECCENTRICITY.		
Milli-lamberts	10	20	30
0.1	(1.3)	1.5	(1.4)
0.5	(0.6)	0.95	(1.3)
1.0	(0.8)	1.1	(1.4)
1.5	(0.7)	0.9	1.0

Figures between brackets include estimated values.

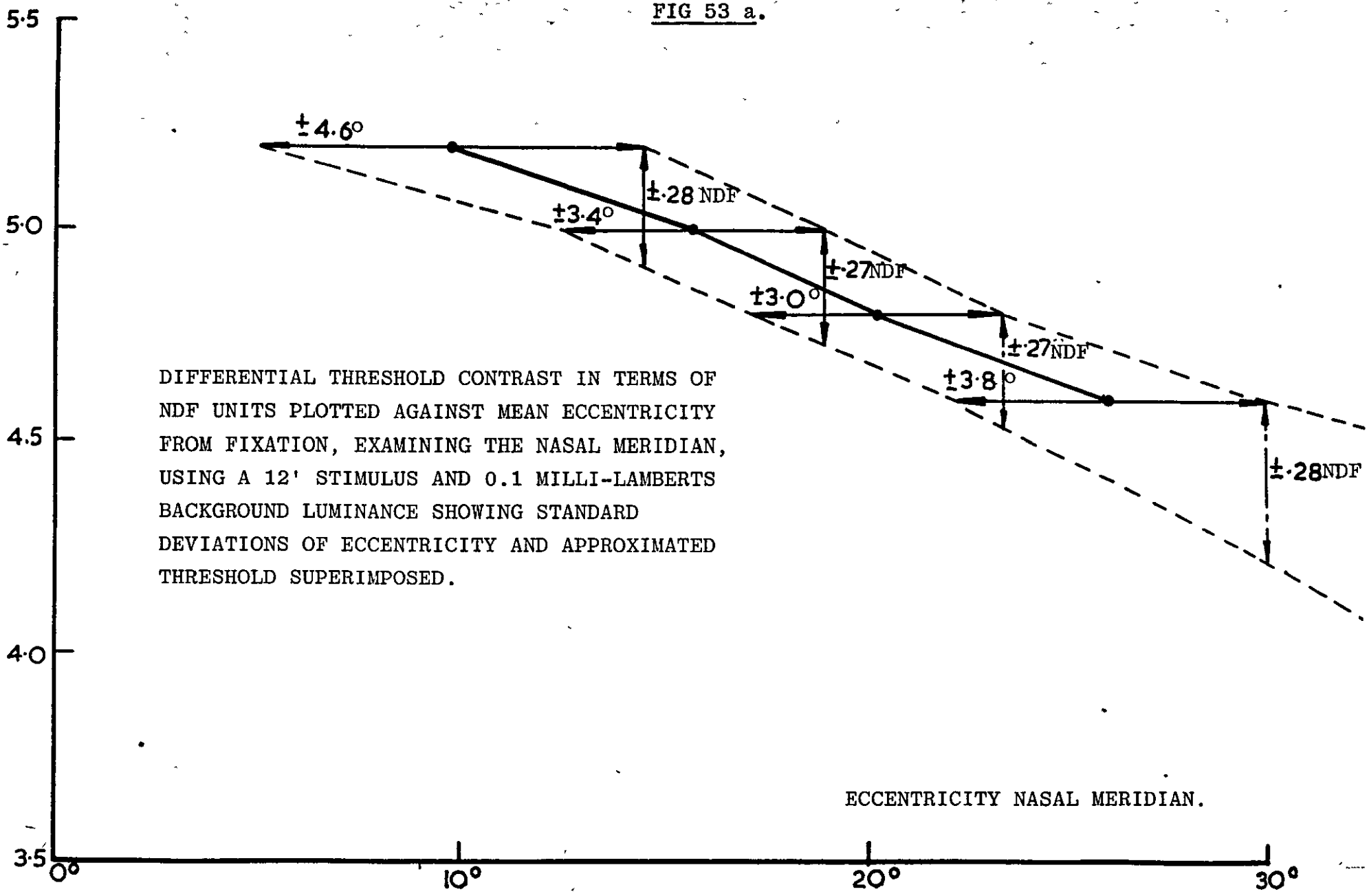
The findings on summation in this research are confirmed in principle by Fankhauser and Schmidt, (1958), who with a different type of stimulus also found that summation decreased with increasing stimulus size, and also with increasing background luminance.

FIG 53 b.



DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN USING A 24' STIMULUS AT 0.1 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.

FIG 53 a.



DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN, USING A 12' STIMULUS AND 0.1 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.

As it appears that deterioration of summation may occur in certain ocular pathological conditions, the employment of a level of background luminance near the photopic/mesopic border, which increases the co-efficient of summation in the normal subject, should be a clinical advantage when investigating the abnormal subject.

XIII

THE INVESTIGATION OF THE RESPONSE OF NORMAL SUBJECTS BY MULTIPLE STATIC STIMULI.

(A) Differential Threshold Contrast in Normal Subjects.

The assessment of differential threshold contrast for normal observers, (Section X), obtained using a prototype instrument, provided adequate initial data for the application of the technique of multiple static quantitative perimetry to the routine investigation of the normal visual field, and for the detection of abnormality.

When the Analyser was in production it was felt that a more rigorous study of the threshold responses at each of the stimuli positions was required to provide additional data on normal subjects.

The original front-plate apertures were designed to allow for average variation in differential threshold contrast over the mid-peripheral field out to 25^{o}. Neutral density filter, N.D.F., settings were suggested for different age groups that might give thresholds that were just sensitive enough to detect the commencement of abnormal reductions of threshold.

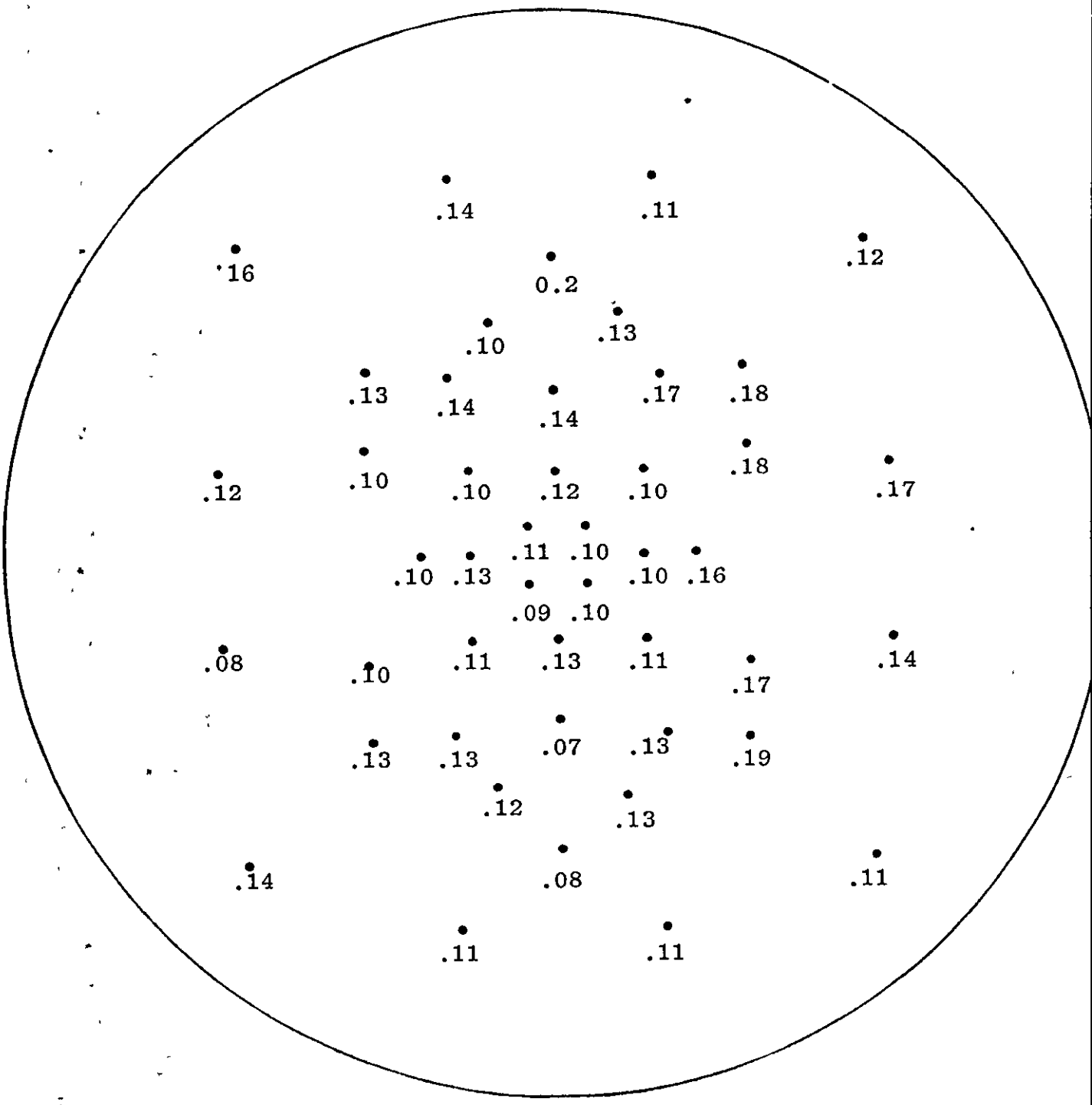


FIG 55.

THE STANDARD DEVIATIONS OF NORMAL THRESHOLD.

The standard deviations of differential threshold contrast in terms of N.D.F. Setting, for each of the 46 stimuli positions over the Visual Field Analyser front. The right eyes of 26 normal young adults were examined.

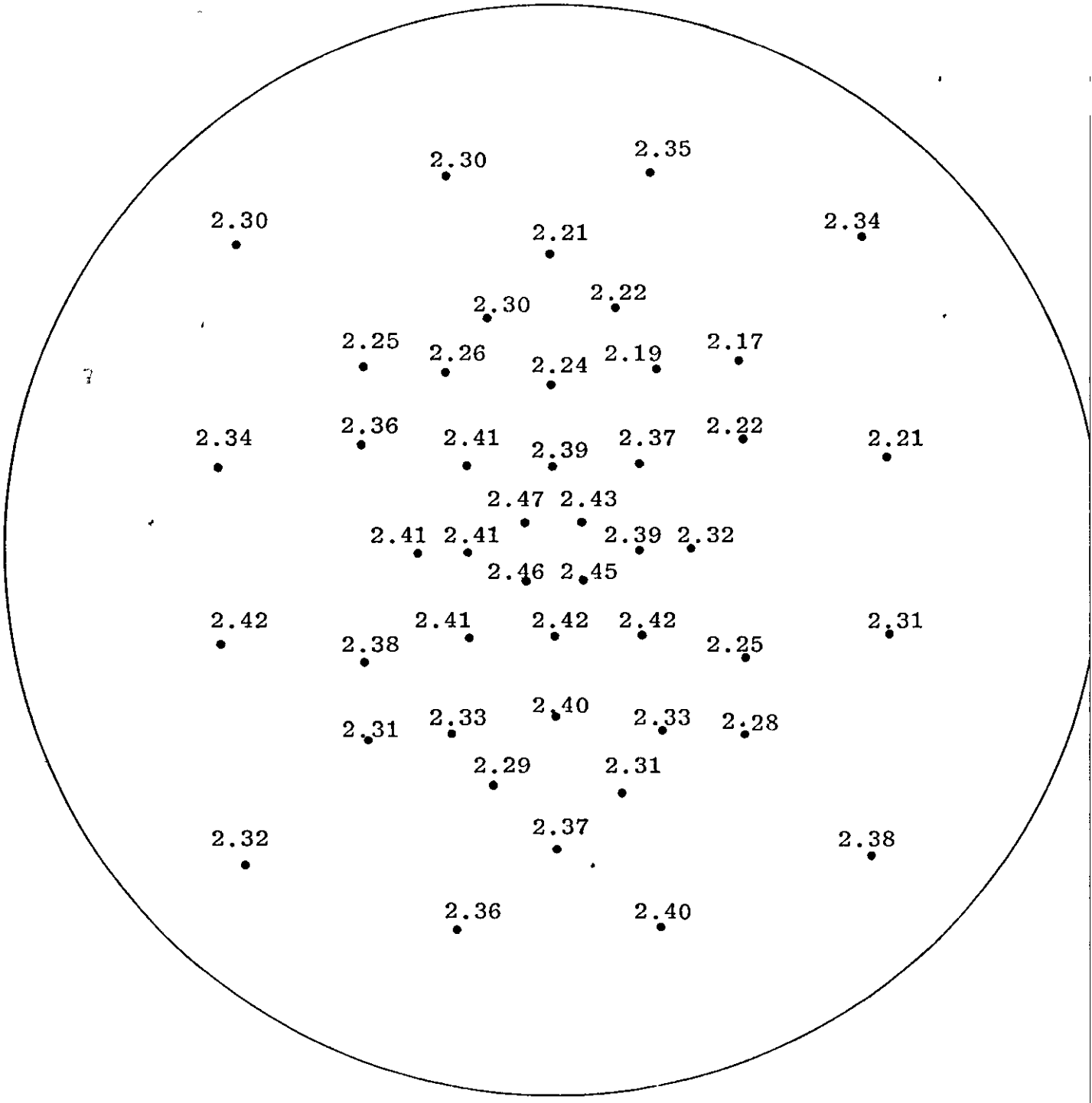


FIG. 54.

MEANS OF NORMAL THRESHOLD.

The mean values of differential threshold contrast in terms of N.D.F. setting, for each of the 46 stimuli positions over the Visual Field Analyser front. The right eyes of 26 normal young adults were examined.

Mean of above means 2.3

Variations in neutral density filter setting were therefore determined for 26 normal right eyes of a group of young adults. Individual threshold visibility was determined at each of the stimuli positions. The criteria for perception at threshold was that 3 out of 4 responses should be positive.

The detailed results from this survey are contained in Appendix D, showing the neutral density filter setting required for response at threshold, at each of the stimuli positions for the individual subjects.

The means of the filter setting were calculated for each stimulus position for the 26 right eyes, and are shown in Fig 54. The standard deviations of these means are shown in Fig 55.

The difference between the means of the thresholds over the field is of the order of 0.2 N.D.F. units. Considered in relation to the standard deviations for the different stimulus positions, and the slight differences in response between the temporal and nasal fields, it would appear that the attempt to achieve an average threshold response over the field is satisfactory.

In any sample of a population, the values obtained from a range of twice the standard deviation are more meaningful clinically than when only one standard deviation

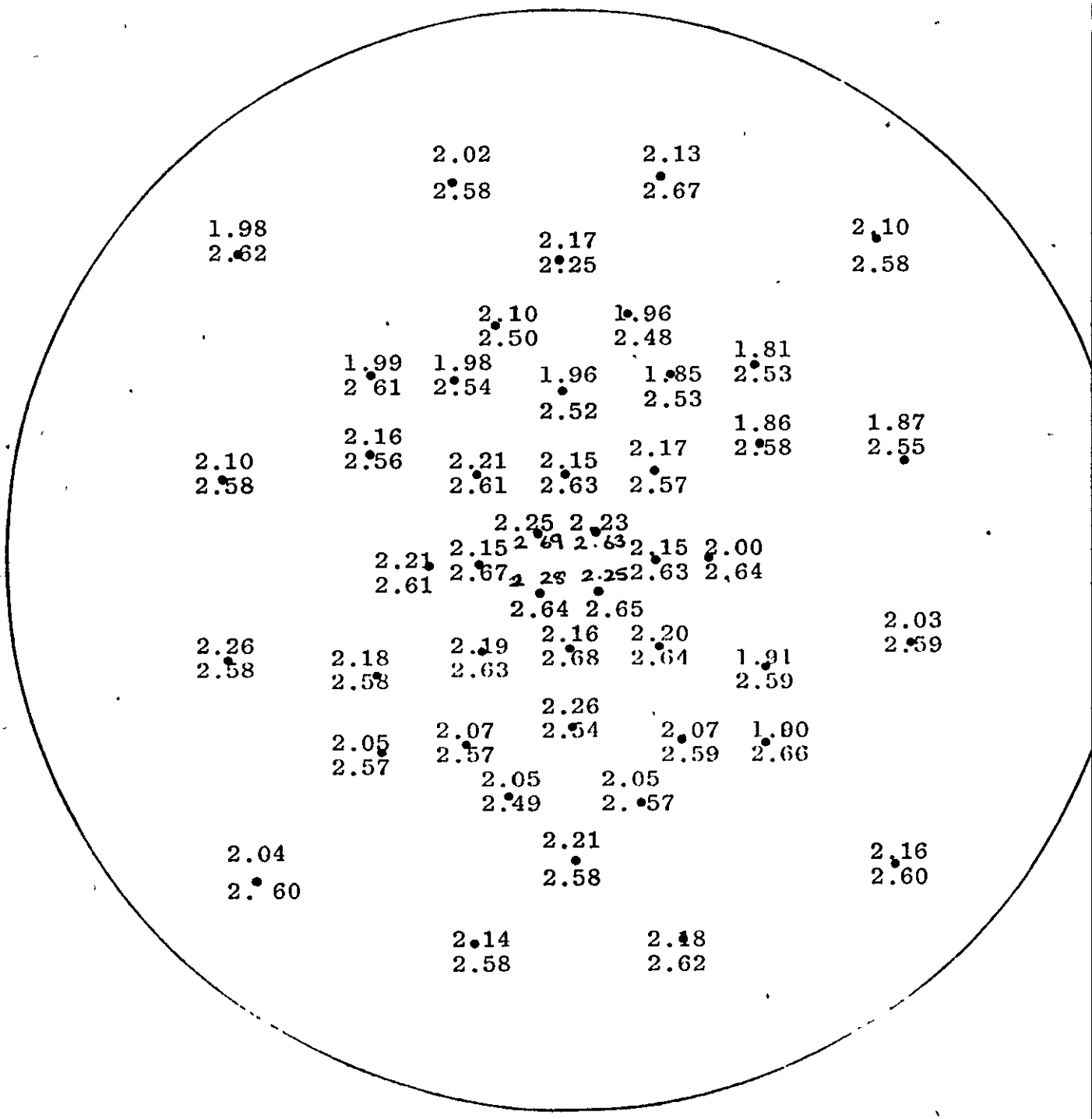


FIG 56.

Minimum and maximum N.D.F. values for differential threshold contrast for the right eye based on 2 x ± the standard deviation containing 95% of sample of normals.

is employed. The minimum and maximum N.D.F. values based on these means and twice the standard deviations, and therefore containing 95% of the sample, are shown in Fig 56.

Examining the range and locations of these variations indicates an expected variation in thresholds over the field, which tends to increase from the centre to the periphery. In particular there appears to be a greater variation in the immediate arcuate area above and below the temporal side of the field, where the retinal vessels emerge and spread out from the optic disc, as represented by the blind spot on a field chart.

The location and range of variations of thresholds found for these flashed stimuli also compares well with the results of the basic research discussed in Section XII, and they are what would have been expected from a study of the physiological factors involved.

(B) Physiological and Abnormal Variations in Differential Threshold Contrast.

In any group of individuals with no visual field loss there will be a variation both above and below a mean neutral density filter setting for threshold. When any abnormality affecting visual function is present, this will always show up as an increase in differential threshold contrast, or lower N.D.F. values, over the

affected area(s).

During the development, initial trials, and clinical appraisal of the instrument, experience had indicated that a reduction of 0.2 N.D.F. units below the threshold setting for the examination could be taken as being within normal physiological limits. If the reduction was greater than 0.4 N.D.F. units, especially if several points in an area were depressed, then the response was likely to be abnormal.

Examination of the variation of response amongst a sample of normals showed that the mean responses over all stimulus positions for the group is 2.32 N.D.F. units with a standard deviation of plus and minus 0.095. The average minimum threshold is therefore approximately 2.2 N.D.F. units for approximately 65% of this group, and 2.1 N.D.F. units for approximately 95% of this group. For individual stimulus positions the maximum reduction of threshold for approximately 95% of this group against the mean of 2.3. N.D.F. units would be approximately 0.5 N.D.F units.

The approximate allowance for physiological variation in threshold of a reduction of 0.2 N.D.F. units below an average threshold appears to be the reasonable minimum based on this study of normals. A reduction of 0.4 N.D.F. units below this mean seems to be a conservative

allowance for phsyiological variation. A reduction of more than 0.4 N.D.F. units from the normal suspected threshold therefore appears to be needed to indicate the beginning of an abnormal response.

(C) Stimuli Luminance for Clinical Investigation.

For a clinical examination of a group of young adults the initial guide setting for age of 2.0. N.D.F. units and under would permit the detection of the beginnings of abnormal loss. This setting would apply for a maximum local threshold of just over 2.4 N.D.F.units.

In the case of this group of young adults the minimum threshold would be approximately 1.8 N.D.F. units and the maximum 2.6 N.D.F.units, considering all the stimuli positions. To detect abnormality near the maximum threshold a neutral density filter setting of 2.2 N.D.F.units would therefore be safer, as recommended earlier, even though there could be some random negative responses for the positions of minimum threshold.

When a higher sensitivity of investigation is felt desirable clinically, then a setting of 0.2 N.D.F.units below the approximate individual thresholds would be advisable. Based on a knowledge of the variations in response obtained in this study, stimuli positions N1,2,3, and 4, give a reasonably consistant response,

and could be used to assess this individual threshold setting. For special cases it is possible to commence the investigation at an infra-threshold setting and record the threshold for each individual stimulus position, as was done in this investigation.

(D) Other Research on Clinical Thresholds.

Greve (1973) undertook a similar study on 21 normal subjects, and found somewhat the same individual variations as the author. Like the author Greve commenced all his visual field investigations at below threshold settings. Initially the patient did not see the stimulus when flashed. The luminance was then increased by 0.2 N.D.F. units until the threshold for the different stimulus positions had been obtained. A local reduction of threshold contrast of 0.4 NDF units lower than the general threshold for the other stimuli positions may be taken as an early loss of sensitivity. The results obtained could be influenced by individual differences of steepness or flatness of differential threshold contrast from the centre to the periphery in different meridians. For the centre stimuli positions P and O Greve found that a slightly higher level of stimuli luminance or lower N.D.F. value may be found. This latter finding was not confirmed in the author's survey.

In Greve's study of 21 normal subjects, differences in threshold contrast of 0.2 N.D.F. units over all the stimuli positions were found for all subjects. In 6 subjects differences of 0.4 N.D.F. units, and in 3 subjects differences of 0.6 N.D.F. units were found.

Greve (1973) pointed out that the physical size of the stimuli did not increase with a smooth, nearly linear course with eccentricity. Research undertaken by Bedwell and Obstfeld (1972), indicated that the sensitivity gradient with eccentricity was not linear over most of the retinal area. This non-linearity would really be expected from a study of the differences of retinal receptors and their population and system of neural interconnections.

XIV

SCREENING OF THE VISUAL FIELD FOR ABNORMAL VISUAL FUNCTION BY MULTIPLE STATIC QUANTITATIVE PERIMETRY.

The problem of differentiating between abnormal and normal visual responses, and hence the detection of visual loss, was approached in two ways. The first was to use the instrument in clinical investigations at settings of differential threshold contrast just above average threshold, and examine further those who did not pass the screening proceedure. The second approach, which really had to be taken as a combined operation with the first, was to undertake extensive clinical trials on patients referred for visual field investigation, and on those returning for periodical re-examination, and compare the data with that from the then generally accepted techniques of visual field examination.

In the early stages of development Friedmann compared the data obtained from an examination of patients using a Visual Field Analyser, with that obtained using the Bjerrum screen and the Goldmann bowl perimeter, (Friedmann 1966).

The results of this work showed that it was possible to detect more readily clinically significant central visual field defects by employing this new approach than was possible by the Bjerrum screen or the Goldmann bowl perimeter techniques. The reason is that with kinetic

perimetry it is very difficult to examine near threshold responses over the whole field, and thus early losses can readily be missed. With multiple static quantitative perimetry all the stimuli could be set near threshold, and a quick assessment of any loss, both in area and degree was possible. As indicated earlier, single point static quantitative perimetry could really only be used in everyday clinical practice where indications of localised depressions had already been found by the kinetic approach, using the Goldmann bowl perimeter. Even then the time taken for the investigation was excessive for busy clinical conditions.

The author was more concerned with using the instrument for the detection of early visual field loss in patients presenting themselves for a routine eye examination, and then referring those who were felt to be abnormal for a further investigation. Mr Friedmann was particularly concerned in using multiple static quantitative perimetry in the efficient and sensitive investigation of patients with a suspected abnormality, where the ready detection of visual loss, both as regards size, position, and relative density, was a very considerable advantage in patient management.

(A) Screening for Visual Loss.

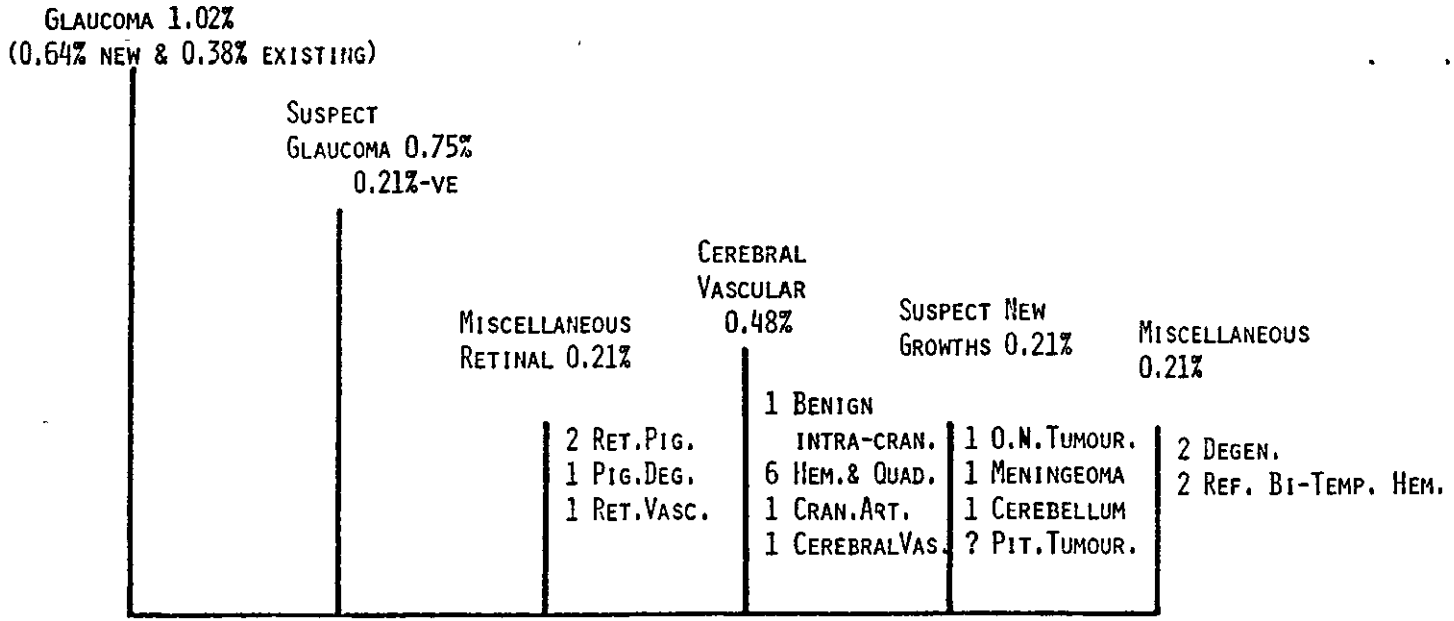
In order to obtain a better overall picture of the proportions and types of visual field defects likely to be

detected with this new approach, the author undertook a study of 1860 patients attending for routine ophthalmic examination. It would have been impossible with previous techniques and instruments to conduct a quick and sensitive investigation as a routine procedure, but this was easily achieved with the new instrument. As the risk of pathology in people over 40 years of age is greater than at younger ages nearly all the patients examined were over forty years of age. To be adequately sensitive the filter setting of just below threshold - usually 0.2 N.D.F. units above that recommended for the age - was normally used. A reduction of threshold of more than 0.4 N.D.F. units below this average threshold for the age group was taken as an indication of possible abnormal visual loss, and that further investigation may be necessary.

A number of situations involving readily observable fundus changes were omitted, in particular myopic degeneration, senile macular degeneration, spent choroidal changes, active and passive evidence of retinal haemorrhage, and amblyopia. The purpose of eliminating these types of cases was to indicate the role of visual field investigation in detecting pathological conditions which could not be readily detected by ophthalmoscopy.

The investigation of the visual field using this method of multiple static quantitative perimetry could be undertaken, by an ophthalmic assistant if required, in about three minutes for the two eyes. Because of the experiments

ROUTINE VISUAL FIELD SCREENING USING THE VISUAL FIELD ANALYSER TOTAL DEFECTS 2.86%



TYPES AND PROPORTIONS OF FIELD DEFECTS OUT OF 1860 CASES SCREENED NEARLY ALL OVER 40 YEARS OF AGE.

FIG 57.

C.H.BEDWELL.

Facing p. 119

that had already been undertaken, the number of false positives detected was minimised, and therefore reduced the time spent on investigation. An actual quantitative assessment of loss could be determined on the same instrument as was used for the visual field screening. If it was debatable whether the reduction in threshold was likely to be clinically significant, the patient could be kept under observation, and serial studies made over time, to determine if an active deteriorating situation existed.

(B) The Results of the Survey.

Of the 1860 cases screened, (see Fig 57) 2.86% (54) demonstrated some form of visual field defect. As would be expected, glaucoma was found to exhibit the highest incidence of clinical condition confirmed, of which 12 were newly diagnosed, and 5 already known. Of the 14 with suspected glaucoma field defects, 4 were found later to be clear, and 10 still suspect. Of the 12 new cases of glaucoma detected, 4 appeared to have optic discs within normal limits. A further 2 who showed disc changes when examined by Bedwell appear to have been accepted as normal originally by previous investigators. Of the 12 glaucoma patients detected 9 were found to have raised intraocular pressure, and 3 had normal pressure.

The second main cause of visual field defect was found to be various forms of cerebral vascular lesions,

6 presenting hemianopias or quadranopias, 1 benign intracranial hypertension, 1 cranial arteritis, and 1 general cerebral vascular degeneration. Of the 4 with field defects indicating cerebral new growths, 1 was an optic nerve tumour, 1 a meningeoma, 1 a cerebellum tumour, and the 4th was suspected to have a pituitary tumour, but was found to be clear on subsequent investigation. Of the 4 miscellaneous retinal conditions, 2 exhibited retinitis pigmentosa, one with no pigmentary change over a large inner part of the whole area where visual loss was detected, 1 senile pigmentary degeneration at early middle age, and the 4th exhibited an arcuate field defect which appeared to be associated with a past retinal vascular lesion, not evident on examination with an ophthalmoscope. In addition 2 of these miscellaneous visual field defects appeared to be due to degenerative changes not obvious from ophthalmoscopy, and 2, who exhibited slight bi-temporal hemianopia, were thought on subsequent investigations to have refractive origins.

The number and type of visual field defects found during this survey appeared to amply justify the value of routine visual field screening. The incidence of glaucomatous visual loss was particularly significant. The number of glaucoma cases detected in this survey on visual loss did not include a smaller number who might be detected by significantly raised intraocular pressure alone, as assessed by Goldmann applanation tonometry, or who exhibited closed angle glaucoma. An analysis of the visual loss

detected in the cases of new glaucoma found in this survey will be analysed separately in the next section.

A significant proportion of those whose fields had been screened would have passed the normal ophthalmic examination with a serious condition remaining undetected.

(D) Other Screening Surveys.

Greve (1973) using the Visual Field Analyser for a large screening survey of 1834 supposedly normal subjects, and with a neutral density filter setting of 0.2 N.D.F.units above threshold, found large-scale visual field screening quite possible allowing 5 minutes for both eyes. In nearly 2% of those supposedly normal subjects visual field defects were found, with half demonstrating an intensity of loss of more than 0.4 N.D.F. units. In this large number of subjects only about 1% were found to show false positive responses.

In a comparative analysis of the time taken to examine visual fields, Greve (1973) showed that his technique of infra-liminal threshold, applied to a normal subject could take about 4 minutes. Kinetic perimetry performed on a normal subject takes about 9 minutes. If single stimulus static perimetry had been used in steps of 0.2 N.D.F. units, it would have taken about 12 minutes. Apart from other considerations, a considerable amount of time is therefore saved by using this new technique of

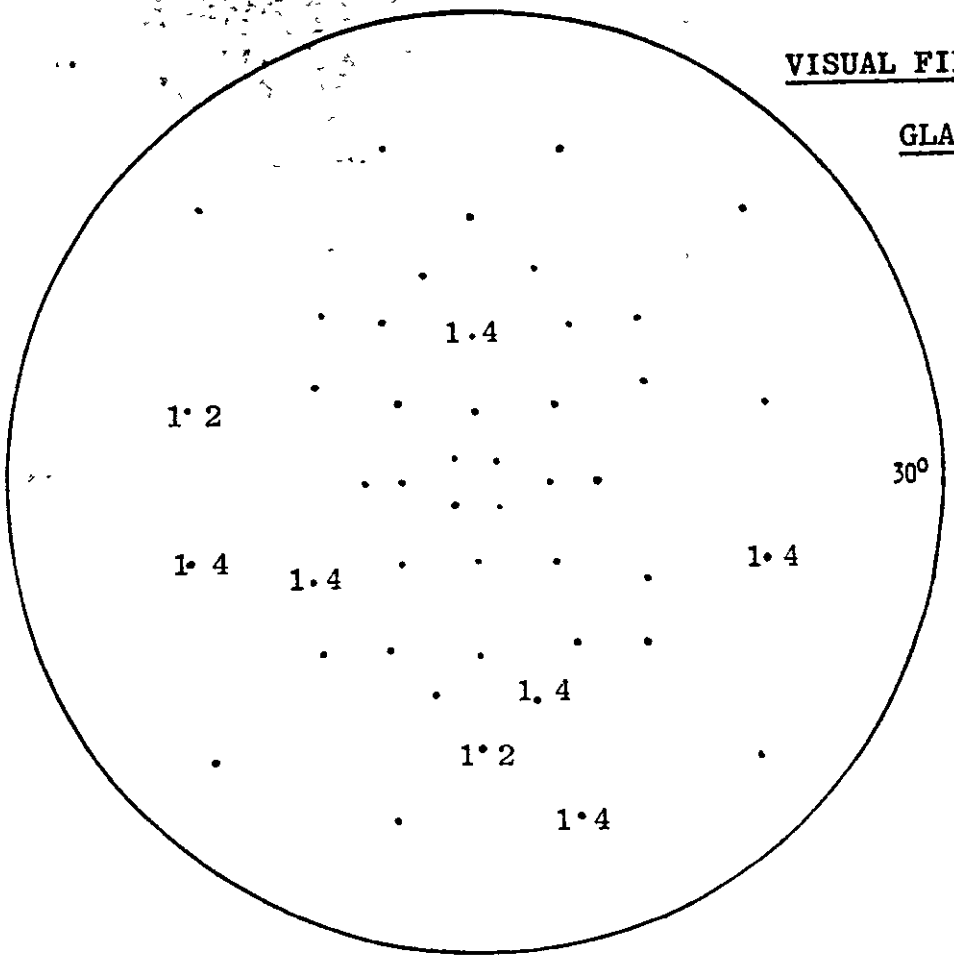
presenting multiple stimuli.

Fewer positions over the visual field are examined by the method of kinetic perimetry than is the case with multiple static quantitative perimetry, and the chances of detecting abnormalities are thereby reduced using a kinetic technique. With the Goldmann perimeter larger steps of 0.5 N.D.F. units are used to control stimulus luminance compared to steps of 0.2 N.D.F. units for the Visual Field Analyser. In the case of static perimetry, greater spatial accuracy is achieved along meridians and isopters examined but outside of them large areas of the visual fields remain unexamined. When a defect has been found with the new instrument the condition can then be more accurately defined by using the procedures of single static perimetry.

The work by Greve (1973) confirms that multiple static quantitative perimetry is a sensitive and effective method of screening out abnormal visual field loss from the normals, and that the investigation can be undertaken more readily and in a much shorter time, than would have been possible by existing classical methods of visual field investigation.

VISUAL FIELD ANALYSER.

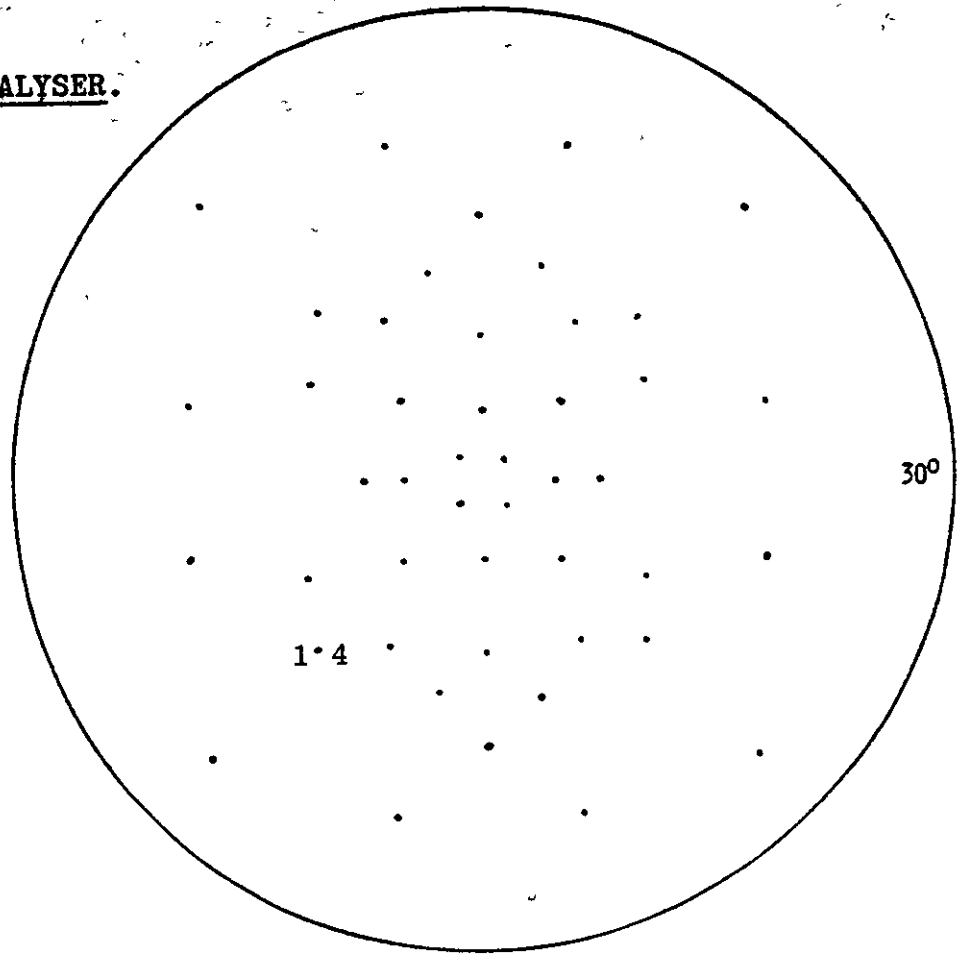
GLAUCOMA.



MR.G. L. V/A 6/7.5- AGE 75

STIMULI NOT MARKED SEEN AT 1.6 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.



MR.G. R. V/A. 6/7.5 - AGE 75

STIMULI NOT MARKED SEEN AT 1.6 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.

FIG 58.

Facing p. 123.

XV

THE INVESTIGATION OF VISUAL LOSS BY MULTIPLE STATIC QUANTITATIVE PERIMETRY IN GLAUCOMA.

(A) Analysis of New Glaucoma Cases Detected.

There are a number of new techniques that can be applied to the investigation of visual loss for individual cases but not readily for routine sensitive screening. In the programme of visual field screening of 1860 patients attending for routine ophthalmic examination the technique of multiple static quantitative perimetry was found to be effective in the detection of visual loss. Of the abnormal conditions producing visual loss, glaucoma was the most common, with total incidence of 1.02% (19) of whom 12 had not been detected before and 7 who were known to have glaucoma from a previous diagnosis. In this sample a total of 19 eyes exhibited glaucomatous field loss. Amongst the new cases of glaucoma it is disturbing to realise that many had an appreciable degree of established visual loss, that they were as yet unaware of this loss, and that it would not have been detected unless the visual fields had been examined as a routine.

Of the 12 new cases of glaucoma detected in this survey, 7 demonstrated field defects in both eyes, 4 in the right eye only, and 1 in the left eye. Typical charts of glaucomatous field defects are shown in Fig 58, demonstrating very early visual loss in the arcuate area, just beginning inferiorally in both eyes and also superiorally in the left. The V.A. was 6/7.5 in each eye, and the optic disc appeared normal. The intraocular pressure by Goldmann

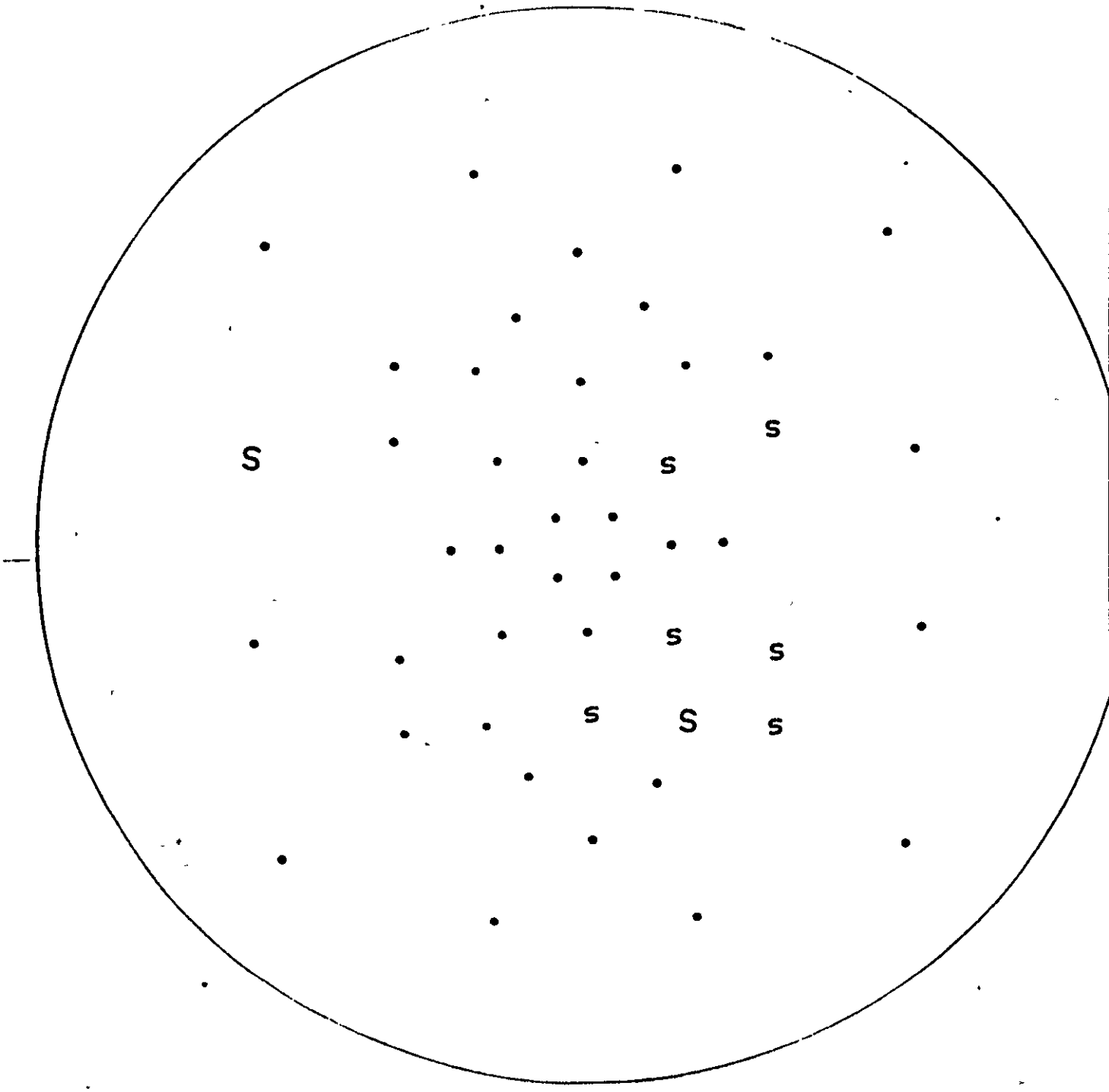


FIG 59 b.

CLINICAL SIGNIFICANCE OF VISUAL LOSS IN NEW GLAUCOMA CASES. - LEFT EYE.

s Demonstrates clinically significant loss of 0.4 N.D.F.

S Demonstrates highly clinically significant loss of 0.8 N.D.F. or more. Mean age 65.

Loss based on initial guide for age of 1.4 N.D.F.

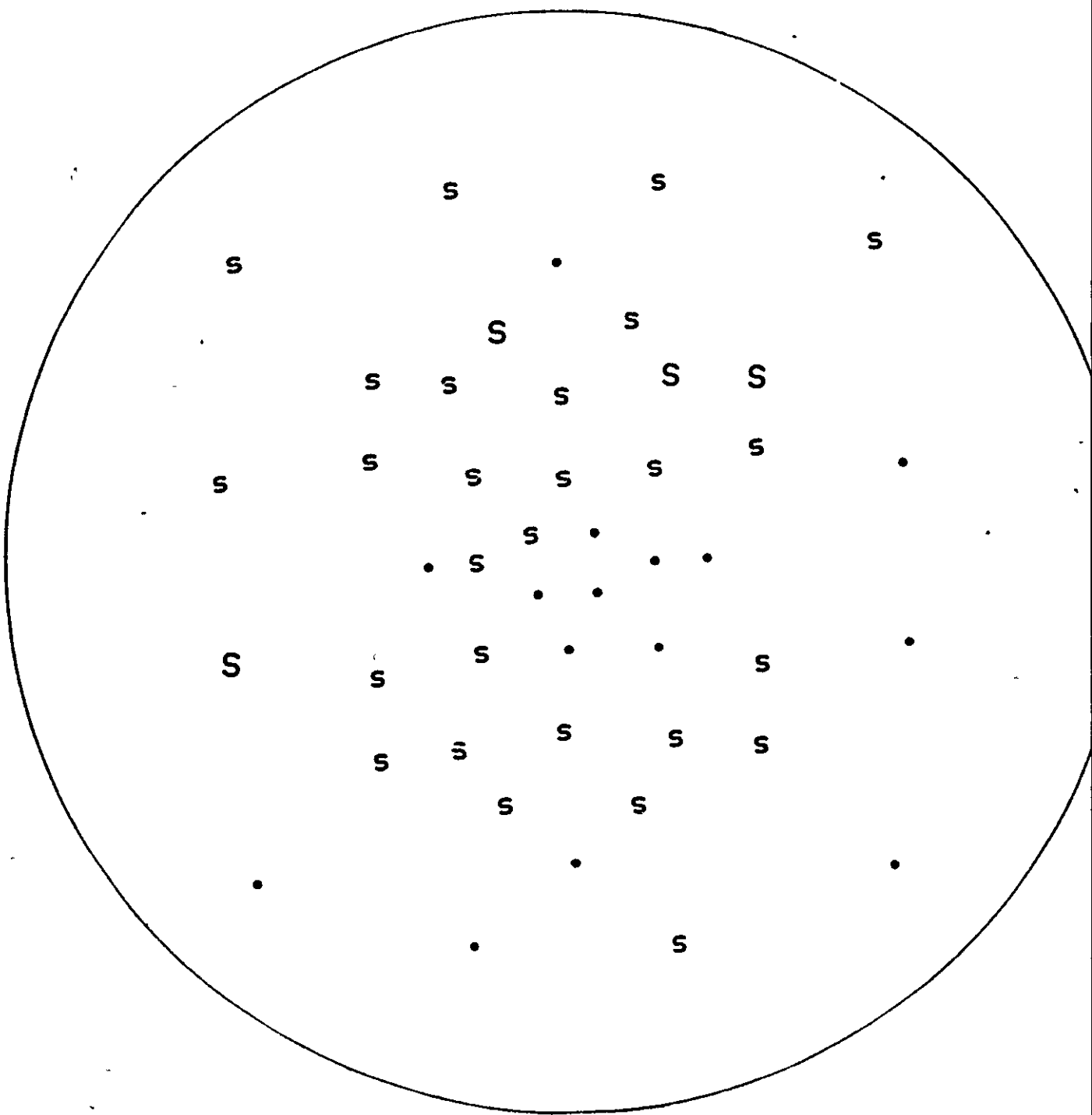


FIG 59 a.

CLINICAL SIGNIFICANCE OF VISUAL LOSS IN NEW GLAUCOMA CASES - RIGHT EYE.

s Demonstrates clinically significant loss of 0.4 N.D.

S Demonstrates highly clinically significant loss of 0.8 N.D.F. or more. Mean age 60.5 years.

Loss based on initial guide for age 1.4 N.D.F.

applanation was 27 mm.Hg in each eye. These early losses could not be detected on the Bjerrum screen with 1/1000 white target.

(B) The Clinical Significance of the Visual Loss Detected.

The mean thresholds of response in terms of N.D.F. units for the glaucomatous cases for the different stimulus positions for the right and left eyes are shown in Appendix E with relevant standard deviations. The mean age of the group was 60.5 years for those with right eye field defects, and 65 years for those with left eye field defects. The mean normal threshold for age based on the original data for threshold and age, averaged over the stimuli positions, would have been 1.7 N.D.F. units for the right eye, and 1.6 N.D.F. units for the left eye. In each case the initial guide setting for age of neutral density filter would have been 1.4 N.D.F. units, whilst 1.6 N.D.F. units would be a more sensitive setting.

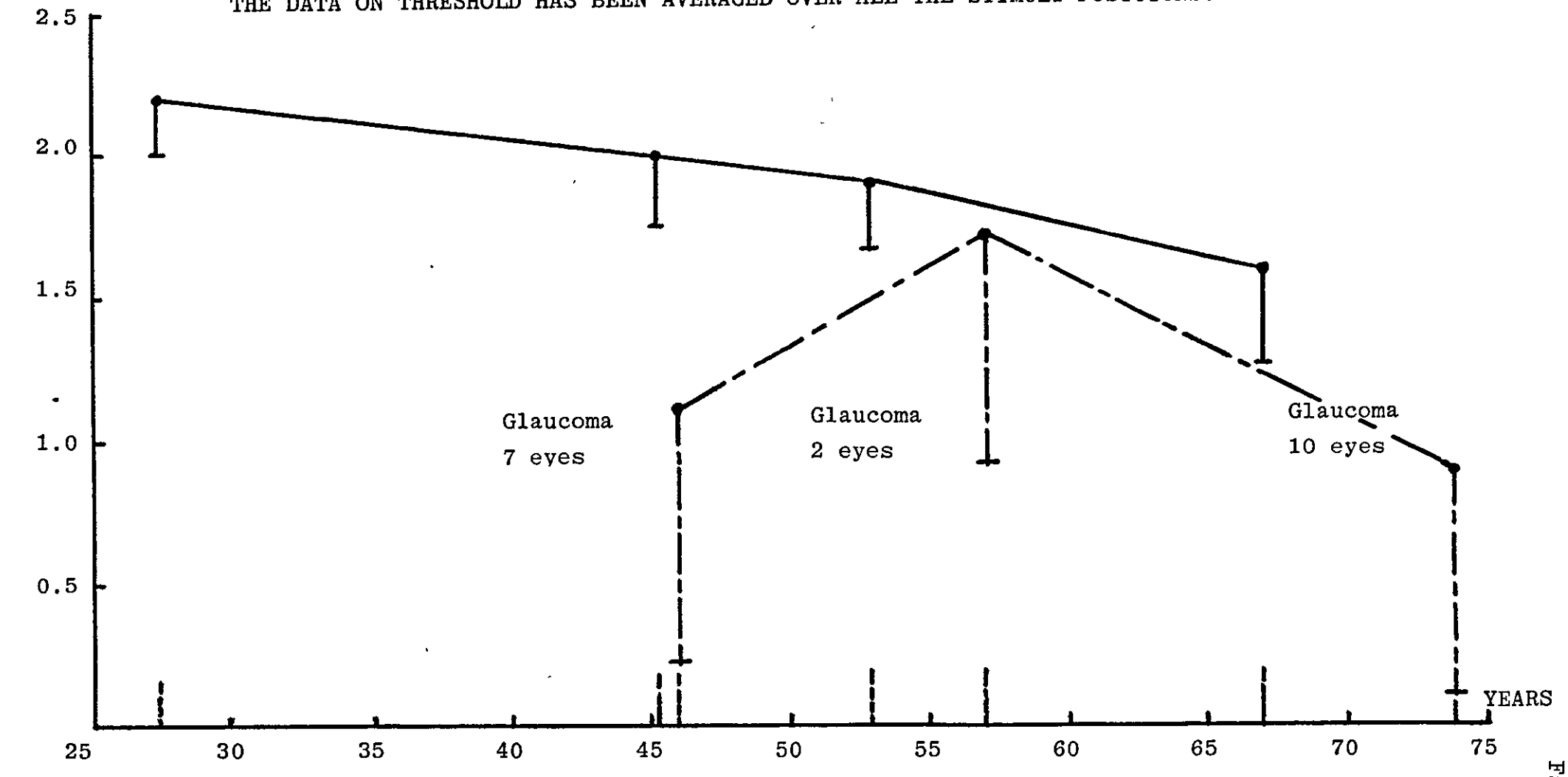
Clinical significance of the visual loss in this glaucomatous group is shown diagramatically in Fig 59 (a) and (b). The analysis is based on a guide setting of 1.4 N.D.F.units where **s** at the stimulus position indicates a loss of 0.4 N.D.F. units upwards, and **S** indicates a loss of 0.8 N.D.F. units or more. A loss of 0.4 N.D.F. units or more is regarded as the early indication of abnormality and therefore clinically significant, and a loss of 0.8 N.D.F. units indicates a more profoundly

established condition, and highly clinically significant. A comparison by statistical significance would have required different data not available and would not have been adequate alone clinically. Glaucoma like most pathological conditions is diagnosed on examination of a number of clinical criteria.

From examination of Appendix E on glaucoma cases and of the means and standard deviations of threshold for each of the stimulus positions, a large number of stimulus positions show a mean response of 0.4 or more N.D.F. units below the mean normal threshold for age. This normal mean would be 1.7 N.D.F. units for the right eye, and 1.6 N.D.F. units for the left eye, based on the original data of threshold for age. In addition at many of these positions the standard deviation is much greater than would have been expected from a study of the variations obtained in Section XIII amongst normals, even if a generous allowance is made for the somewhat greater standard deviations that one would expect in older age groups. In the study of the responses of young adults in Section XIII the standard deviation at any stimulus position did not exceed 0.2 N.D.F. units. In the glaucomatous group the standard deviations ranged from 0.2 N.D.F. units at stimuli positions where there was less evidence of visual loss to 0.8 N.D.F. units at stimulus positions of high incidence of visual loss. For the right eye the degree of loss appears greater in the upper part of the field, and somewhat less in the lower half.

FIG 59 c

AGE AND MEAN N.D.F. SETTINGS FOR THRESHOLD FOR 152 NORMAL EYES AND FOR THE 19 GLAUCOMATOUS EYES DETECTED WITH MINUS TWICE THE STANDARD DEVIATION SUPERIMPOSED. THE DATA ON THRESHOLD HAS BEEN AVERAGED OVER ALL THE STIMULI POSITIONS.



Facing p.

In the left eye, the visual loss over the whole field is less, and possibly slightly more in the lower fields than in the upper field. A larger sample may give a better differentiation. If the shape of the loss is studied, it will be seen to occur mainly in the arcuate area represented by the nerve fibre bundles on the visual field, particularly in the region 10 to 20° from fixation. In the case of the right eye, there appears also to be an indication of Roenné s nasal step, representing where the retinal nerve fibres terminate at the horizontal nasal raphé. Multiple static quantitative perimetry is therefore demonstrating the presence of loss in the arcuate areas of the field, well recognised by established workers as an area where early loss can occur.

In clinical practice visual loss would be looked for in areas relevant to the pathology of the condition suspected, enchancing the significance clinically of any loss detected.

A grosser approach, and therefore less favourable clinically, would be to find the mean loss over all the stimuli positions for each glaucomatous eye, and to compare this with the means for normal eyes in each of the three age groups investigated. The data from such a comparison is depicted graphically in Fig 59 c. For the glaucomatous eyes there is a clinically significant difference of distribution of reduced thresholds based on the means less twice the standard deviation, compared to normal eyes. The standard deviation for the glaucomatous cases

is about four times that for normal eyes in each age group. For the 41 - 50 and the 61 + groups there is a separation of the means of 0.9 and 0.7 N.D.F. units,and therefore highly clinically significant, even for such a gross analysis. For the 51 - 60 age group the sample was small but even here there was very little overlap of twice the negative standard deviation.

(C) Multiple Static Quantitative Perimetry and Glaucoma Detection.

The results indicate that multiple static quantitative perimetry can readily detect clinically significant visual loss in the arcuate area characteristic of glaucoma. These losses are more readily missed by kinetic perimetry. In addition it will be seen that there is a tendency for some visual loss to occur around the macula area in the right eye. Again loss in this region has been shown to be an early indication of glaucoma by other workers, using single point static perimetry. In this region,very near fixation, loss is likely to be even more readily missed by kinetic techniques.

From the clinical investigations of glaucoma cases conducted by the author it can be seen that using the initial guide setting of the neutral density filter for age under examination, visual field loss indicative of glaucoma would be detected. If a setting of 0.2 N.D.F. units higher, for extra sensitivity of investigation,is used a

lowering of threshold over a greater number of points in relation to this higher setting would result, although the diagnosis would remain the same. There are some individuals with above average thresholds for their age, where the employment of a higher initial threshold of 0.2 N.D.F. units for the investigation is likely to be safer.

XVI

THE COMPARISON OF MULTIPLE STATIC QUANTITATIVE PERIMETRY WITH OTHER TECHNIQUES IN THE INVESTIGATION OF VISUAL LOSS.

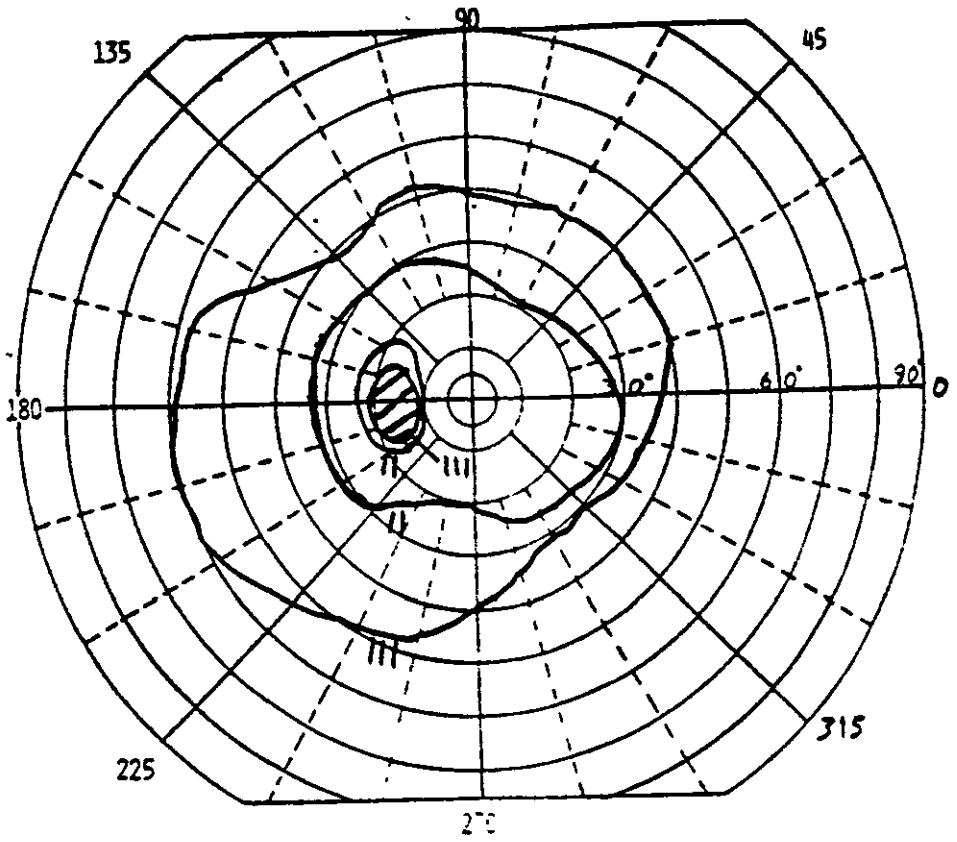
The validity of the techniques of multiple static quantitative perimetry for use in the detection and investigation of visual loss can be shown by comparing it with established methods such as kinetic perimetry using the Bjerrum screen or with the Goldmann bowl perimeter, or with single stimulus static perimetry on a bowl perimeter.

During the development of the technique for investigating visual fields by multiple static quantitative perimetry, cases were also examined by Friedmann by the classical methods of kinetic perimetry.

Friedmann (1966) discusses how the new technique revealed a small right upper quadrantic temporal defect, a defect which could not be found with the Bjerrum screen. In another case, involving oedema of the optic disc, the Bjerrum screen revealed only an enlargement of the blind spot, while the new instrument showed a slight decreased visual function in the Bjerrum arcuate area.

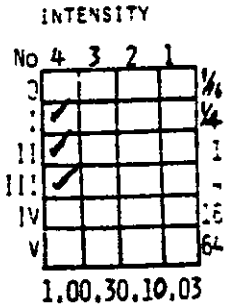
In another case a man 55 years of age was suffering from early glaucoma in both eyes, with cupping of the left optic disc, and raised intraocular pressure, but no defect was found using the Bjerrum screen. Multiple static perimetry revealed a small nerve fibre defect in the right eye.

GOLDMANN PERIMETER.

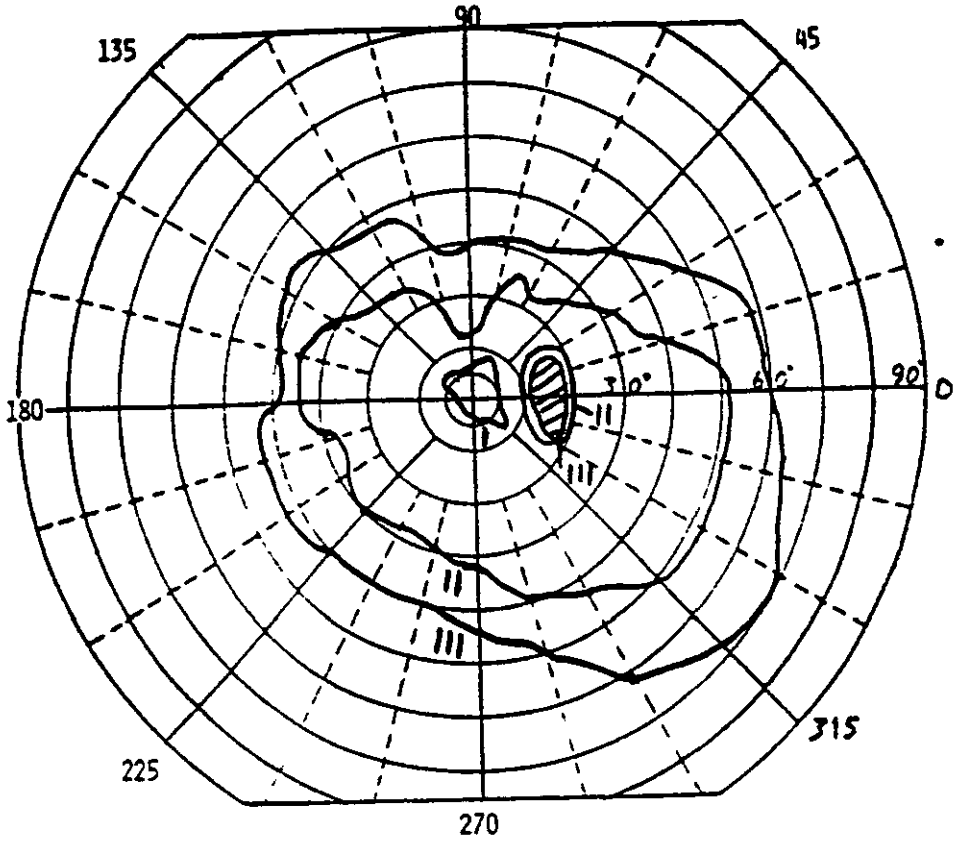


MRS.J. L.EYE.

AGE 50 V/A 6/18

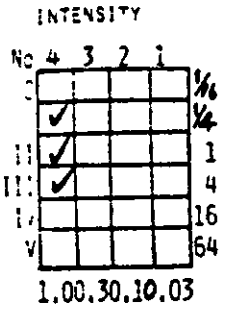


GOLDMANN PERIMETER.



MRS.J. R.EYE.

AGE 50 V/A. 6/18.

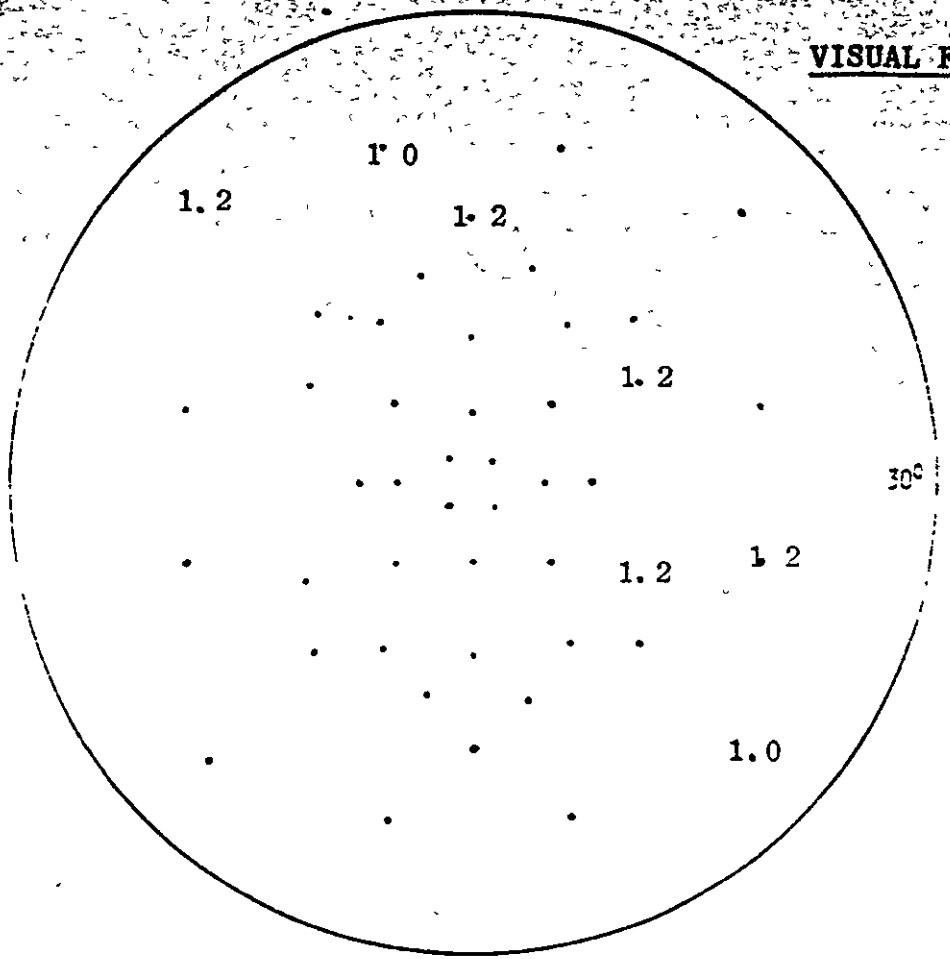


GOLDMANN PERIMETER.

FIG 64.

Facing p. 12

VISUAL FIELD ANALYSER.

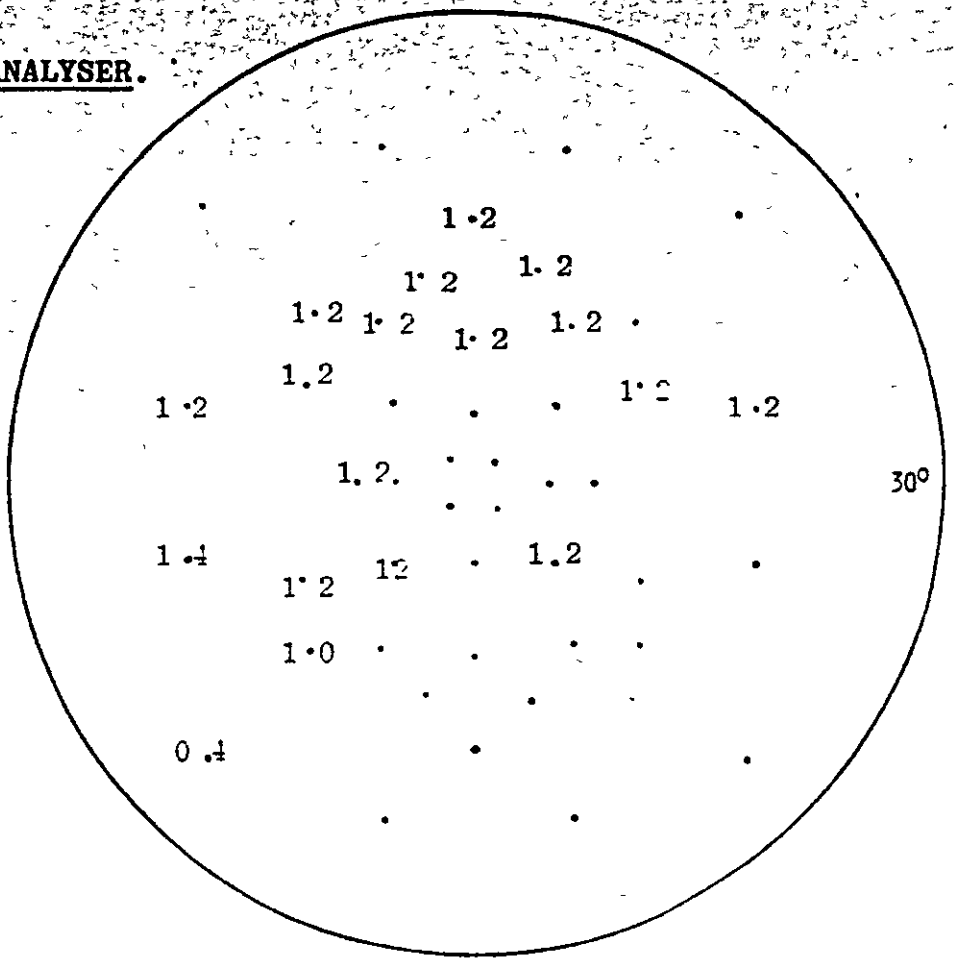


MRS J. L.V/A. 6/18 AGE 50

STIMULI NOT MARKED SEEN AT 1.4 N.D.F.

MACULAR FUNCTION 2.2 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.



MRS J. R.V/A. 6/18 AGE 50

STIMULI NOT MARKED SEEN AT 1.4 N.D.F.

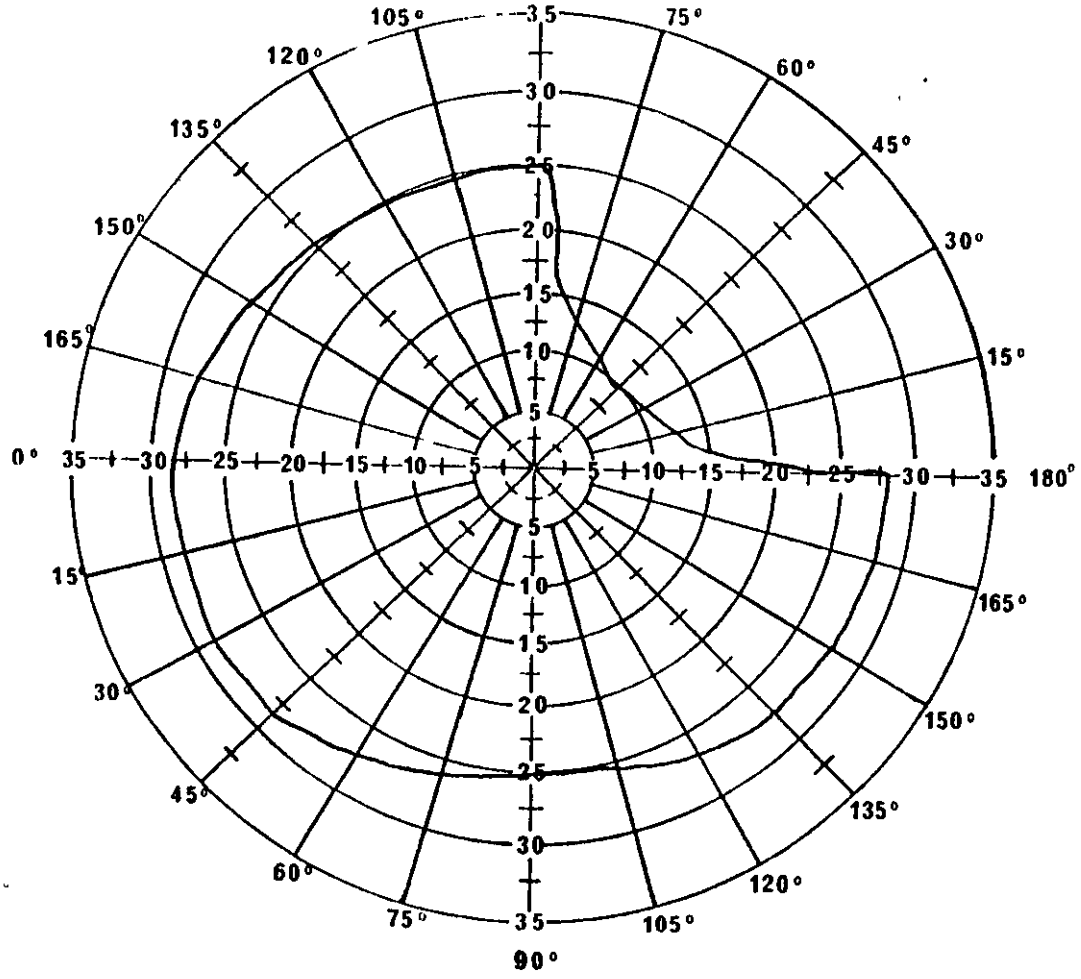
MACULAR FUNCTION 2.0 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.

FIG 63.

Facing p. 129

BJERRUM SCREEN CHART.



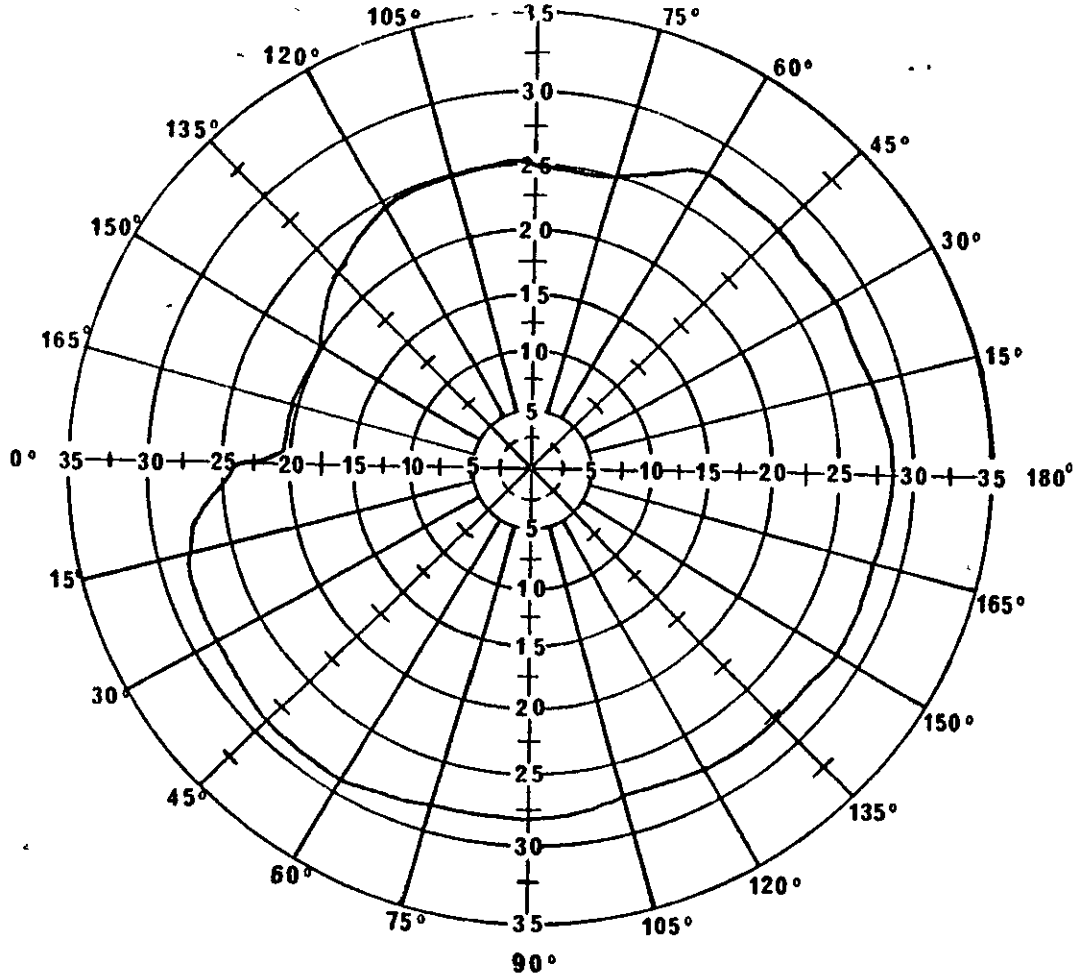
MR.W. L.V/A. 6/6 AGE 57

SIZE OF TEST OBJECT IN MM.

WHITE 2/1000.

FIG 62 (b).

BJERRUM SCREEN CHART



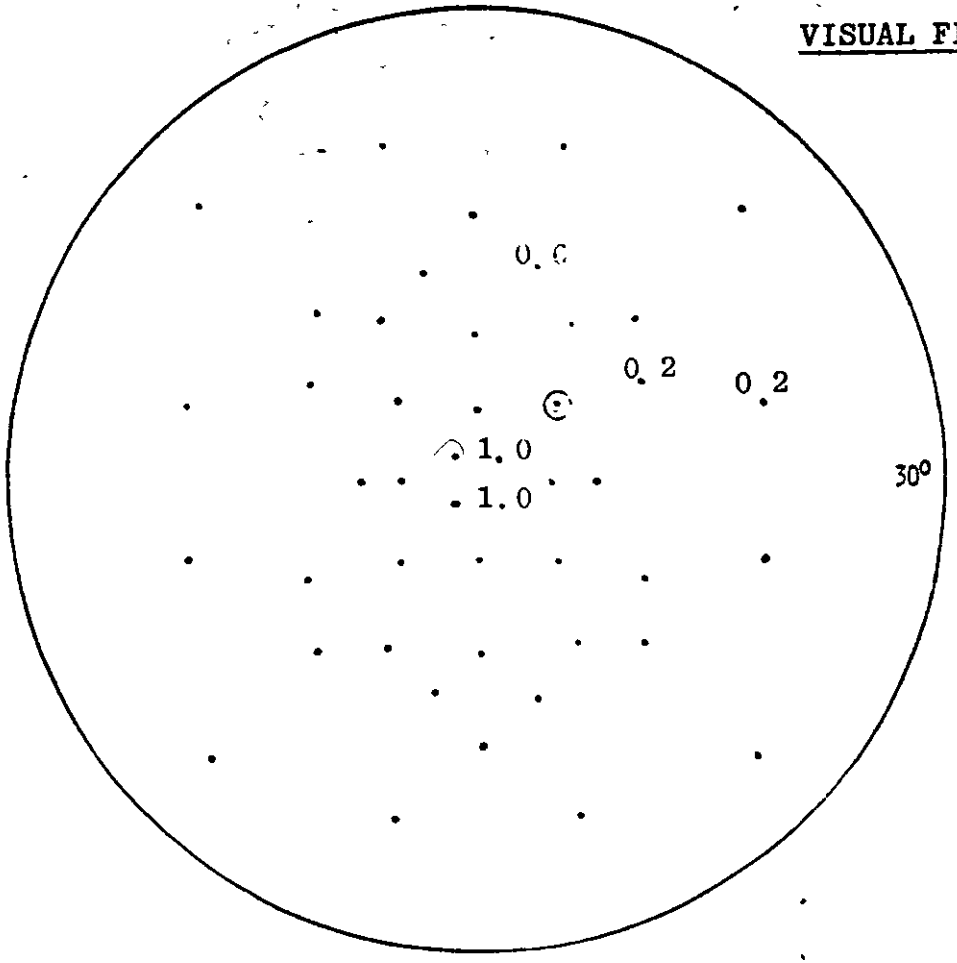
MR.W. R. V/A 6/6 AGE 57

SIZE OF TEST OBJECT IN MM.

WHITE 2/1000

FIG 6.2 (a).

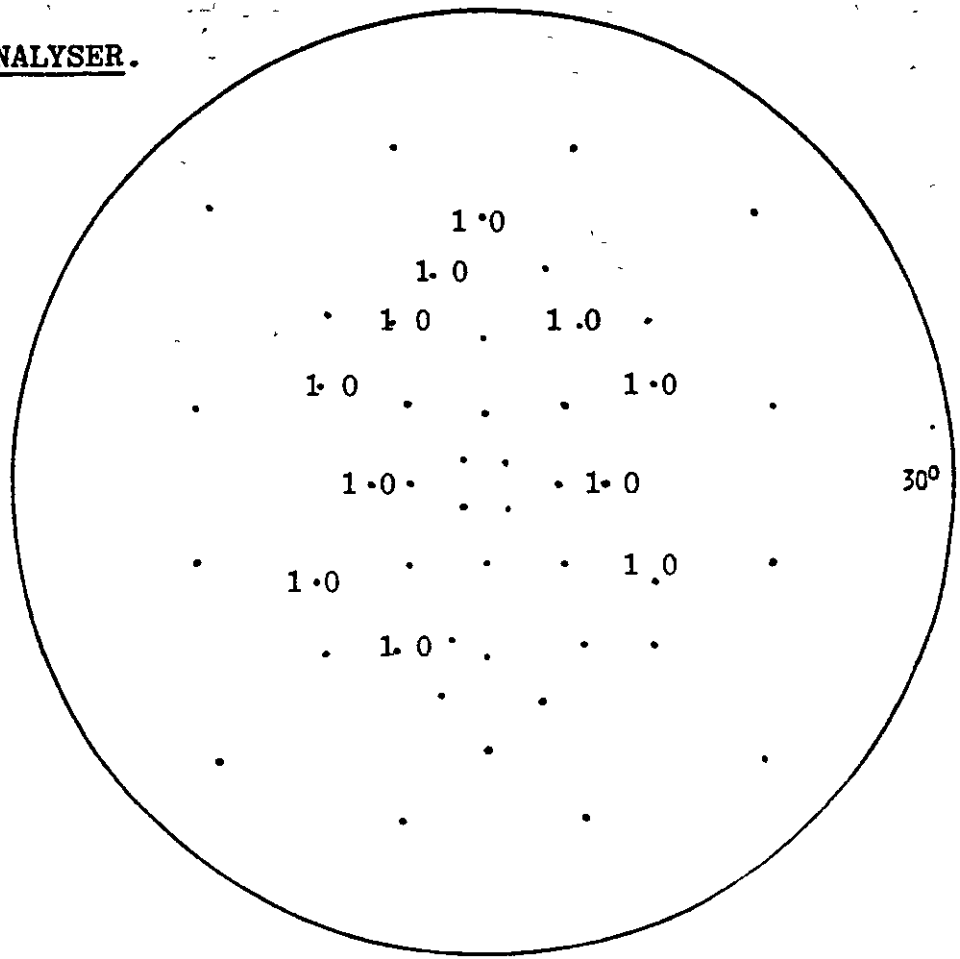
VISUAL FIELD ANALYSER.



MR.W. L.V/A. 6/6 AGE 57

STIMULI NOT MARKED SEEN AT 1.8 N.D.F

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.



Mr.W. R.V/A. 6/6 AGE 57.

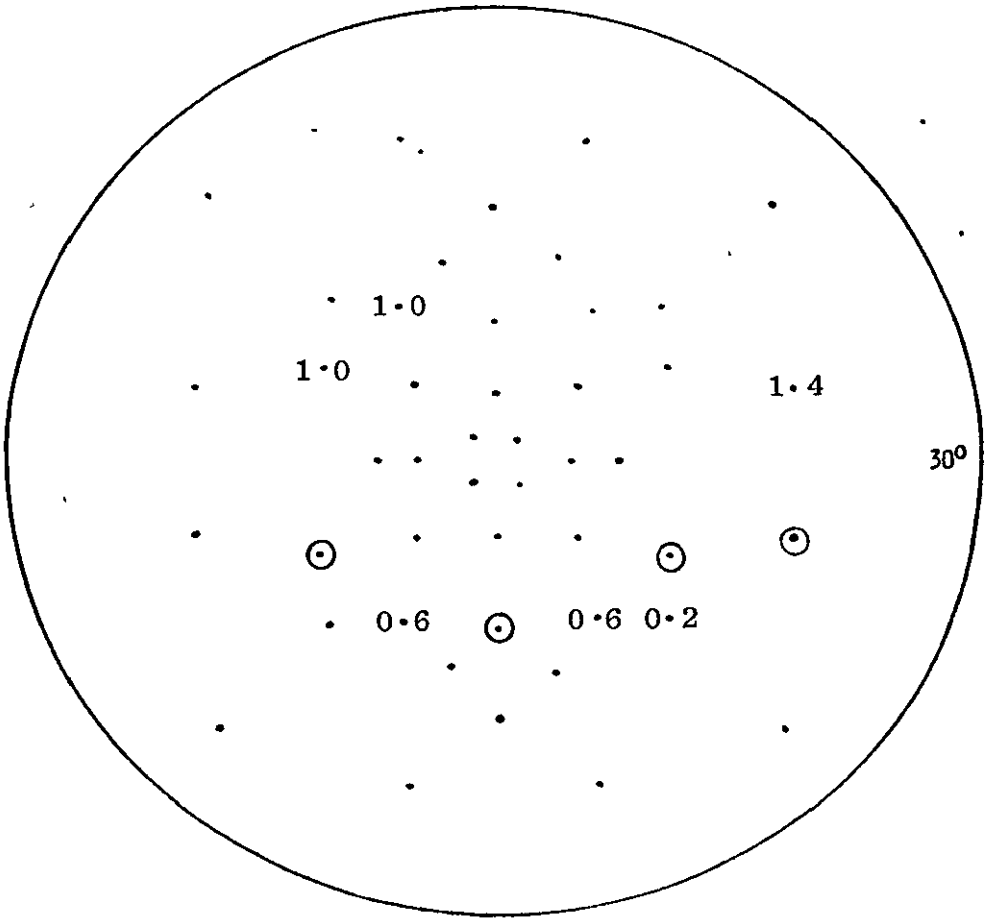
STIMULI NOT MARKED SEEN AT 1.8 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.

FIG 61.

Facing p. 129

VISUAL FIELD ANALYSER.



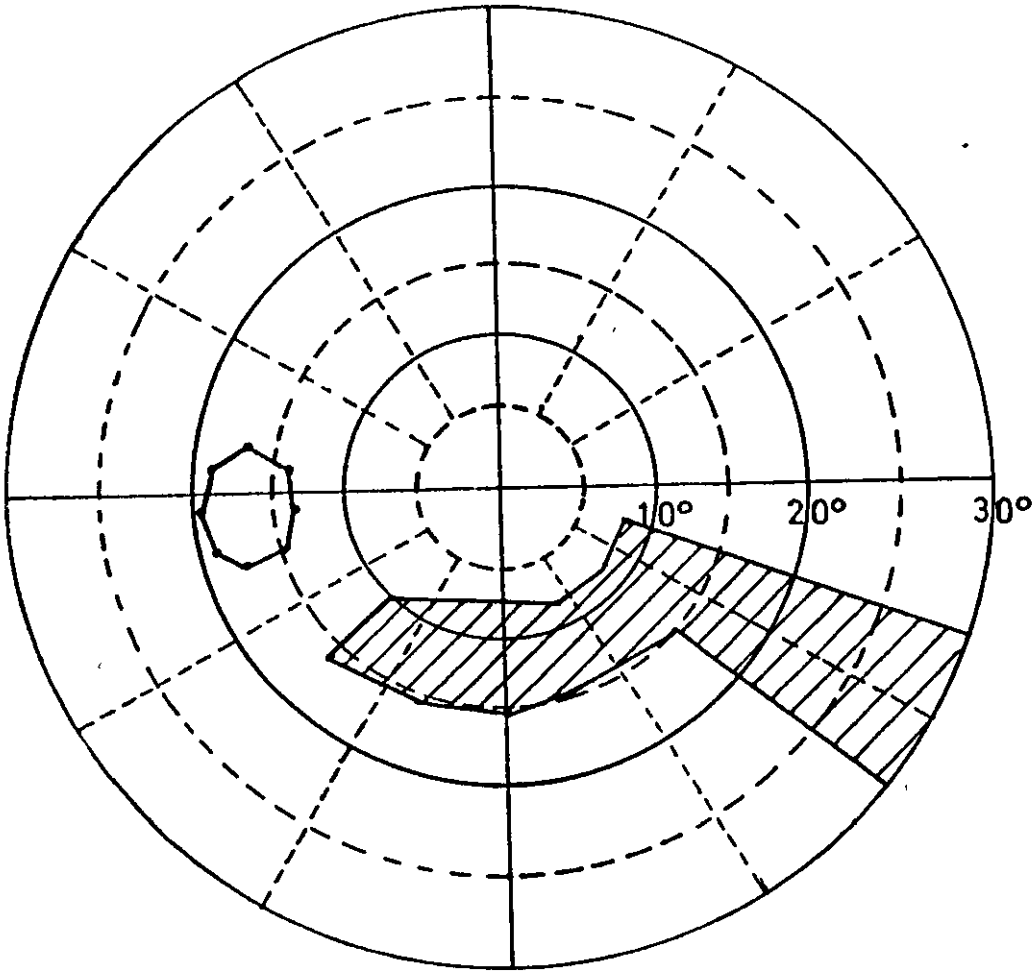
MR.L.T. L.E. V/A 6/6 AGE 50.

STIMULI NOT MARKED SEEN AT 1.8 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD. STIMULI MARKED ⊙ CAN BE SEEN AT THE BRIGHTEST SETTING.

FIG 60 (c).

BJERRUM SCREEN.

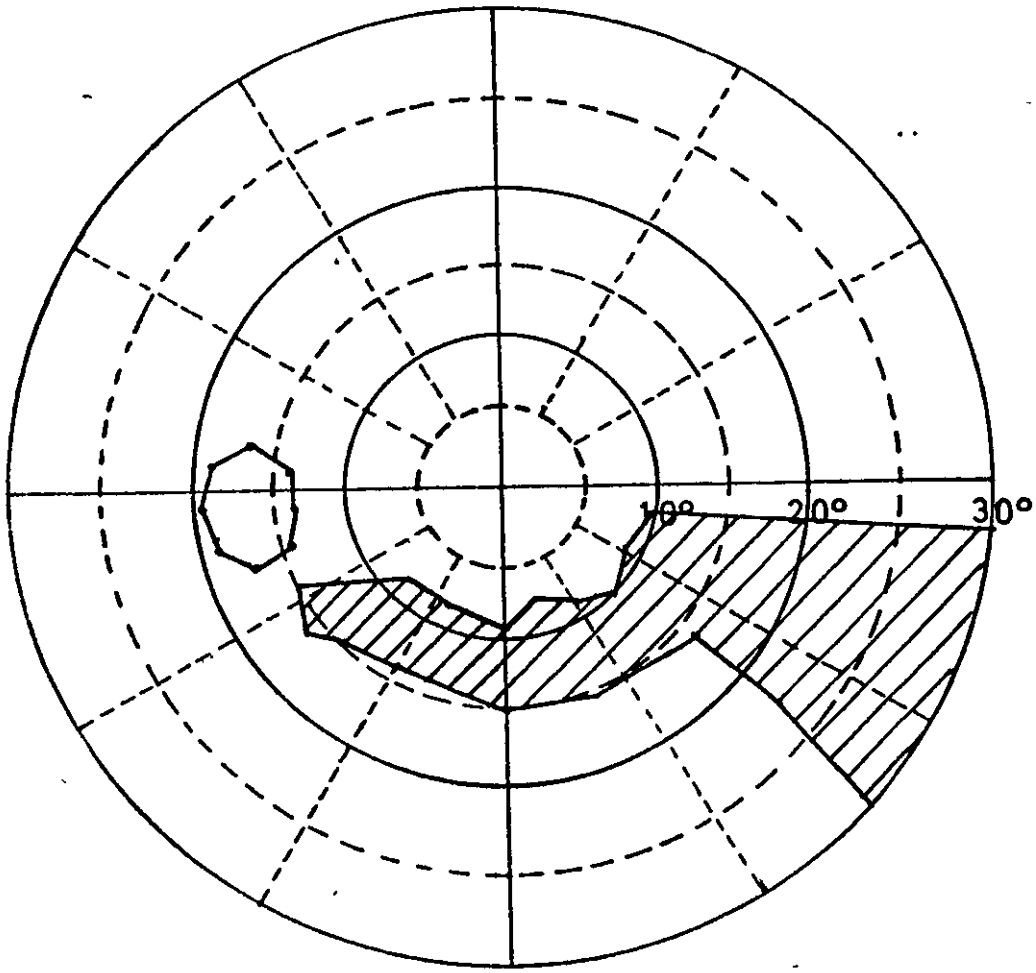


MR.L.T. L. V/A 6/6 AGE 50

TEST OBJECT 1/1000 WHITE BACKGROUND LUMINANCE 0.7 MILLI-LAMBERTS.

FIG 60 (b).

BJERRUM SCREEN.



Mr.L.T. L. V/A 6/6 AGE 50

TEST OBJECT 2/1000 WHITE BACKGROUND LUMINAN

0.1 MILLI-LAMBERTS

FIG 60 (a)

Bedwell (1973) compared the visual loss detected by multiple static quanitative perimetry with that using the Bjerrum screen, both at the normal incident illumination of 70 lux, and then later with 10 lux, to give the same adaptation conditions as were employed in the Visual Field Analyser. A 2 mm white target at 1 m was used at the lower level of screen luminance of 0.1 millilamberts (Fig 60 a) and compared with the usual 1 mm target for the higher level, (Fig 60 b), of 0.7. millilamberts. Investigation with the lower luminance demonstrated a larger field defect. Multiple static quantitative perimetry, (Fig 60 c), revealed a similarity in the shape of the field defect, but the greater extent of the defect, and the variation in degree of loss, were evident in a way which was not possible with kinetic perimetry.

In another case study by the author the visual field loss assessed quantitatively by multiple static perimetry in a case of glaucoma, (Fig 61), was compared with the loss for the same patient employing the Bjerrum screen, (Fig 62 a & b), using the same screen luminance. Again the extent and the variation of the degree of loss was very much more evident using multiple static quantitative perimetry than it was from ordinary kinetic perimetry.

In Fig 63 & 64 the author shows a case of visual loss in a patient with papilloedema due to raised cerebrospinal fluid pressure. In Fig 63 is illustrated the loss determined by the Visual Field Analyser using multiple

static quantitative perimetry and in Fig 64 by kinetic perimetry on the Goldmann bowl perimeter. With both techniques the considerable loss in the upper part of the right field is demonstrated but the early loss in the upper nasal field of the left eye is better exhibited by multiple static perimetry.

Wenker (1970) investigated the visual fields of approximately 250 patients suffering from simple chronic glaucoma, using the Goldmann bowl perimeter and the II/1 stimulus as a comparison. Her study gave results that coincided with the findings of other workers. This was especially true in respect of the lowered points of function in the Bjerrum area between 5^{o} to 15^{o} from fixation. The superior zone appears to be more frequently affected in subjects under 50 years of age, or older than 60 years, whereas the inferior zone was more often disturbed in patients between 50 and 60 years of age. The central area appeared to be more frequently involved in reduced function in the young patient. The age group most likely to be at risk were those under 40 and over 60 years of age. In this study the right eye was more often affected than the left eye, and to a greater extent, giving rise to the possibility of a connection between degree of impairment of function in chronic simple glaucoma and the dominant hemisphere.

As with other studies, Wenker found that reduced function, particularly in the Bjerrum area was detected by

multiple static quantitative perimetry, but employing the Goldmann kinetic visual field technique gave results that indicated a normal visual field.

Greve undertook a considerable number of studies with the Visual Field Analyser. He reported (1973) on a comparative study of the visual fields of 1372 eyes from 716 patients with raised intraocular pressure. He employed the multiple stimulus method of the Visual Field Analyser in the detection phase. He also carried out kinetic perimetry on the periphery and the blind spot as a comparison. He supplemented his method with single static perimetry in 72 fixed positions, within an area of 30^{o} eccentricity from fixation superiorally and inferiorally when either of the first two tests indicated the necessity. He regarded the detection of a relative wedge-shaped scotoma, which could appear anywhere in the 30^{o} field, and isolated wedge-shaped scotomas, as being important indications of the earliest signs of reduction of light sensitivity due to glaucoma. This approach was in agreement with Aulhorn and Harms (1967), Friedmann, the author, and others using single or multiple stimulus static techniques.

In this survey by Greve (1973), 26% were found to have no visual field loss, 52% a complete arcuate scotoma or larger, and 22% a small visual field defect. All the cases of arcuate scotoma were detected by the Visual Field Analyser. For the group of small visual field defects,

17 were missed, mainly because they fell on nasal areas where there were insufficient stimulus positions, and not because of inadequacy of the multiple stimuli presentation technique itself.

A comparative study was undertaken by Greve (1973) of the threshold measurements by multiple and single static perimetry over 100 positions on the field, of patients with visual field defects using the Visual Field Analyser and the Tubinger perimeter. The results of his survey are summarised below by Bedwell.

TOTAL OF 1001 POSITIONS OVER THE FIELD EXAMINED.

No defect V.F.A. or Tubinger	V.F.A. defect and Tubinger same intensity.	V.F.A.defect Tubinger no defect.
49%	30%	8%
V.F.A. no defect Tubinger a defect	V.F.A.defect greater intensity than Tubinger.	V.F.A.defect smaller intensity than Tubinger.
5%	5%	3%

Of the 5% of cases demonstrating no defect on the Visual Field Analyser but a defect on the Tubinger, 4% of these 5% is explained by type of defect, and also by no stimulus on the Analyser covering the affected area. The author feels that the use of a 98 hole front with

the Analyser in these cases would have shown up a defect.

In the 8% of cases where the density of the defect found by the Visual Field Analyser was either higher or lower than that found by the Tubinger perimeter, about 8 out of 10 could be explained by the type of defect. The possibility of finding a difference of density of defect is likely to be similar in the case of both instruments.

The conclusion was that especially where there was a difference in intensity of thresholds in the range of 0.4 to 0.6 N.D.F. units false positives and negatives can occur. If the new 98-hole front-plate had been available the author feels that where a defect had been found with the Tubinger perimeter, it would also have been detected by the Visual Field Analyser.

From these results, comparing multiple static perimetry on the Visual Field Analyser with the Tubinger single point static perimetry, it appears that with few exceptions sensitivity of positions over the retinal areas when measured with multiple static stimuli, is the same as the light sensitivity measured with a single static stimulus. This applies to both normal and defective retinal conditions. Multiple stimulus static perimetry has the advantage that it is a more rapid method for detecting visual defects than the classical method of single static perimetry, and it also provides more information per unit of time.

Bynke (1974), discussed the application of the Visual Field Analyser to the investigation of hemianopic visual field defects. With a neutral density filter of 0.2 units above that normally suggested for the appropriate age, he found that there were 10% false negatives, and 13% false positives. He felt that the Analyser was suitable for routine diagnosis of such cases, and could be used by an ophthalmic assistant.

VISUAL FIELD ANALYSER.

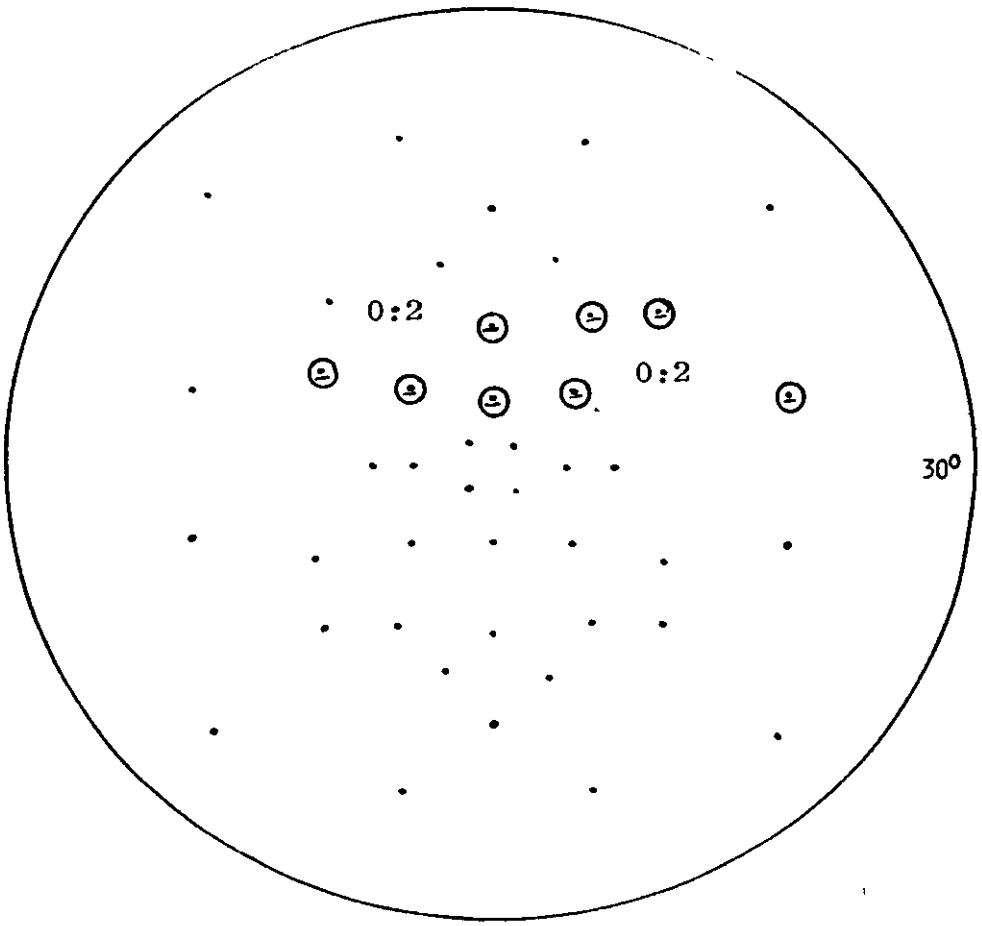


FIG 65 (b)

MRS P.K. L. V/A 6/20 AGE 50.

STIMULI NOT MARKED SEEN AT 1.8 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD.
STIMULI MARKED ⊖ NOT SEEN AT THE BRIGHTEST SETTING.

VISUAL FIELD ANALYSER.

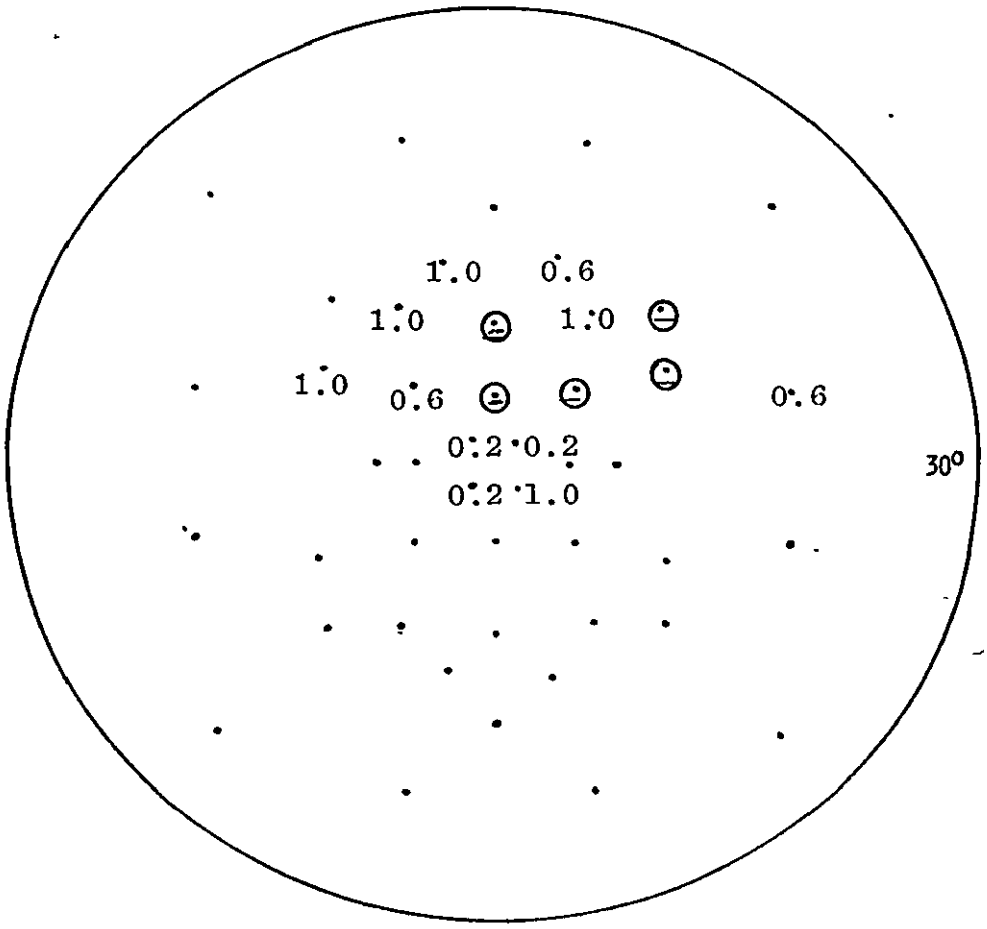


FIG 65 (a)

MRS P.K. L. V/A 6/12 AGE 34

STIMULI NOT MARKED SEEN AT 1.8 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD.
STIMULI MARKED ⊖ NOT SEEN AT THE BRIGHTEST SETTING.

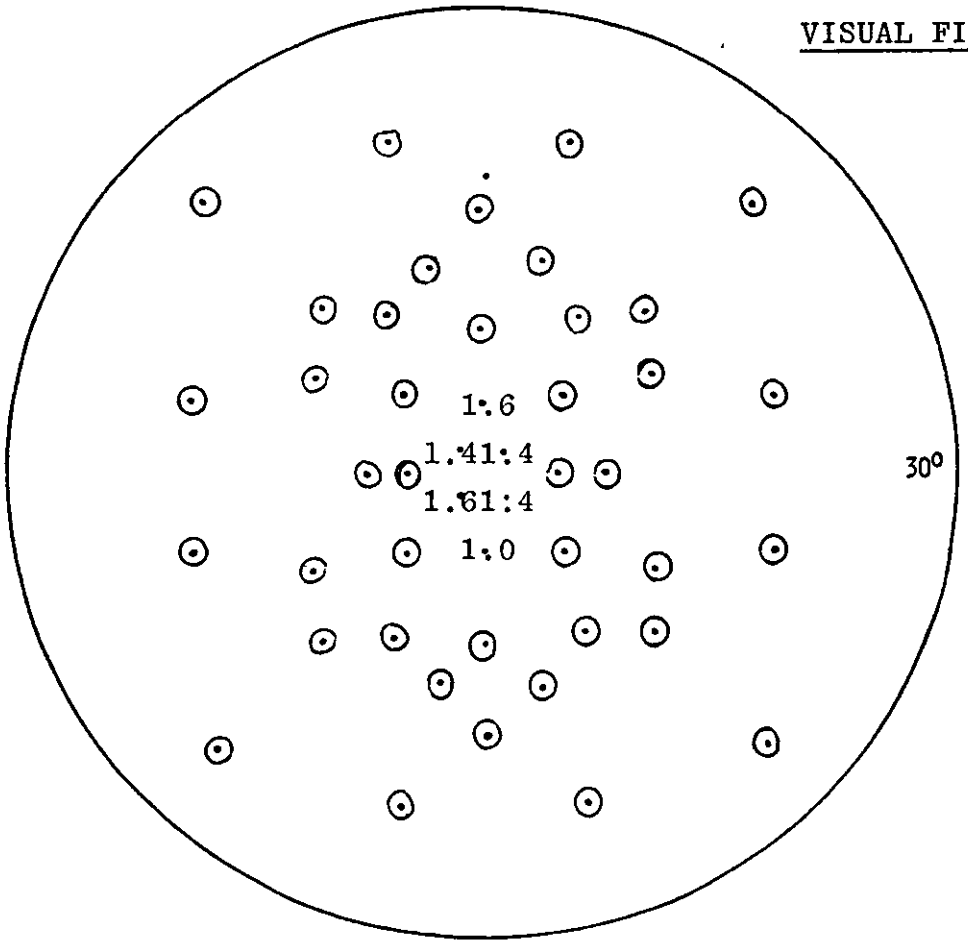
XVII

THE INVESTIGATION OF VISUAL LOSS BY MULTIPLE STATIC QUANTITATIVE PERIMETRY USING SERIAL ANALYSIS.

Sometimes visual field investigations reveal a definite loss of function although there are no other indications of a pathological situation. In other cases a slight abnormality may be apparent beyond what may be expected from normal physiological variations in threshold. The method of multiple static perimetry lends itself well to serial studies, which are particularly appropriate for observing possible changes in threshold over a period of time and of great diagnostic value when other symptoms are absent. If a condition is active, then it is likely that any visual loss will become both larger and exhibit decreased thresholds over time. It is then possible to monitor any visual field abnormality and take the appropriate action. Such an approach would be very difficult with kinetic perimetry, which cannot quantify visual loss.

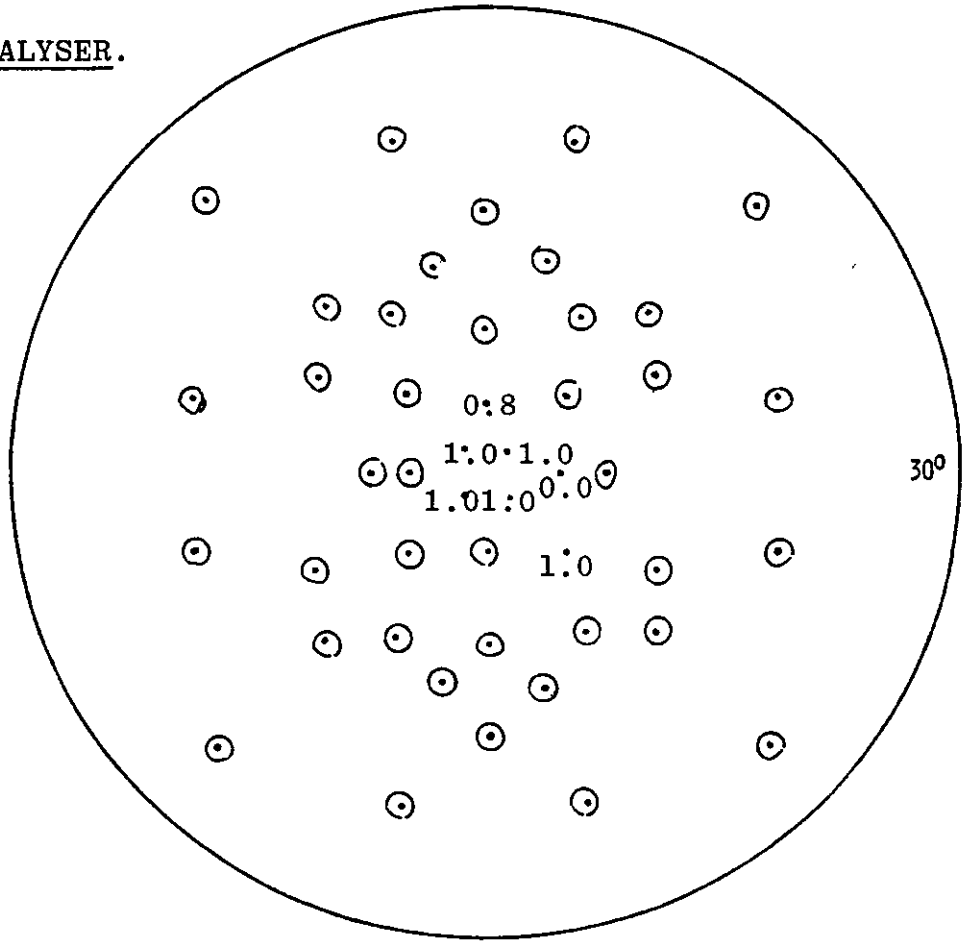
The case of a patient demonstrating visual loss in the arcuate area of the left eye during a routine visual field screening is illustrated in Fig 65(a) & (b) Such a field loss is typical of glaucoma but there were no other clinical indications of the condition, and it is unusual to develop primary glaucoma at 34 years of age. There was a small left convergent strabismus and slight amblyopia in that eye, and therefore the cause of the abnormality, Fig 65(a,)was thought to be either congenital in origin, or to be due to a previous vascular lesion. As

VISUAL FIELD ANALYSER.



MR.J. L. V/A 6/9 AGE 38

EXAMINED AT 1.6 N.D.F.
MACULA FUNCTION 2.2. N.D.F.
RELATIVE VISUAL LOSS ASSESSED
QUANTITATIVELY.



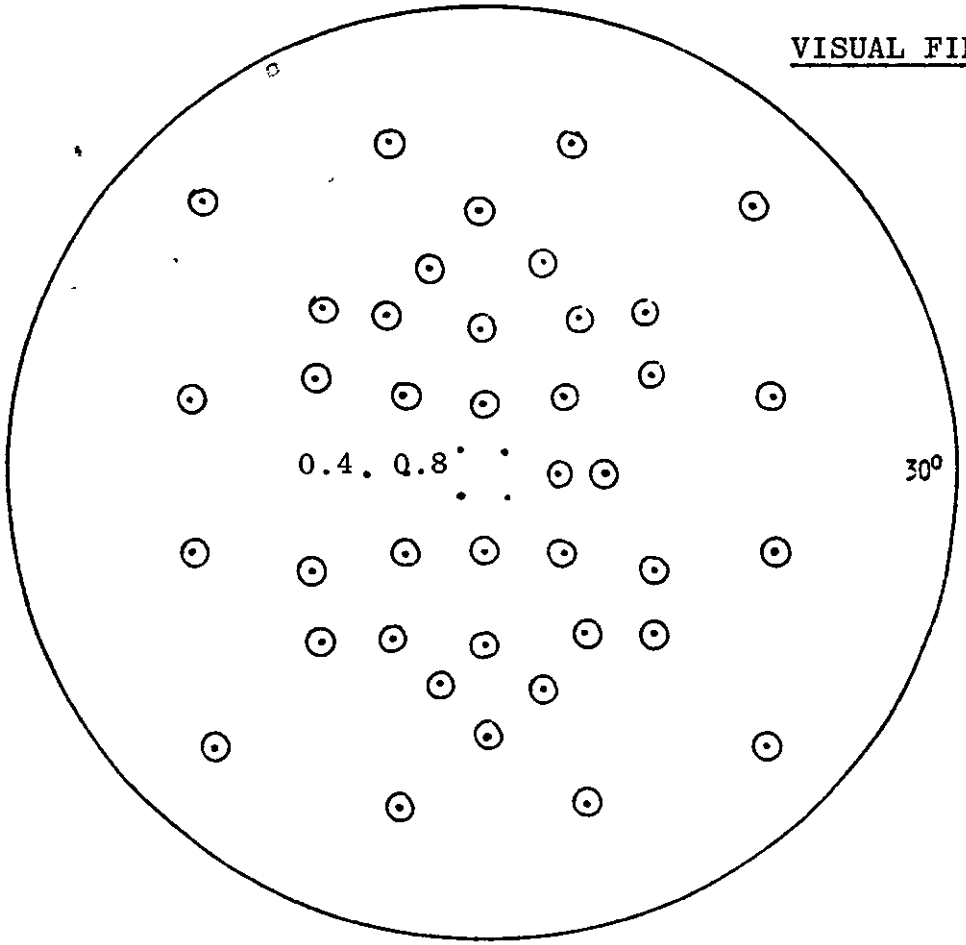
MR.J. R. V/A 6/18 AGE 38

EXAMINED AT 1.6 N.D.F.
MACULA FUNCTION 2.0 N.D.F.
RELATIVE VISUAL LOSS ASSESSED
QUANTITATIVELY.

FIG 67.

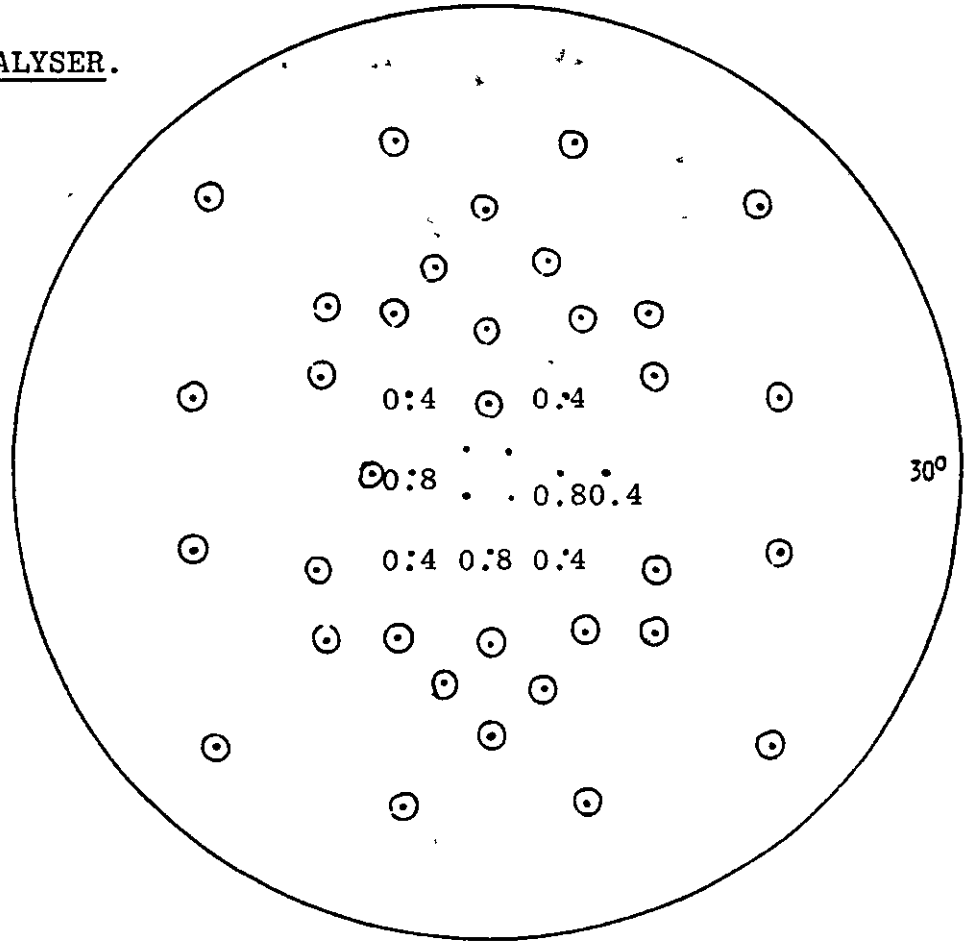
Facing p. 136

VISUAL FIELD ANALYSER.



MR J. L.V/A 6/7.5 AGE 32.

STIMULI NOT MARKED SEEN AT 2.0 N.D.F.
RELATIVE VISUAL LOSS ASSESSED
QUANTITATIVELY.



MR J. R.V/A 6/7.5 AGE 32.

STIMULI NOT MARKED SEEN AT 2.0 N.D.F.
RELATIVE VISUAL LOSS ASSESSED
QUANTITATIVELY.

FIG 66.

Facing p.136

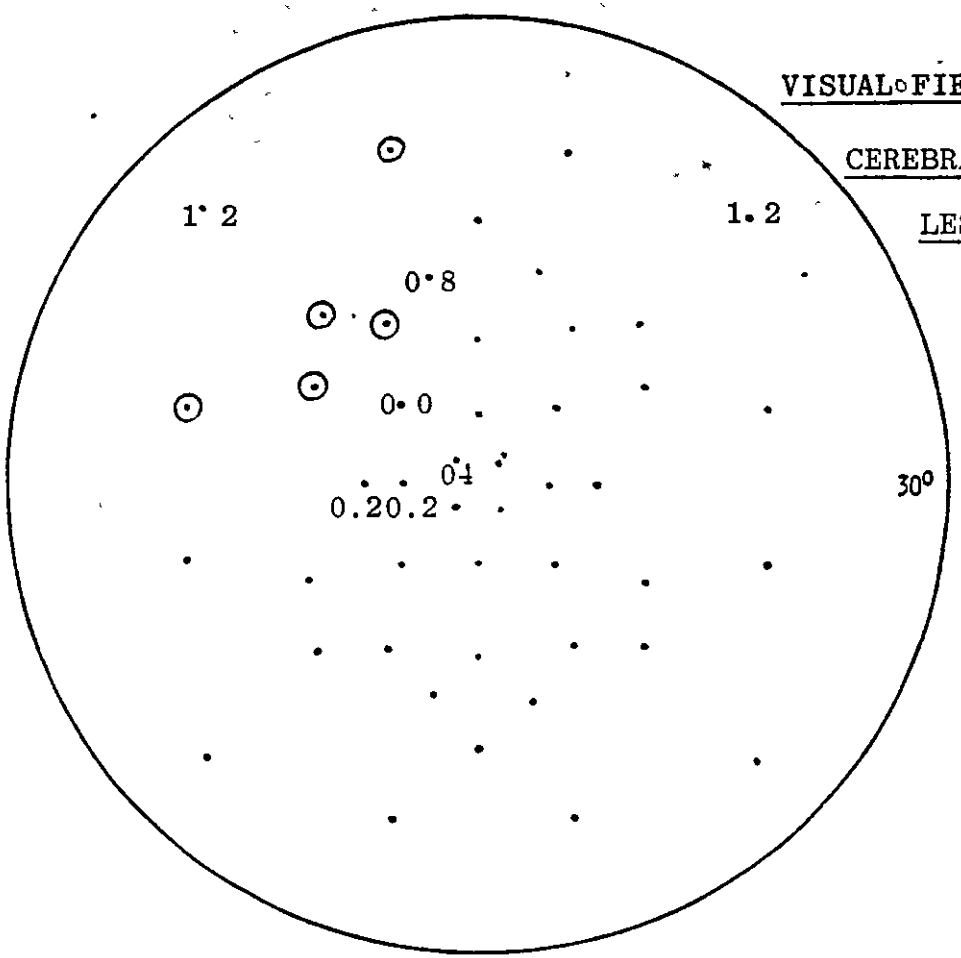
a precaution the visual fields were analysed at intervals, and Fig 65(b)shows the quantitative assessment some sixteen years later. If an active pathological lesion had been present, the increase in field loss would have been very marked. over this period and would not have exhibited the rather similar features actually obtained between repetitions of the tests.

Some conditions producing visual loss unfortunately tend to be progressive, e.g. retinitis pigmentosa. In these cases it is very important when making a prognosis about a patient to assess quantitatively the degree of loss present, and to compare the data over intervals of time. An example of the procedure is illustrated in Fig 66, for a case of retinitis pigmentosa. When first investigated the central visual acuity was not affected and retinal pigmentary changes were noted only further out. A dense visual loss was evident over a much larger area of the field than would have been indicated by ophthalmoscopic appearances. Fig 67 illustrates a serial study of the same case taken 6 years later demonstrating that the degeneration was affecting the macula area, further decreasing the remaining tunnel of vision.

When a case of glaucoma is initially detected and the degree of visual loss is assessed quantitatively, and treatment instituted, an important part of patient management is regular examination of the visual fields with the hope that treatment has prevented further visual

VISUAL FIELD ANALYSER.

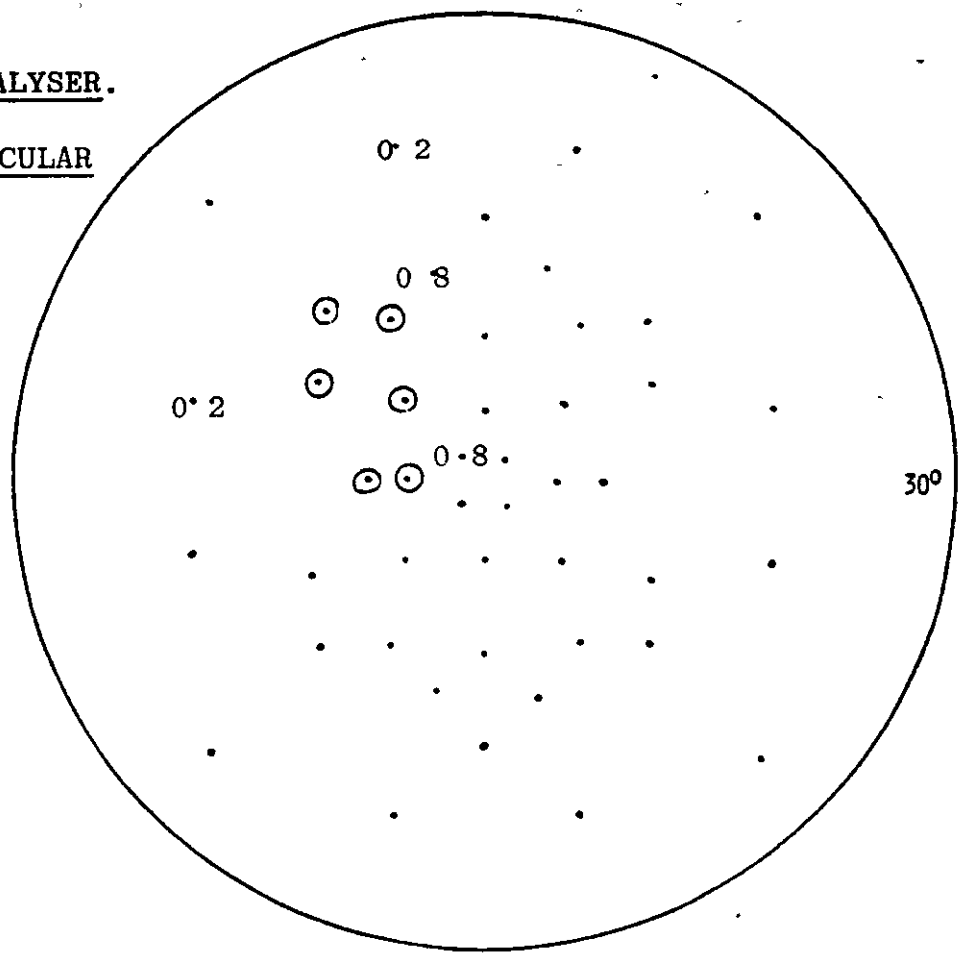
CEREBRAL VASCULAR LESION.



MR.H. L.V/A. 6/7.5+ AGE 53.

STIMULI NOT MARKED SEEN AT 1.8 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.



MR.H. R. V/A. 6/7.5+ AGE 53.

STIMULI NOT MARKED SEEN AT 1.8 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.

FIG.70.

Facing p. 137 c

VISUAL FIELD ANALYSER.

GLAUCOMA.

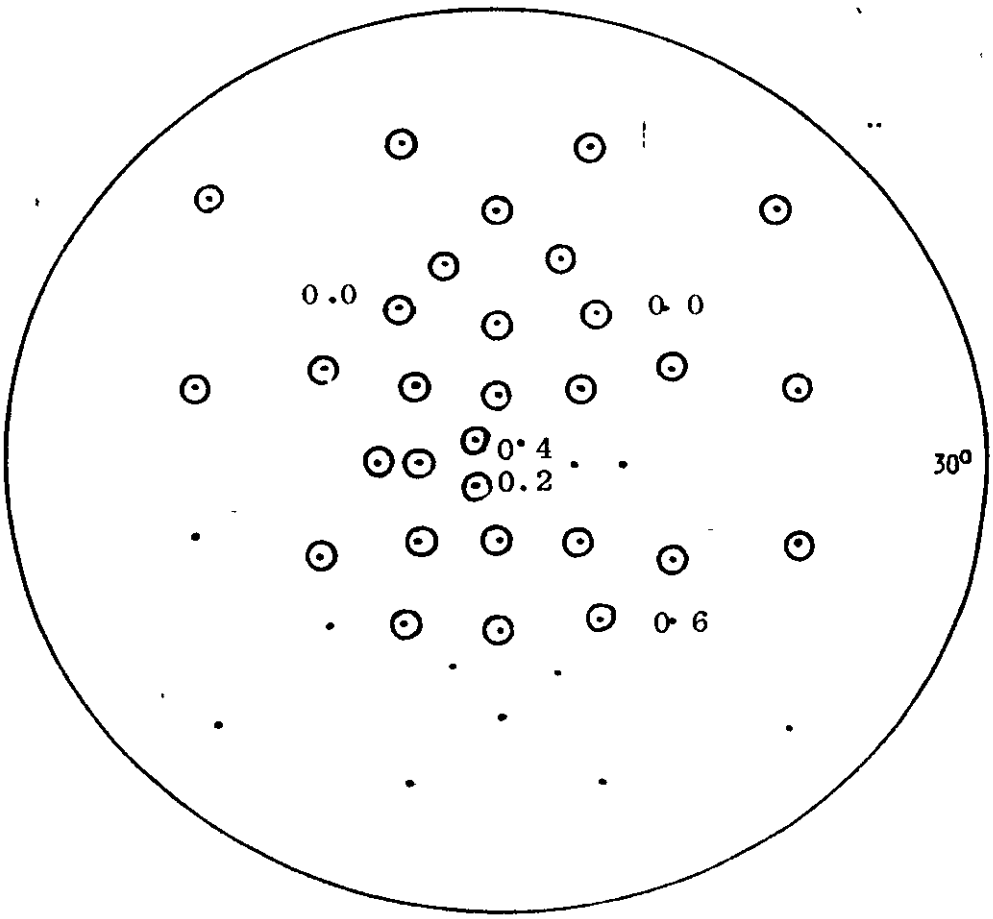


FIG. 69.

MRS.J. R. V/A. 6/9- AGE 58.

STIMULI NOT MARKED SEEN AT 1.6 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD.

STIMULI MARKED ⊙ NOT SEEN AT THE BRIGHTEST SETTING.

VISUAL FIELD ANALYSER.

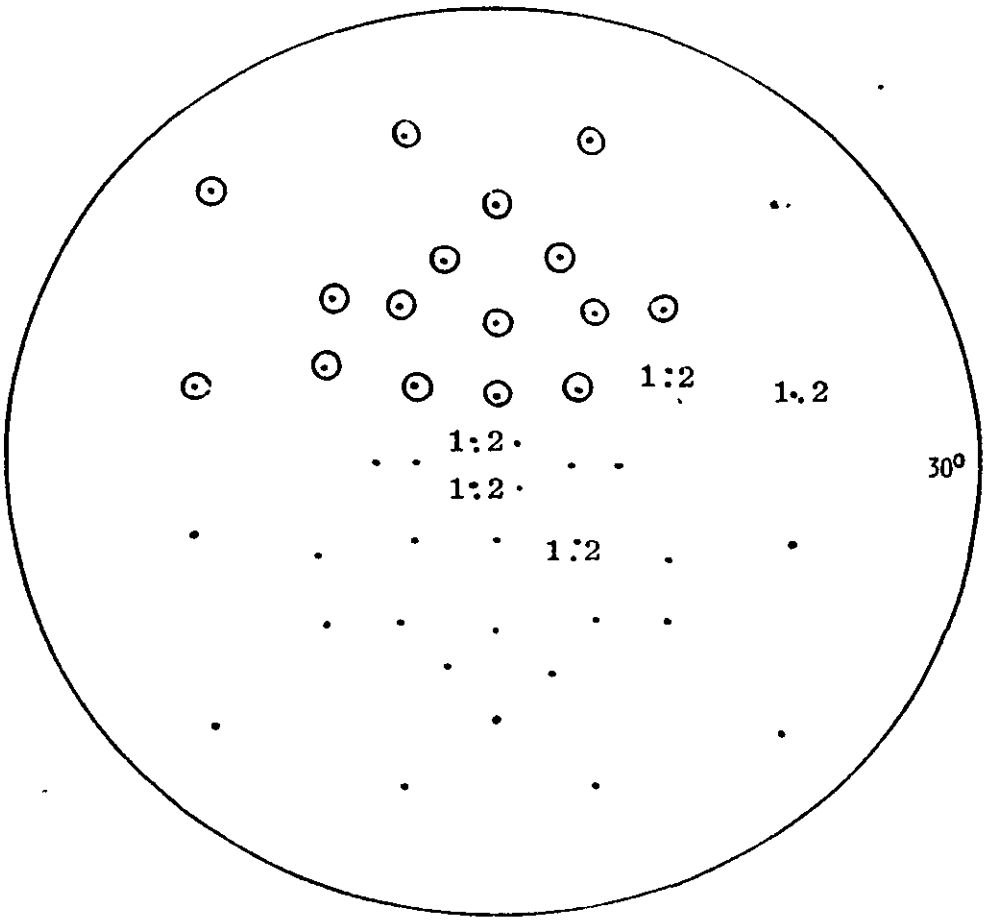


FIG 68.

MRS J. R. V/A 6/9 AGE 48.

STIMULI NOT MARKED SEEN AT 1.8 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD.
STIMULI MARKED ⊙ NOT SEEN AT THE BRIGHTEST SETTING.

loss occurring. Here the ability of quantitatively assessing loss under controlled condition and making serial studies is invaluable. Fig 68 illustrates the field loss in the right eye discovered on an initial routine investigation of a patient aged 48 years. An interesting aspect of this case is that she was amblyopic in her left eye and therefore dependent on her right eye. She had not noticed however the dense visual loss developing in the upper field of her right eye, largely because in everyday life the upper part of the visual field is used less than the field below the horizontal. After the diagnosis of glaucoma and the institution of miotic therapy, she was examined at regular intervals, Fig 69 illustrates the analysis of the visual field some ten years later, demonstrating that the condition had been controlled quite well.

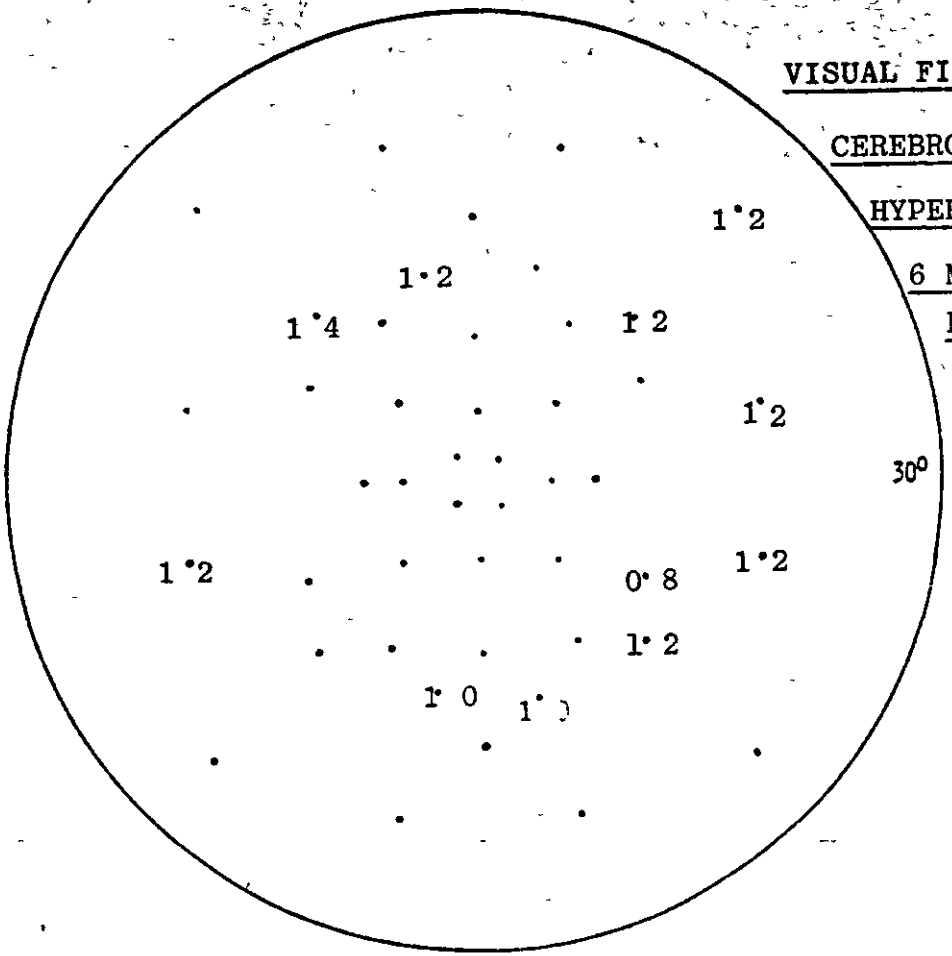
Cerebral vascular lesions are quite common in later life, but unfortunately the visual fields are often not examined. If they were, a quadranopic or hemianopic field loss would commonly be demonstrated, such as in the case of a patient illustrated in Fig 70, who was somewhat hypertensive, and had suffered a recent "blackout". Later his passenger was killed in a fatal motor accident when the patient was driving when advised not to do so even though his vision was right and left 6/7.5+.

Sometimes, other conditions develop at a later stage e.g. simple chronic glaucoma, and if a quantitative record of the original field loss had been available for that patient, subsequent interpretation of further loss would

VISUAL FIELD ANALYSER.

CEREBRO SPINAL FLUID HYPERTENSION.

6 MONTHS LATER.

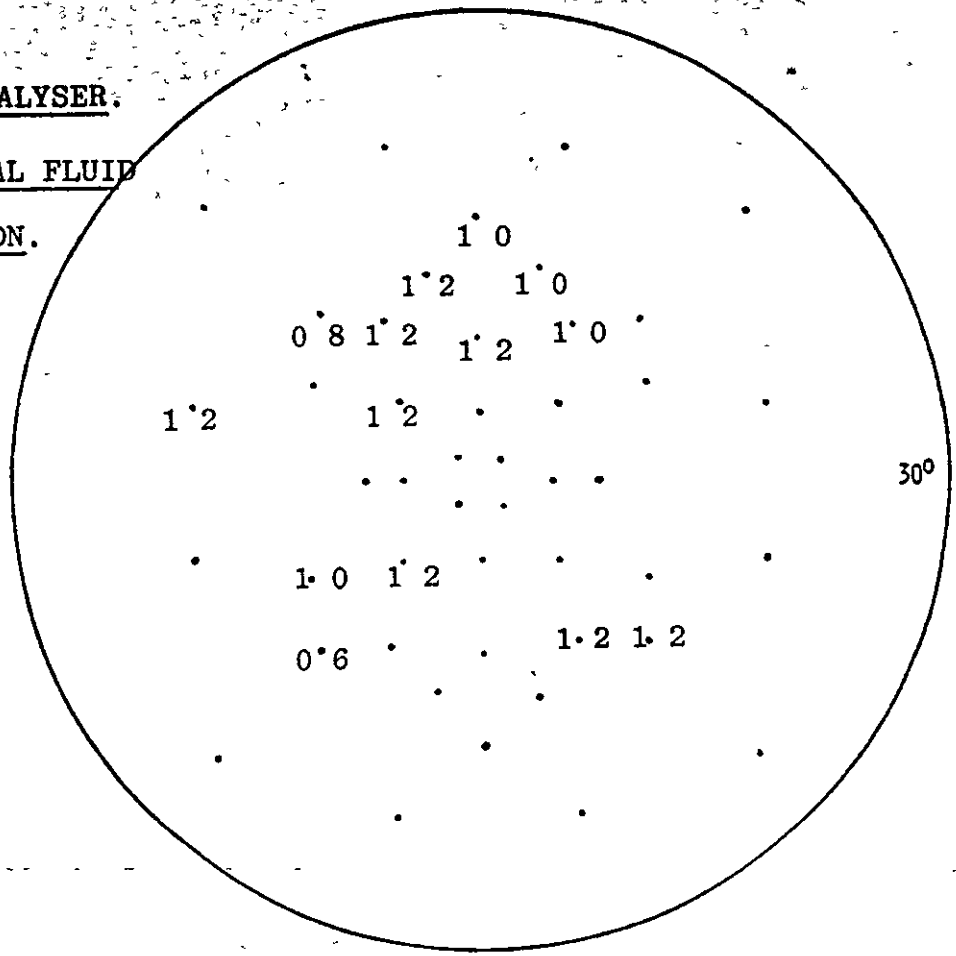


MRS.J. L. V/A 6/24 AGE 60.

STIMULI NOT MARKED SEEN AT 1.4 N.D.F.

MACULAR FUNCTION 2.0 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.



MRS.J. R. V/A. 6/24 AGE 60.

STIMULI NOT MARKED SEEN AT 1.4 N.D.F.

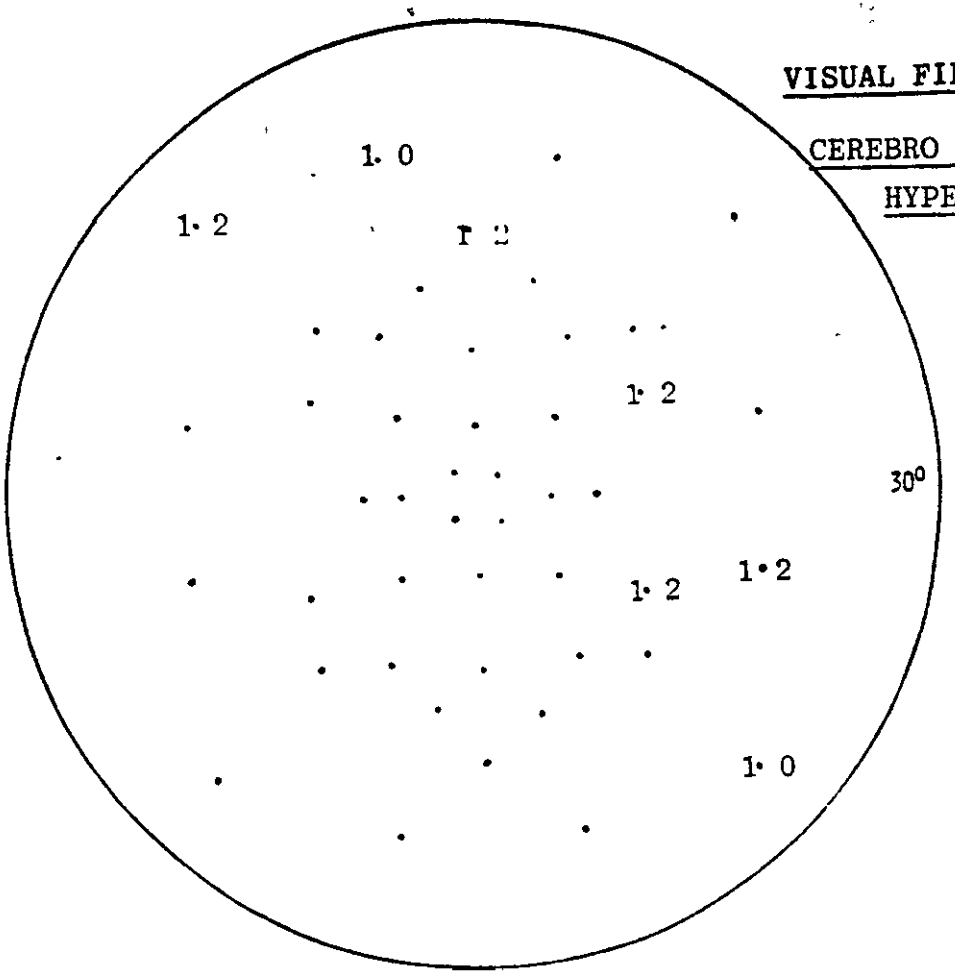
MACULAR FUNCTION 2.0 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.

Facing p. 138

VISUAL FIELD ANALYSER.

CEREBRO SPINAL FLUID HYPERTENSION.

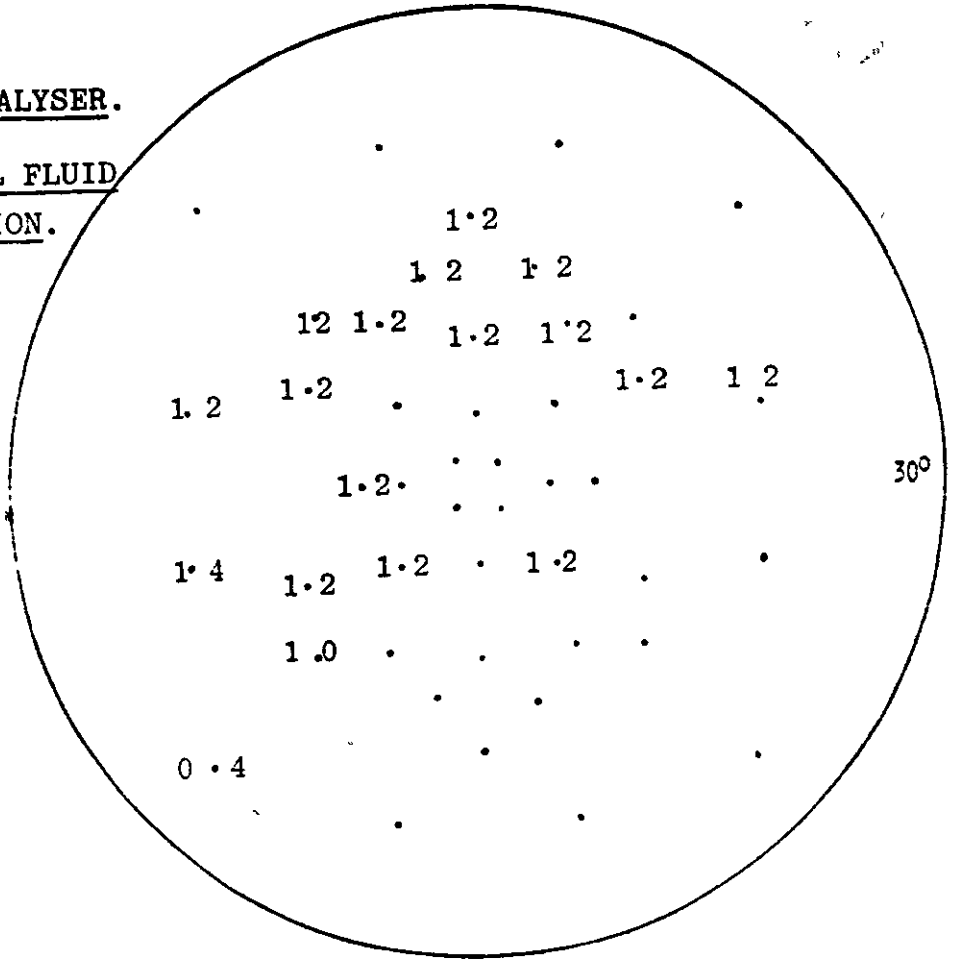


MRS.J. L. V/A. 6/18 AGE 60.

STIMULI NOT MARKED SEEN AT 1.4 N.D.F.

MACULAR FUNCTION 2.2. N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY.



MRS.J. R. V/A. 6/18 AGE 60

STIMULI NOT MARKED SEEN AT 1.4 N.D.F.

MACULAR FUNCTION 2.0 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY

Facing p. 138

be very much easier.

Serial analysis of field loss is particularly valuable in cases of neurology. Friedmann (1976), illustrates the case of a 52 year old man showing almost congrous left homonymous hemianopia with macula sparing. A diagnosis of calcarine arterial occlusion was made as there were no other neurological or ophthalmological signs or symptoms. Two weeks later a serial check-up by multiple static perimetry demonstrated further field changes, oedema of the optic disc, and an astrocytoma of the temporal lobe.

In Fig 71 & 72, the author illustrates a case of bilateral papilloedema due to hypertension of the cerebro-spinal fluid, where serial visual field studies were employed to aid in assessing the effect on vision of treatment by lumbar puncture and with steroids. After about 6 months of treatment the retinal vessels became tortuous, bilateral subconjunctival haemorrhages occurred, and lenticular changes developed. The visual loss is demonstrated at this stage in Fig 71, and after some 6 months of reduced steroid therapy in Fig 72, showing that further loss had been largely prevented.

XVIII

THE INVESTIGATION OF FOVEAL AND MACULA FUNCTION.

A valuable feature incorporated in the Visual Field Analyser is a facility for making assessments of differential light threshold contrast at the fovea, as well as over the macula area. This operates by cutting out the multiple stimuli, and removing the fixation target, so that the aperture then available can be used as a single-point static quantitative stimulus.

There are many cases seen in clinical practice where there may be a slight, or major, reduction of visual acuity, as expressed in terms of letter chart visual acuity. It is very important to know whether the reduction is due to pathological conditions affecting the visual pathway, or to amblyopic ex-anopsia where there is reduction in vision due to dis-use, or to a binocular suppression situation affecting monocular vision. Where there is normal functioning of the visual pathway it has been found that, provided the transmission of the optical media is approximately the same in each eye, macula response can be accepted as normal if the difference in threshold between each eye is not greater than 0.2 N.D.F.units, Friedmann (1974)

VISUAL FIELD ANALYSER.

SERIOUS MACULAR DETACHMENT 3 WEEKS LATER.

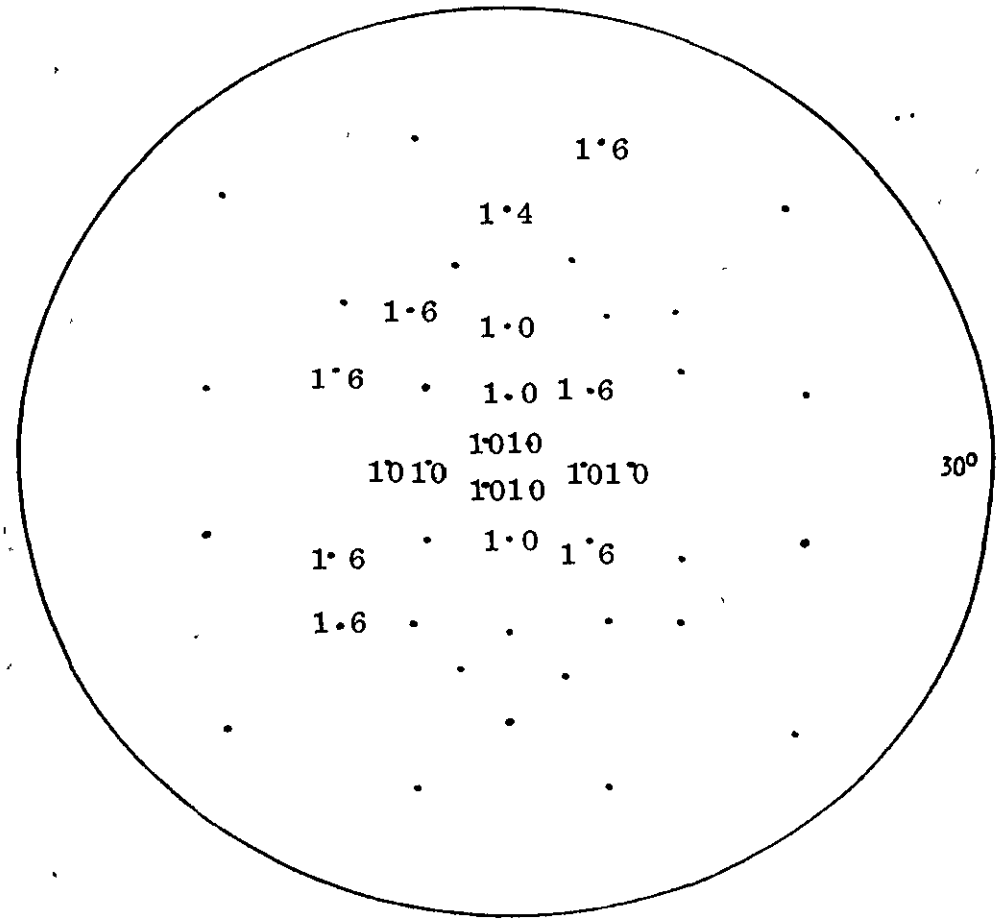


FIG 73.b

MRS.E. R.V/A 6/7.5- AGE 57

STIMULI NOT MARKED SEEN AT N.D.F.

MACULAR FUNCTION 1.4 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD.

STIMULI MARKED ⊙ NOT SEEN AT THE BRIGHTEST SETTING.

VISUAL FIELD ANALYSER.

MACULAR DISTURBANCE.

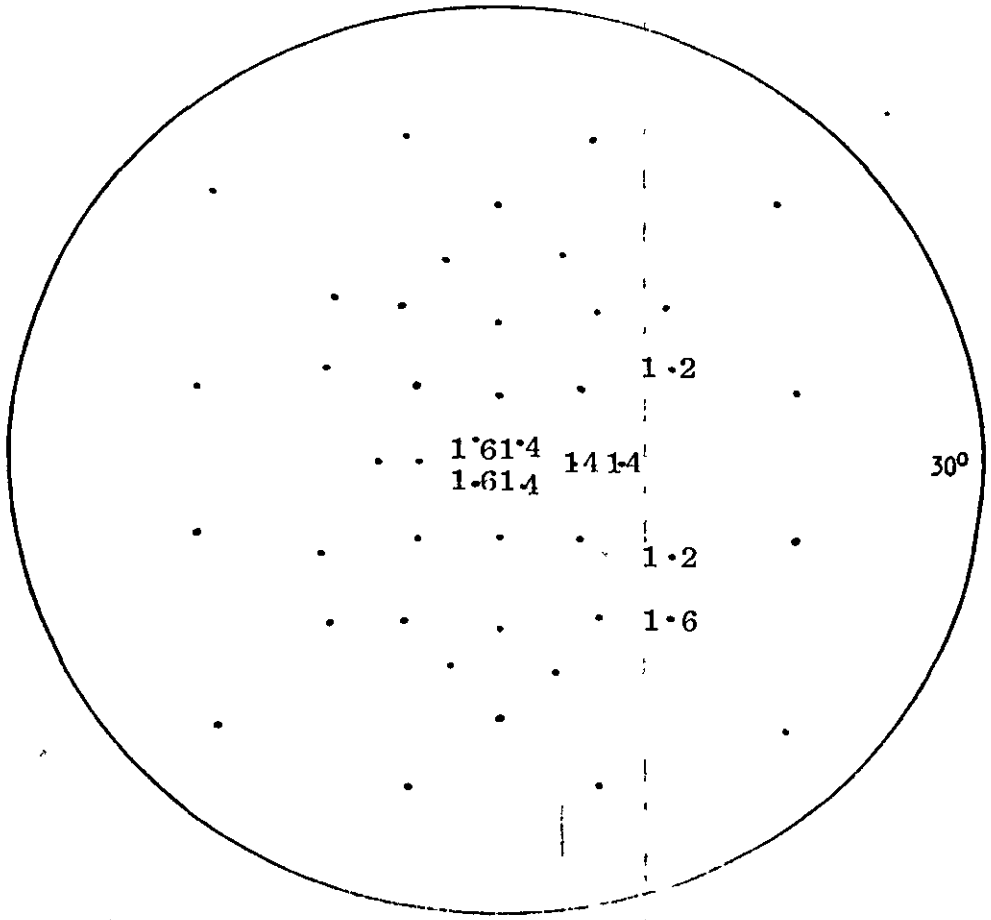


FIG 73 a

MRS E. R. V/A 6/7.5 AGE 57

STIMULI NOT MARKED SEEN AT 1.8 N.D.F.

MACULAR FUNCTION 2.0 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD.

STIMULI MARKED ⊙ NOT SEEN AT THE BRIGHTEST SETTING.

As well as examining thresholds for immediate foveal fixation with white light, it is also possible by using an appropriate filter, to examine thresholds with light of a selected spectral characteristic. For example, Friedmann (1969) showed, using a Wratten 29 red filter, that the light threshold over the macula area was reduced for red light compared with white light, when systemic treatment by chloroquine was beginning to affect vision. In the earliest stages of this differential loss for red light, colour vision and electro-oculography can appear normal.

Bedwell (1977) illustrated the case of a child with reduced visual acuity without strabismus where the assessment of a normal foveal light function similar for both eyes could be used to show that a reduction in the visual acuity was due to a suppression phenomenon, and not to a pathological defect in the visual pathway.

In another instance where there were no initial ophthalmoscopic signs, Fig 73(a) & (b)serial analysis of both foveal and macula area function showed over a few weeks how a macula area visual disturbance could be differentiated as an early serious macula area retinal detachment, and action taken before extensive changes had developed.

XIX

SPECIAL DEVELOPMENTS AND APPLICATIONS OF THE VISUAL FIELD ANALYSER.

ECCENTRIC FIXATION DEVICE.

The original 46-hole front-plate assembly was designed to provide an effective general examination as efficiently as possible over the mid-peripheral field. An increased number of stimulus positions would give more information on a visual field defect, and improve the overall accuracy of detection of visual loss.

To increase the number of positions on the visual field that could be examined by multiple static quantitative perimetry, Friedmann devised an eccentric fixation device, Fig 74 which could be substituted for the normal fixation target. It allowed a fixation to be made at $2\frac{1}{2}^{o}$ off centre, in any direction. This device is usually used in the horizontal or vertical positions, and enables the examiner to make a more detailed investigation in between the existing stimulus positions.

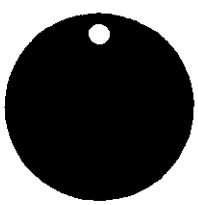


FIG 74

SPECIAL FRONT FOR SINGLE STIMULUS STATIC PERIMETRY.

The construction of the Analyser readily facilitates the interchanging of different front-plate assemblies. To enable a more detailed analysis of a field defect to be made, Friedmann devised an experimental single-hole front. With this front, it was possible to introduce a single stimulus along a meridian every $2\frac{1}{2}^{o}$ from near fixation to 25^{o} eccentric. The size of the stimulus was gradually increased with eccentricity to maintain an averaged threshold response. By rotating the plate, the stimuli could be exposed along any meridian thus making single point static quantitative perimetry possible over the mid-peripheral field, with the same basic instrument used for multiple static perimetry.

THE 98-HOLE FRONT.

Some cases have arisen where greater detail of investigation by multiple static perimetry of the visual field would have been a clinical advantage. Experiments were therefore undertaken by Friedmann with a specially designed front-plate assembly, initially with 100 apertures, and in the final model 98, interchangeable with the original 46-hole front.

Friedmann (1976 a & b), and Bedwell (1977), showed that this new front-plate, with extra stimuli in the critical areas where visual loss was likely to develop

VISUAL FIELD ANALYSER.

GLAUCOMA.

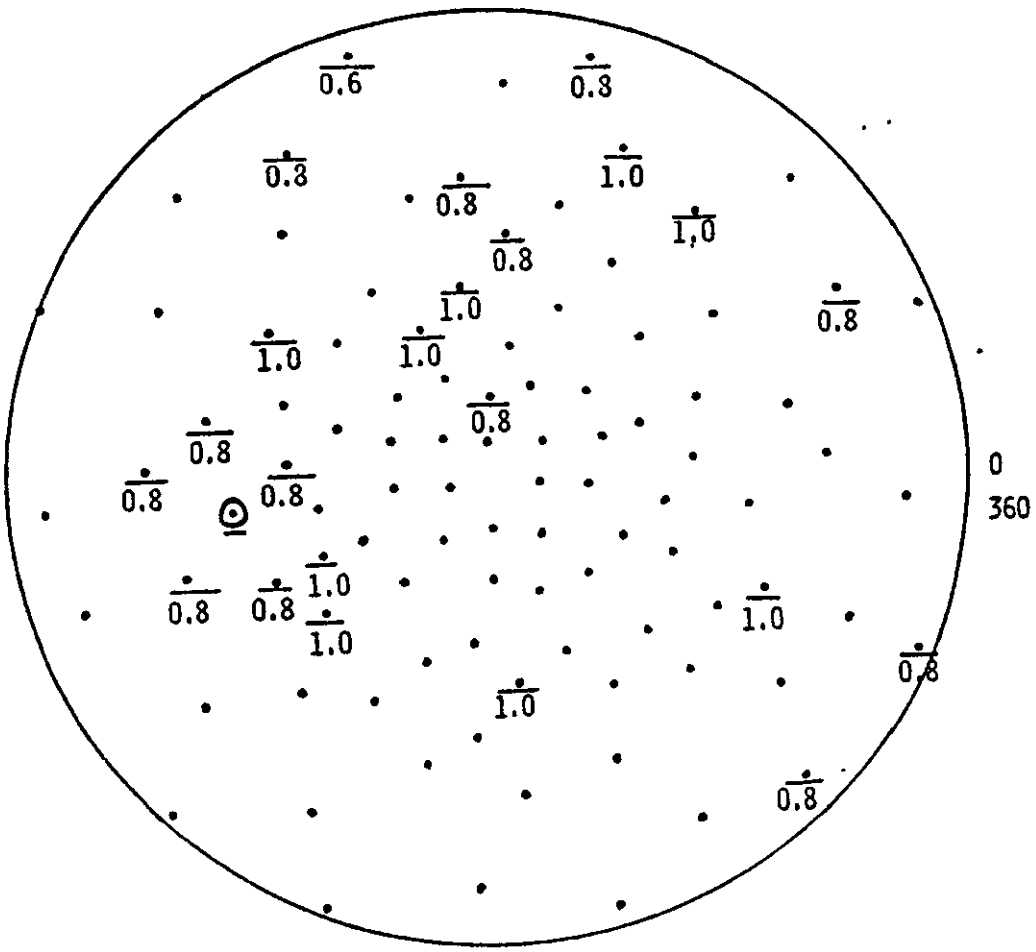


FIG. 77.

MR.T. L.V/A. 6/12. AGE 73.

STIMULI NOT MARKED SEEN AT 1.2 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD USING THE 98-HOLE FRONT. STIMULI MARKED ⊙ NOT SEEN AT THE BRIGHTEST SETTING.

VISUAL FIELD ANALYSER.

GLAUCOMA.

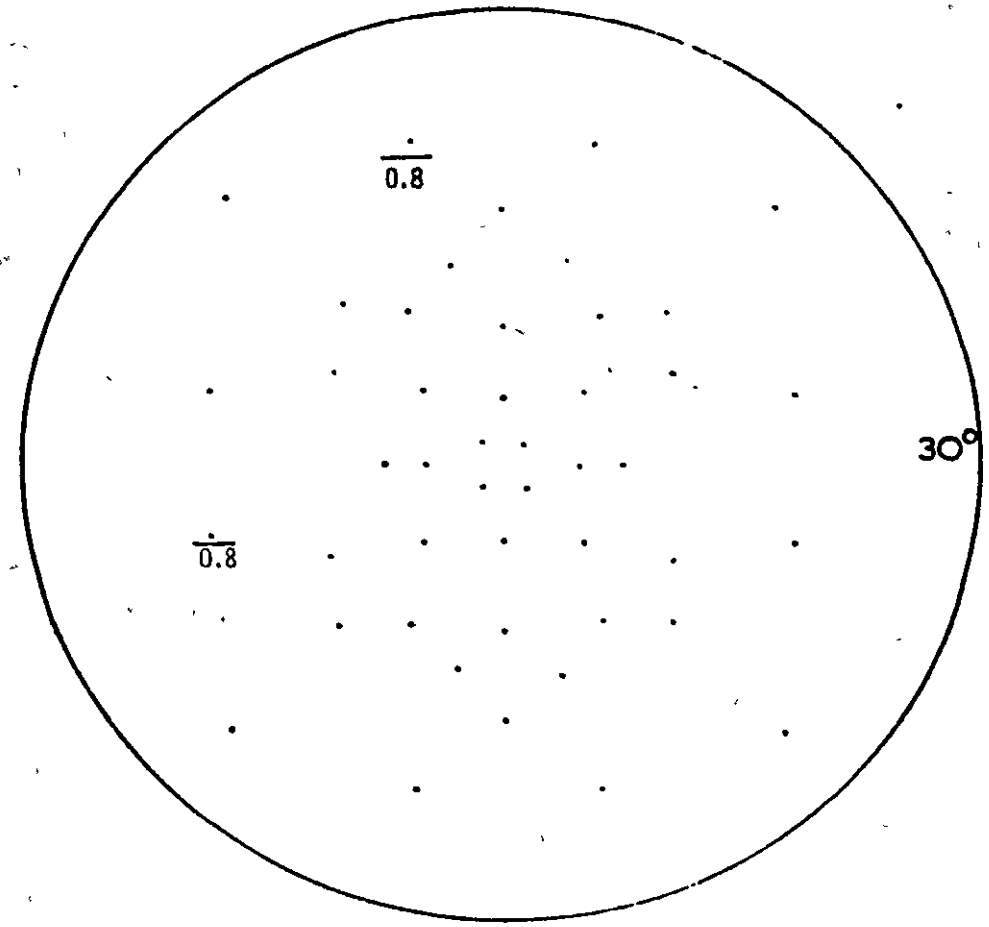


FIG 76

MR.T. L. V/A. 6/12 AGE 73.

STIMULI NOT MARKED SEEN AT 1.2 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD USING THE 46-HOLE FRONT. STIMULI MARKED ⊙ NOT SEEN AT THE BRIGHTEST SETTING.

VISUAL FIELD ANALYSER.

GLAUCOMA.

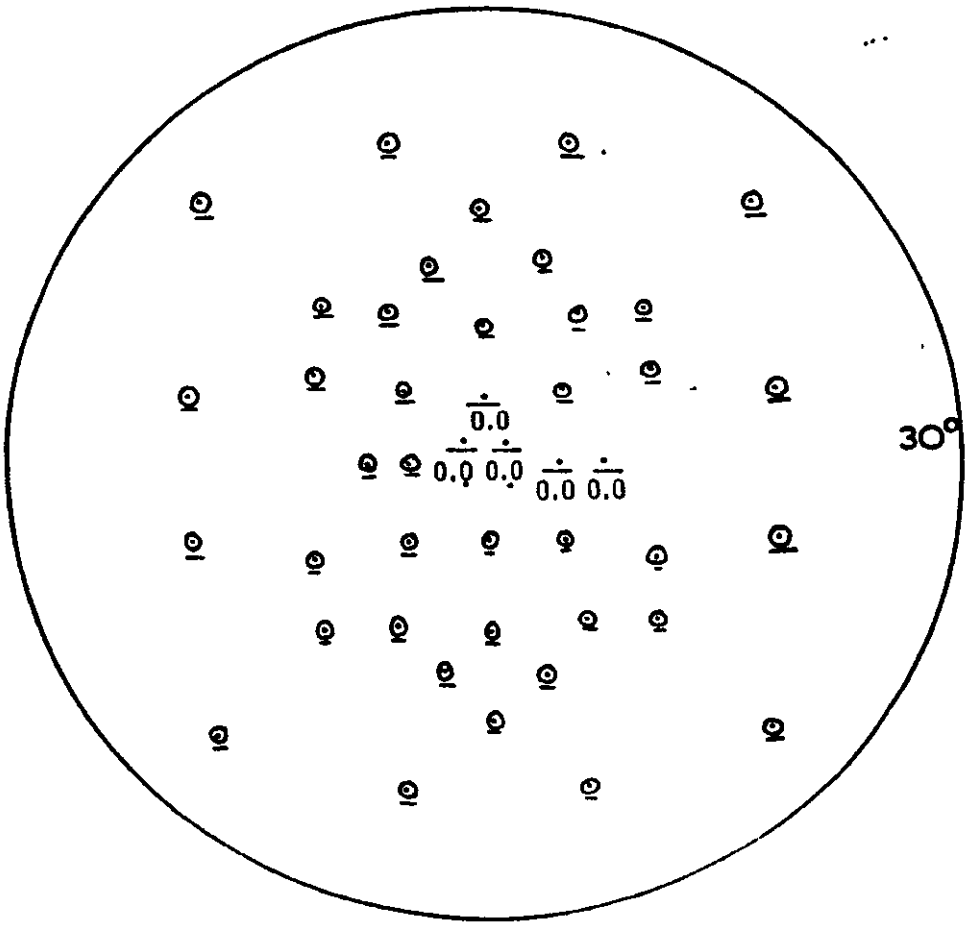


FIG 75.

MR.T. R. V/A 6/24 AGE 73.

STIMULI NOT MARKED SEEN AT 1.2 N.D.F.

RELATIVE VISUAL LOSS ASSESSED QUANTITATIVELY OVER THE CENTRAL VISUAL FIELD USING THE 46-HOLE FRONT. STIMULI MARKED ⊙ NOT SEEN AT THE BRIGHTEST SETTING.

would give greater information about the extent and degree of loss, than was possible with the 46-hole front-plate. It was also possible to obtain static profile sections from the 98-hole recording chart, comparable with that obtainable from the Goldmann bowl perimeter, but with greater rapidity. If the $2\frac{1}{2}^{o}$ eccentric fixation device is used with the 98-hole front-plate an even greater degree of detail is achieved.

With the new 98-hole front-plate extra stimuli were also placed on either side of the vertical line through fixation, and Friedmann (1976) demonstrated how the greater number of stimuli in this new front aided investigation and diagnosis in neuro-ophthalmology. In one case of neuro-toxicity due to Ethambutal, which caused bi-temporal visual field defects, visual acuity and visual fields improved after the cessation of treatment and appeared normal on investigation with the perimeter and the tangent screen. However, using the 98-hole plate a large temporal area demonstrated a slight but definite depression of function. Goldmann static perimetry profiles through the 45^{o} meridian confirmed the abnormality.

In Fig 75,76,77, the author demonstrates the visual field loss of a patient with advanced glaucomatous loss in the right eye, and two points of loss of 0.4 N.D.F. units in the arcuate area of the left eye. When investigated on the 98-hole front a much greater detail of loss was

evident in this left eye.

OTHER EXPERIMENTAL FRONT PLATES.

In addition to the new front-plate described above, Greve (1973) suggested a special plate containing 50 stimuli for the preliminary detection of glaucoma. If any large visual field defect was found in this phase the detection phase should be extended, using a plate with 150 stimuli. These stimuli positions were obtained by arranging that the new 50 stimuli plate should move 15 degrees to the right or the left of the standard position. Greve also designed a second plate with 100 apertures to it, to allow a fuller examination over the whole central field.

Lavergne (1974) used the standard 46-hole front-plate to determine the threshold for the four points P in the macula area, and used this setting for the rest of the points on the standard front. He then replaced this with a special front containing 34 apertures, using points not fully covered by the standard front. Employing the two fronts, a total of eighty points could be examined, maximising the sensitivity of the instrument for assessing density of loss in the arcuate area. The results obtained with this technique were compared with those using the Goldmann bowl perimeter. From sixty eyes studied, thirty-five presented no defects with the two methods, twelve presented defects which were more or less in agreement in six cases. In two cases a defect was detected by the

Visual Field Analyser but missed by Goldmann kinetic perimetry, but confirmed by static profile perimetry. One case of significant elongation of the blind spot detected by the Goldmann perimeter was not found on the Analyser because no stimulus was present on the standard 46-hole front which would have stimulated the area. It was felt that the agreement between the results obtained demonstrated the full value of the Analyser fitted with the special front.

Shinzato (1976), developed a new front-plate assembly containing 51 stimulus positions, subtending 10 minutes of arc at the eye, and used under a mesopic state of adaptation. Comparing central visual field changes in 200 glaucoma subjects, he found results on the Goldmann bowl perimeter similar to those obtained with the new modified Analyser front-plate.

XX

SUMMARY AND CONCLUSIONS.

The investigation of the integrity of the monocular visual field is essential for the early detection of many pathological conditions that can produce visual loss. Previous techniques and instrumentation were inadequate as a routine screening procedure for the quick and effective detection of visual losses. Multiple static quantitative perimetry is shown in this thesis to be an alternative approach which meets the desired criteria, and has been employed in the design of a new instrument, the Visual Field Analyser. An important consideration in static visual field investigation is the quantitative assessment of the difference in luminance required for threshold perception at points over the field. The initial stage in determining the appropriate stimuli specification is to present to the eye stimuli of the same angular subtense and luminance at all the points to be examined against a controlled background luminance. The size of the stimuli can then be varied to allow them to be perceived at the same differential threshold contrast. An even distribution of luminance for the stimuli is provided by an integrating bowl hemisphere from a single Xenon discharge tube. Stimuli luminance is controlled quantitatively by neutral density filters, enabling examination to be made at the appropriate clinical threshold. Any localised visual loss can be recorded in increments of neutral density filter by increasing stimuli luminance until perception, if possible. A built-in ring illuminator provides a background luminance for an adaptation level on the border of photopic/

mesopic sensitivity. A nearly flat gradient of change of stimulus threshold with eccentricity can be obtained, making for an even sensitivity of investigation over the field, especially in the 10 to 20^{o} eccentric region, where early loss due to glaucoma is most likely to occur.

The front plate of the new instrument was designed with apertures to give an averaged threshold response. The mean and standard deviation in threshold were determined for the different stimuli positions, a mean difference over the field of 0.2 log units being found. For 95% of the group of young adults examined the maximum and minimum difference in threshold over the stimuli positions was approximately 0.5 log units. The difference in mean threshold for varying ages of normal observers was determined and found to range from 2.2 log units for those below forty years, to 1.6 log units for those sixty years and older. If a threshold setting 0.2 log units below these means for age was employed for a clinical investigation, it was found that a reduction of threshold of more than 0.4 log units below this setting indicated an abnormal response for most observers.

The new instrument was used for routine visual field screening of 1360 patients attending for ophthalmic examination, among whom the types and proportions of abnormalities that would be expected were detected. An analysis of the largest group, 0.64% of new glaucoma cases, showed that all had a clinically significant visual loss of 0.4 log units or more occurring in the

group, 12 of new glaucoma cases, showed that all had a clinically significant visual loss of 0.4 NDF units or more occurring in the arcuate areas of the field, the characteristic finding for glaucoma. The investigation of visual loss by multiple static quantitative perimetry was compared to the data obtained using other techniques of visual field investigation and was found to give similar, and in some instances superior, sensitivity of investigation. Whether a condition was likely to be progressive could be readily observed by quantitative serial studies undertaken at intervals. In addition to assessing visual loss over the mid-peripheral field, it is also possible to assess foveal light thresholds to determine whether a reduction in visual acuity is pathological or due to a suppression phenomena. The increasing employment of the method of multiple static quantitative perimetry, made possible by the development of the Analyser, has encouraged special developments and applications.

In conclusion the ability to assess, both quickly and efficiently, the integrity of monocular vision by multiple static quantitative perimetry has been achieved, The detection and investigation of visual loss in the one instrument as part of a routine ophthalmic examination has been made possible.

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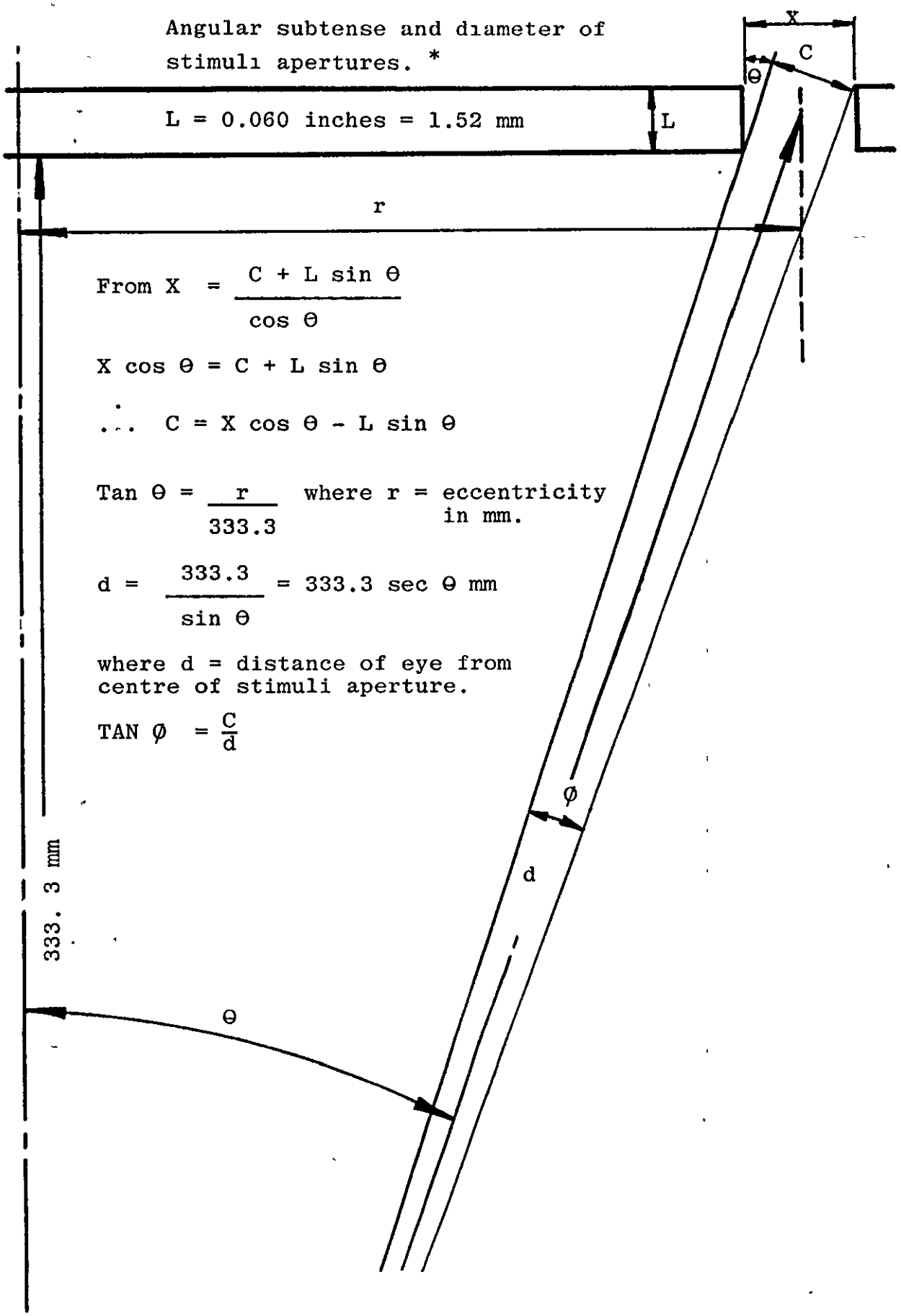
APPENDIX A.

SUCCESSIVE STAGES IN THE DESIGN AND SPECIFICATION OF THE APERTURES IN THE FRONT-PLATE ASSEMBLY.

VISUAL FIELD ANALYSER FRONT PLATE DESIGN.

Angular subtense and diameter of stimuli apertures. *

L = 0.060 inches = 1.52 mm



$$\text{From } X = \frac{C + L \sin \Theta}{\cos \Theta}$$

$$X \cos \Theta = C + L \sin \Theta$$

$$\therefore \quad C = X \cos \Theta - L \sin \Theta$$

$$\text{Tan } \Theta = \frac{r}{333.3}$$ where r = eccentricity in mm.

$$d = \frac{333.3}{\sin \Theta} = 333.3 \sec \Theta \text{ mm}$$

where d = distance of eye from centre of stimuli aperture.

$$\text{TAN } \phi = \frac{C}{d}$$

* with acknowledgements to Mr.L. Wray.

APERTURE	A1	A2	A3	A4	B1	B2	
ECCENTRICITY.	25°	25°	25°	25°	22½°	22½°	
MERIDIAN.	45°	135°	135°	45°	75°	105°	
STAGE A	.087	.087	.087	.087	.087	.112	ins
STAGE B1	.136	.136	.136	.136	.128	.158	ins
STAGE B2	.123	.123	.123	.123	.118	.146	ins
STAGE B3	.123	.123	.123	.123	.118	.146	ins
STAGE B4	.123	.123	.123	.123	.118	.146	ins
STAGE C1	.116	.116	.116	.116	.112	.139	ins
STAGE C2	.116	.116	.116	.116	.112	.139	ins
STAGE C3	.116	.116	.116	.116	.112	.139	ins
STAGE C4	.116	.116	.116	.116	.112	.136	ins
STAGE C5	.116	.116	.116	.116	.112	.120	ins
STAGE C6	.116	.116	.116	.116	.112	.112	ins
STAGE C6	2.95	2.95	2.95	2.95	2.84	2.84	mm.
STAGE C6	0.829	0.829	0.829	0.829	0.801	0.801	Log mm^2
STAGE C6	0° 19'	0° 19'	0° 19'	0° 19'	0° 24'	0° 24'	

APERTURE	C1	C2	C3	D1	D2	E1	
ECCENTRICITY.	$17\frac{1}{2}^{o}$	20^{o}	20^{o}	$22\frac{1}{2}^{o}$	$22\frac{1}{2}^{o}$	20^{o}	
MERIDIAN.	90^{o}	165^{o}	15^{o}	105^{o}	75^{o}	15^{o}	
STAGE A	.068	.087	.087	.087	.112	.068	ins.
STAGE B1	.095	.121	.121	.128	.158	.100	ins.
STAGE B2	.090	.113	.113	.118	.146	.094	ins.
STAGE B3	.090	.113	.113	.118	.146	.110	ins.
STAGE B4	.090	.113	.113	.118	.146	.110	ins.
STAGE C1	.077	.103	.103	.112	.139	.101	ins.
STAGE C2	.081	.103	.103	.112	.139	.101	ins.
STAGE C3	.081	.103	.103	.112.	.139	.101	ins.
STAGE C4	.081	.101	.101	.112	.136	.101	ins.
STAGE C5	.081	.101	.101	.112	.120	.101	ins.
STAGE C6	.089	.101	.101	.112	.112	,101	ins.
STAGE C6	2.26	2.56	2.56	.284	2.84	2.56	mm.
STAGE C6	0.603	0.711	0.711	0.801	0.801	0.811	Log mm^2
STAGE C6	0^{o} 20'	0^{o}18'	0^{o}18'	0^{o} 21'	0^{o} 21'	0^{o} 18'	

APERTURE	E2	E3	F1	F2	F3	F4	
ECCENTRICITY.	20°	17½°	15°	15°	15°	15°	
MERIDIAN.	165°	90°	45°	135°	135°	45°	
STAGE A	.068	.087	.068	.068	.087	.087	ins.
STAGE B1.	.100	.100	.121	.089	.089	.110	ins.
STAGE B2.	.094	.113	.085	.085	.106	.106	ins.
STAGE B3.	.110	.136	.085	.085	.106	.106	ins.
STAGE B4.	.110	.136	.085	.085	.106	.106	ins.
STAGE C1	.101	.114	.073	.073	,096	.096	ins.
STAGE C2.	.101	.114	.073	.073	.096	.096	ins.
STAGE C3.	.101	.114	.073	.073	.096	.096	ins.
STAGE C4.	.101	.114	.073	.073	.093	.093	ins.
STAGE C5	.101	.101	.073	.073	.073	.073	ins.
STAGE C6	.101	.101	.073	.073	.073	.073	ins.
STAGE C6	2.56	2.56	1.86	1.86	1.86	1.86	mm.
STAGE C6	0.811	0.811	0.435	0.435	0.435	0.435	Log mm^2
STAGE C6	0° 20'	0° 18'	0° 14'	0° 14'	0° 14'	0° 14'	

APERTURE	G1	G2	H1	H2	H3	J1	
ECCENTRICITY.	15°	15°	12½°	12½°	10°	15°	
MERIDIAN.	75°	105°	60°	120°	90°	105°	
STAGE A	.068	.087	.052	.052	.068	.068	ins.
STAGE B1	.089	.110	.068	.068	.081	.089	ins.
STAGE B2	.085	.106	.067	.067	.080	.085	ins.
STAGE B3	.085	.106	.067	.067	.080	.085	ins.
STAGE B4	.085	.106	.070	.070	.080	.085	ins.
STAGE C1	.073	.096	.053	.053	.069	.073	ins.
STAGE C2	.073	.096	.059	.059	.069	.078	ins.
STAGE C3	.073	.096	.063	.063	.069	.081	ins.
STAGE C4	.073	.093	.063	.063	.069	.081	ins.
STAGE C5	.073	.073	.063	.063	.063	.073	ins.
STAGE C6	.073	.073	.067	.067	.067	.073	ins.
STAGE C6	1.86	1.86	1.60	1.60	1.60	1.86	mm.
STAGE C6	0.435	0.435	0.303	0.303	0.303	0.435	Log mm^2
STAGE C6	0° 14'	0° 14'	0° 14'	0° 13'	0° 14'	0° 14'	

APERTURE	J2	K1	K2	K3	L1	L2	
ECCENTRICITY.	15°	10°	12½°	12½°	12½°	12½°	
MERIDIAN.	75°	90°	120°	60°	30°	150°	
STAGE A	.087	.052	.068	.068	.068	.068	ins.
STAGE B1	.110	.064	.085	.085	.085	.085	ins.
STAGE B2	.106	.063	.083	.083	.083	.083	ins.
STAGE B3	.106	.063	.083	.083	.083	.083	ins.
STAGE B4	.106	.063	.083	.083	.083	.083	ins.
STAGE C1	.096	.044	.069	.069	.069	.069	ins.
STAGE C2	.096	.055	.069	.069	.069	.069	ins.
STAGE C3	.096	.059	.069	.069	.073	.073	ins.
STAGE C4	.093	.059	.069	.069	.073	.073	ins.
STAGE C5	.073	.059	.069	.069	.073	.073	ins.
STAGE C6	.073	.063	.063	.063	.073	.073	ins.
STAGE C6	1.86	1.50	1.75	1.75	1.86	1.86	mm.
STAGE C6	0.435	0.247	0.321	0.321	0.435	0.435	Log mm^2
STAGE C6	0° 14'	0° 12'	0° 14'	0°14'	0°15'	0°15'	

APERTURE	L3	L4	M1	M2	N1	N2	
ECCENTRICITY.	$12\frac{1}{2}^{o}$	$12\frac{1}{2}^{o}$	8^{o}	8^{o}	$7\frac{1}{2}^{o}$	$7\frac{1}{2}^{o}$	
MERIDIAN.	150^{o}	30^{o}	0^{o}	180^{o}	45^{o}	135^{o}	
STAGE A	.068	.068	.052	.052	.052	.052	ins.
STAGE B1	.085	.085	.061	.061	.061	.061	ins.
STAGE B2	.083	.083	.061	.061	.060	.060	ins.
STAGE B3	.083	.083	.061	.061	.060	.060	ins.
STAGE B4	.083	.083	.063	.063	.060	.060	ins.
STAGE C1	.069	.069	.044	.044	.038	.038	ins.
STAGE C2	.069	.069	.052	.052	.055	.055	ins.
STAGE C3	.073	.073	.059	.059	.059	.059	ins.
STAGE C4	.073	.073	.063	.063	.063	.063	ins.
STAGE C5	.073	.073	.063	.063	.063	.063	ins.
STAGE C6	.073	.073	.063	.063	.063	.063	ins.
STAGE C6	1.86	1.86	1.60	1.60	1.60	1.60	mm.
STAGE C6	0.435	0.435	0.303	0.303	0.303	0.303	Log mm^2
STAGE C6	$0^{o}15'$	$0^{o}15'$	$0^{o}11'$	$0^{o}11'$	$0^{o}11'$	$0^{o}11'$	

APERTURE	N3	N4	O1	O2	O3	O4	
ECCENTRICITY.	$7\frac{1}{2}^{o}$	$7\frac{1}{2}^{o}$	5^{o}	5^{o}	5^{o}	5^{o}	
MERIDIAN.	135^{o}	45^{o}	0^{o}	90^{o}	180^{o}.	90^{o}	
STAGE A	.052	.052	.031	.031	.031	.031	ins.
STAGE B1	.061	.061	.036	.036	.036	.036	ins.
STAGE B2	.060	.060	.036	.036	.036	.036	ins.
STAGE B3	.060	.060	.043	.043	.043	.043	ins.
STAGE B4	.060	.060	.063	.063	.063	.063	ins.
STAGE C1	.038	.038	.044	.044	.044	.044	ins.
STAGE C2	.055	.055	.055	.055	.055	.055	ins.
STAGE C3	.059	.059	.059	.059	.059	.059	ins.
STAGE C4	.063	.063	.063	.063	.063	.063	ins.
STAGE C5	.063	.063	.063	,063	.063	.063	ins.
STAGE C6	.063	.063	.063	.063	.063	.063	ins.
STAGE C6	1.60	1.60	1.60	1.60	1.60	1.60	mm.
STAGE C6	0.303	0.303	0.303	0.303	0.303	0.303	Log mm^2
STAGE C6	0^{o} 11'	0^{o} 11'	0^{o} 13'	0^{o} 13'	0^{o}13'	0^{o}13'	

APERTURE	P1	P2	P3	P4	
ECCENTRICITY.	2^{o}	2^{o}	2^{o}	2^{o}	
MERIDIAN.	45^{o}	135^{o}	135^{o}	45^{o}	
STAGE A	.031	.031	.031	.031	ins.
STAGE B1	.033	.033	.033	.033	ins.
STAGE B2	.033	.033	.033	.033	ins.
STAGE B3	.037	.037	.037	.037	ins.
STAGE B4	.054	.054	.054	.054	ins.
STAGE C1	.031	.031	.031	.031	ins.
STAGE C2	.046	.046	.046	.046	ins.
STAGE C3	.052	.052	.052	.052	ins.
STAGE C4	.055	.055	.055	.055	ins.
STAGE C5	.055	.055	.055	.055	ins.
STAGE C6	.055	.055	.055	.055	ins.
STAGE C6	1.40	1.40	1.40	1.40	mm.
STAGE C6	0.287	0.287	0.287	0.287	Log mm^2
STAGE C6	$0^{o}14'$	$0^{o}14'$	$0^{o}14'$	$0^{o}14'$	

APPENDIX B.

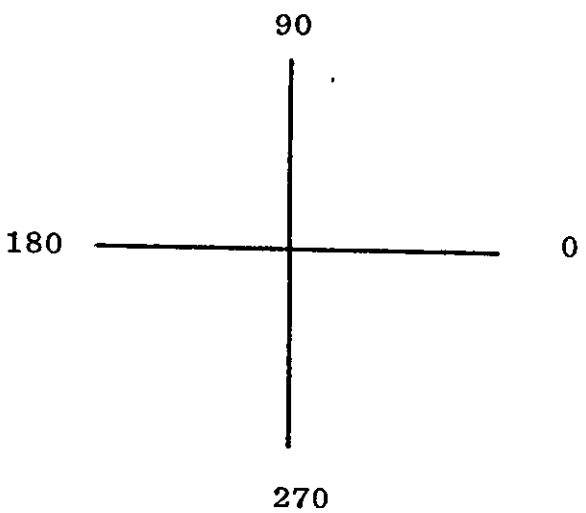
THE EFFECT OF AGE ON DIFFERENTIAL THRESHOLD CONTRAST.

THE EFFECT OF AGE ON THE NEUTRAL DENSITY FILTER SETTING FOR THRESHOLD VISIBILITY OF ALL THE STIMULI.

SUBJECTS UNDER 40	NDF.	SUBJECTS 41-50	NDF.	SUBJECTS 51-60	NDF.	SUBJECTS 61 Plus	NDF.
13	2.0	41	2.0	51	2.0	61	1.6
16	2.2	41	2.0	51	2.0	61	2.0
21	2.2	42	2.0	52	1.8	61	1.8
21	2.2	42	2.0	52	2.0	61	1.8
22	2.2	42	2.2	52	1.8	62	1.6
22	2.2	42	2.2	52	2.0	62	1.8
22	2.2	42	2.0	52	1.8	63	1.8
23	2.2	42	2.2	52	2.2	63	1.8
23	2.4	43	2.0	53	2.0	64	1.8
23	2.2	43	2.2	53	1.8	65	1.6
24	2.2	43	1.8	53	1.8	65	1.6
29	2.2	44	2.2	53	2.0	67	1.4
31	2.2	44	2.0	53	1.8	67	1.8
32	2.2	45	2.0	54	1.8	70	1.6
33	2.2	45	2.0	55	1.8	70	1.4
33	2.0	45	2.0	55	2.0	70	1.8
33	2.2	46	2.2	55	2.0	70	1.6
35	2.0	47	2.0	55	1.8	72	1.8
36	2.2	47	1.8	56	1.8	74	1.6
37	2.2	48	1.8	56	1.8	75	1.4
37	2.0	48	2.0	57	1.8	76	1.4
39	2.0	49	1.8	58	1.8	77	1.5
		49	2.2	58	2.0		
Mean Age	Mean NDF	50	2.0	58	1.6	Mean age	Mean NDF
27.5 yrs	2.2	50	2.0	58	1.8	67.1	1.6
S/D 7.2	S/D 0.1	50	2.0	60	1.8	S/D 5.2	S/D 0.17
		50	1.8	60	2.0		
		Mean Age 45.19	Mean NDF 2.0	Mean Age 53.5	Mean NDF 1.9		
		S/D 3.1	S/D 0.13	S/D 5.22	S/D 0.12		

APPENDIX C.

THE MEANS AND STANDARD DEVIATIONS
OF DIFFERENTIAL THRESHOLD CONTRAST
FOR THE PERCEPTION OF FLASHED STIMULI.



NOTATION USED - SUBJECT FACING SCREEN

Table I

12' Stimulus size.

0.1 milli-lamberts background luminance

N.D.F.	Meridian.	Mean reading.	Standard deviation.
5.2	0	9.90	7.79
5.2	30	8.35	5.96
5.2	60	6.90	4.01
5.2	90	5.85	3.30
5.2	120	6.95	4.07
5.2	150	7.75	3.99
5.2	180	9.70	4.65
5.2	210	7.70	4.08
5.2	240	5.45	2.88
5.2	270	7.70	3.83
5.2	300	8.75	5.05
5.2	330	8.65	5.53
5.0	0.	21.20	12.43
5.0	30	14.20	6.17
5.0	60	11.15	4.39
5.0	90	10.55	3.91
5.0	120	11.35	4.76
5.0	150	13.95	3.94
5.0	180	15.70	3.38
5.0	210	12.40	4.42
5.0	240	12.20	5.05
5.0	270	13.65	3.12
5.0	300	14.65	5.39
5.0	330	15.15	6.52
4.8	0	34.75	9.63
4.8	30	23.65	5.81
4.8	60	17.10	4.81
4.8	90	15.50	5.37
4.8	120	14.50	5.28
4.8	150	17.85	5.00
4.8	180	20.20	3.01
4.8	210	18.15	3.45
4.8	240	16.15	5.20
4.8	270	19.30	4.91
4.8	300	21.05	4.96
4.8	330	23.95	9.65
4.6	0	40.25	11.55
4.6	30	28.95	5.92
4.6	60	24.00	6.23
4.6	90	21.95	5.13
4.6	120	21.70	4.52
4.6	150	22.10	4.52
4.6	180	26.05	3.76
4.6	210	23.55	4.19
4.6	240	23.20	5.69
4.6	270	24.65	4.66
4.6	300	23.95	5.28
4.6	330	30.35	11.25

Table II

12' Stimulus size

0.5 milli-lamberts background luminance.

N.D.F.	Meridian.	Mean reading	Standard deviation
4.8	0	11.2	7.5
4.8	30	8 .0	3.3
4.8	60	6 .1	3.1
4.8	90	6 .7	3.2
4.8	120	7 .4	3.7
4.8	150	10.0	3.6
4.8	180	12.0	4.2
4.8	210	8 .0	3.7
4.8	240	7 .7	3.1
4.8	270	7. 2	3.6
4.8	300	7 .5	4.0
4.8	330	8 .2	3.7
4.6	0	22.4	9.9
4.6	30	11.6	3.4
4.6	60	10.1	2.9
4.6	90	11.0	3.6
4.6	120	13.1	3.2
4.6	150	15.4	4.0
4.6	180	17.9	3.6
4.6	210	14.4	3.9
4.6	240	13.2	3.3
4.6	270	12.4	2.2
4.6	300	13.2	4.3
4.6	330	15.7	5.4
4.4	0	33.0	6.5
4.4	30	20.6	8.8
4.4	60	14.4	5.0
4.4	90	15.4	4.8
4.4	120	18.9	4.4
4.4	150	22.2	4.9
4.4	180	23.5	4.4
4.4	210	20.2	4.9
4.4	240	18.5	6.1
4.4	270	17.6	6.2
4.4	300	20.0	7.2
4.4	330	22.9	9.4
4.2	0	37.0	4.8
4.2	30	28.1	7.9
4.2	60	19.4	4.5
4.2	90	20.0	3.6
4.2	120	24.4	4.6
4.2	150	26.9	4.7
4.2	180	29.0	6.3
4.2	210	25.6	5.4
4.2	240	25.1	6.1
4.2	270	24.2	7.7
4.2	300	27.7	7.4
4.2	330	29.1	7.0

Table III

12' Stimulus size.

1.0 milli-lamberts background luminance

N.D.F.	Meridian.	Mean reading	Standard deviation.
4.6	0	12.7	7.0
4.6	30	8.5	2.9
4.6	60	7.1	3.3
4.6	90	6.6	2.7
4.6	120	8.4	3.3
4.6	150	10.6	3.2
4.6	180	12.2	4.2
4.6	210	9.1	3.7
4.6	240	7.8	3.4
4.6	270	7.7	3.4
4.6	300	8.3	3.6
4.6	330	8.4	3.4
4.4	0	21.0	7.7
4.4	30	13.4	4.3
4.4	60	11.6	2.7
4.4	90	11.7	3.1
4.4	120	14.5	3.0
4.4	150	15.7	3.2
4.4	180	18.0	3.8
4.4	210	15.4	3.6
4.4	240	13.5	3.1
4.4	270	13.9	3.2
4.4	300	14.4	4.4
4.4	330	15.9	5.9
4.2	0	31.2	7.5
4.2	30	18.2	4.9
4.2	60	16.0	3.7
4.2	90	16.1	3.8
4.2	120	18.4	2.8
4.2	150	19.9	2.4
4.2	180	22.2	3.8
4.2	210	19.7	3.1
4.2	240	18.9	3.5
4.2	270	17.1	3.3
4.2	300	18.5	4.4
4.2	330	21.5	5.3
4.0	0	37.5	4.0
4.0	30	28.5	7.0
4.0	60	23.4	5.4
4.0	90	21.5	5.3
4.0	120	24.1	4.3
4.0	150	26.8	5.2
4.0	180	28.6	4.5
4.0	210	26.8	4.7
4.0	240	24.5	4.6
4.0	270	23.9	6.5
4.0	300	26.8	5.4
4.0	330	31.0	6.0

Table III contd.

N.D.F.	Meridian.	Mean reading	Standard deviation.
3.8	0	39.4	1.7
3.8	30	35.0	6.3
3.8	60	29.1	6.4
3.8	90	27.2	5.1
3.8	120	28.4	5.3
3.8	150	30.9	5.5
3.8	180	35.5	4.7
3.8	210	31.1	4.2
3.8	240	29.2	5.1
3.8	270	28.7	6.8
3.8	300	32.2	5.1
3.8	330	35.6	4.0

Table IV

12' Stimulus size.

1.5 milli-lamberts background luminance.

N.D.F.	Meridian.	Mean reading	Standard deviation.
4.6	0.	8.6	5.4
4.6	30	7.0	3.0
4.6	60	6.0	2.9
4.6	90	5.4	2.7
4.6	120	7.4	2.9
4.6	150	8.6	2.3
4.6	180	11.1	3.1
4.6	210	7.4	1.8
4.6	240	7.0	2.3
4.6	270	5.9	2.8
4.6	300	6.9	3.0
4.6	330	7.3	3.0
4.4	0	16.7	9.5
4.4	30	10.6	3.1
4.4	60	8.7	2.7
4.4	90	9.7	2.5
4.4	120	11.1	3.4
4.4	150	12.5	3.0
4.4	180	15.5	3.6
4.4	210	12.2	4.0
4.4	240	11.1	3.3
4.4	270	11.1	4.1
4.4	300	10.6	4.2
4.4	330	13.2	4.7
4.2	0	24.4	9.3
4.2	30	15.5	6.1
4.2	60	13.6	4.3
4.2	90	12.9	3.9
4.2	120	14.9	3.5
4.2	150	16.7	3.9
4.2	180	19.7	3.5
4.2	210	16.9	3.5
4.2	240	15.0	3.9
4.2	270	15.9	5.1
4.2	300	16.2	5.8
4.2	330	19.2	6.5
4.0	0	31.3	8.9
4.0	30	21.5	9.3
4.0	60	19.1	5.4
4.0	90	16.7	4.8
4.0	120	20.6	5.7
4.0	150	22.6	5.2
4.0	180	25.9	6.0
4.0	210	21.2	4.9
4.0	240	20.7	6.2
4.0	270	21.4	7.4
4.0	300	25.6	8.6
4.0	330	25.3	9.4

Table IV contd.

N.D.F.	Meridian.	Mean reading	Standard deviation.
3.8	0	37.6	5.2
3.8	30	30.9	9.6
3.8	60	24.2	7.4
3.8	90	21.9	7.8
3.8	120	25.6	7.2
3.8	150	27.2	7.3
3.8	180	30.6	6.0
3.8	210	27.0	6.5
3.8	240	27.0	7.0
3.8	270	28.0	7.9
3.8	300	30.4	7.3
3.8	330	32.1	8.4
3.6	0	39.7	1.1
3.6	30	34.9	6.6
3.6	60	29.4	9.4
3.6	90	26.4	6.8
3.6	120	30.4	7.4
3.6	150	32.9	8.2
3.6	180	35.0	6.3
3.6	210	32.4	7.2
3.6	240	33.3	9.1
3.6	270	33.2	7.4
3.6	300	35.7	6.3
3.6	330	36.9	5.9
3.4	0	40.0	0.0
3.4	30	35.3	7.1
3.4	60	29.4	8.5
3.4	90	26.2	6.4
3.4	120	27.8	4.7
3.4	150	28.7	5.6
3.4	180	34.4	4.8
3.4	210	31.9	7.8
3.4	240	30.3	7.6
3.4	270	33.1	6.0
3.4	300	35.3	5.4
3.4	330	40.0	0.0

Table V

24' Stimulus size.

0.1 milli-lamberts background luminance.

N.D.F.	Meridian.	Mean reading.	Standard deviation.
5.6	0	20.0	11.51.
5.6	30	13.75	9.82
5.6	60	9.65	8.03
5.6	90	9.00	6.78
5.6	120	8.95	6.12
5.6	150	10.30	7.16
5.6	180	11.75	7.64
5.6	210	10.05	6.40
5.6	240	9.60	7.29
5.6	270	11.40	8.65
5.6	300	11.80	6.77
5.6	330	12.25	10.64
5.4	0	30.30	11.63
5.4	30	20.75	9.70
5.4	60	15.35	7.30
5.4	90	12.15	5.37
5 4	120	18.30	7.28
5.4	150	14.50	6.48
5.4	180	19.05	4.77
5.4	210	15.50	5.44
5.4	240	14.30	7.54
5.4	270	17.30	7.31
5.4	300	17.90	8.00
5.4	330	19.40	9.66
5.2	0	38.00	12.57
5.2	30	24.75	10.22
5.2	60	19.75	7.31
5.2	90	17.95	5.98
5.2	120	18.20	6.96
5.2	150	20.30	4.88
5.2	180	22.50	3.97
5.2	210	20.80	6.56
5.2	240	20.55	6.06
5.2	270	23.65	6.69
5.2	300	24.60	6.54
5.2	330	27.70	8.97
5.0	0	44.55	10.82
5.0	30	31.85	6.90
5.0	60	24.95	6.47
5.0	90	22.45	6.27
5.0	120	22.75	6.71
5.0	150	24.15	3.87
5.0	180	26.45	2.98
5.0	210	25.25	7.39
5.0	240	25.75	6.08
5.0	270	27.30	6.32
5.0	300	31.45	4.94
5.0	330	36.65	7.76

Table VI

24' Stimulus size.

0.5 milli-lamberts background luminance.

N.D.F.	Meridian.	Mean reading.	Standard deviation.
5.2	0	7.2	3.5
5.2	30	5.4	2.2
5.2	60	5.8	2.6
5.2	90	4.5	2.4
5.2	120	5.1	2.3
5.2	150	6.0	3.1
5.2	180	8.1	3.8
5.2	210	5.7	2.9
5.2	240	5.2	2.9
5.2	270	4.1	2.1
5.2	300	6.0	3.1
5.2	330	6.5	3.3
5.0	0	16.6	9.8
5.0	30	8.7	3.8
5.0	60	8.0	3.4
5.0	90	7.9	3.7
5.0	120	9.6	3.6
5.0	150	11.4	3.7
5.0	180	13.7	3.7
5.0	210	11.4	5.3
5.0	240	9.4	4.1
5.0	270	9.6	5.1
5.0	300	10.5	5.1
5.0	330	11.1	4.6
4.8	0	35.5	5.7
4.8	30	28.3	8.8
4.8	60	21.4	5.8
4.8	90	17.2	6.6
4.8	120	21.7	6.8
4.8	150	24.8	5.8
4.8	180	26.0	5.6
4.8	210	24.2	5.6
4.8	240	22.9	5.5
4.8	270	24.1	6.9
4.8	300	27.7	8.4
4.8	330	30.5	8.3
4.6	0	39.6	1.6
4.6	30	36.7	5.9
4.6	60	29.5	7.9
4.6	90	26.0	6.9
4.6	120	29.2	6.2
4.6	150	32.6	5.8
4.6	180	34.4	4.6
4.6	210	32.4	5.8
4.6	240	31.3	6.2
4.6	270	34.1	6.6
4.6	300	36.4	5.6
4.6	330	37.5	5.6

Table VII

24' Stimulus size.

1.0 milli-lamberts background luminance.

N.D.F.	Meridian.	Mean reading.	Standard deviation.
5.0	0	9.0	4.3
5.0	30	8.3	2.8
5.0	60	5.7	2.5
5.0	90	6.1	1.9
5.0	120	8.8	2.9
5.0	150	9.1	3.3
5.0	180	10.8	4.1
5.0	210	8.8	3.5
5.0	240	8.1	3.0
5.0	270	8.2	2.7
5.0	300	8.2	2.4
5.0	330	7.9	3.2
4.8	0	29.0	7.0
4.8	30	20.4	6.9
4.8	60	14.9	4.4
4.8	90	14.7	4.6
4.8	120	16.9	4.2
4.8	150	18.1	2.8
4.8	180	21.4	3.7
4.8	210	18.4	3.2
4.8	240	17.6	4.1
4.8	270	18.1	4.6
4.8	300	19.9	5.0
4.8	330	19.7	5.4
4.6	0	39.4	2.7
4.6	30	31.3	6.5
4.6	60	24.1	6.0
4.6	90	22.6	5.1
4.6	120	24.5	4.8
4.6	150	25.9	3.6
4.6	180	28.6	3.3
4.6	210	25.7	3 4
4.6	240	24.6	4.3
4.6	270	28.6	4.1
4.6	300	30.0	6.4
4.6	330	33.2	7.7
4.4	0	40.0	0.0
4.4	30	38.2	3.4
4.4	60	34.6	5.9
4.4	90	33.1	6.0
4.4	120	33.0	5.8
4.4	150	33.4	4.5
4.4	180	35.5	3.5
4.4	210	33.7	4.3
4.4	240	33.6	3.4
4.4	270	38.8	3.2
4.4	300	38.1	3.8
4.4	330	39.5	1.5

Table VIII

24' Stimulus size.

1.5 milli-lamberts background luminance.

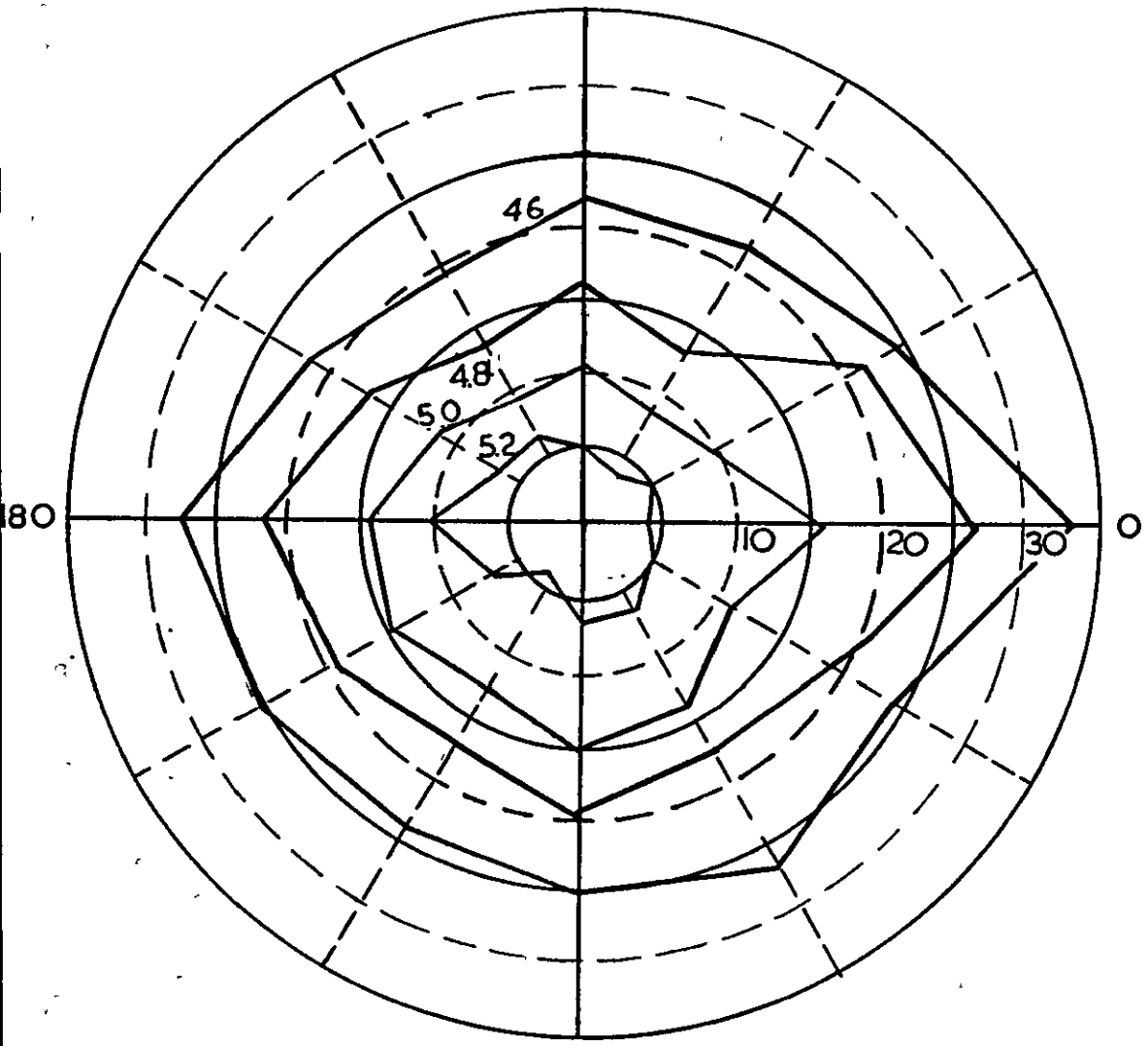
N.D.F.	Meridian.	Mean reading.	Standard deviation.
4.8	0	12.0	7.2
4.8	30	9.5	3.3
4.8	60	7.9	3.6
4.8	90	7.7	3.4
4.8	120	9.7	4.1
4.8	150	11.1	3.9
4.8	180	13.1	4.2
4.8	210	11.4	4.3
4.8	240	10.0	3.3
4.8	270	10.4	4.2
4.8	300	9.9	3.4
4.8	330	10.2	3.9
4.6	0	22.4	9.4
4.6	30	15.9	6.6
4.6	60	13.6	5.4
4.6	90	13.1	4.6
4.6	120	15.2	4.2
4.6	150	16.5	4.8
4.6	180	18.7	4.4
4.6	210	17.2	3.6
4.6	240	16.2	4.8
4.6	270	18.6	5.7
4.6	300	16.0	4.9
4.6	330	17.6	7.9
4.4	0	34.6	7.0
4.4	30	28.9	8.6
4.4	60	20.9	7.6
4.4	90	19.0	5.4
4.4	120	19.9	4.6
4.4	150	23.7	5.7
4.4	180	26.5	6.1
4.4	210	23.2	4.7
4.4	240	23.6	6.3
4.4	270	26.1	8.2
4.4	300	27.0	7.6
4.4	330	28.7	9.9
4.2	0	37.7	6.1
4.2	30	34.1	7.6
4.2	60	28.5	8.4
4.2	90	25.5	7.2
4.2	120	28.0	5.8
4.2	150	28.1	6.5
4.2	180	32.5	5.5
4.2	210	29.1	5.8
4.2	240	29.9	6.8
4.2	270	33.7	6.5
4.2	300	35.1	8.0
4.2	330	35.8	7.8

Table VIII contd.

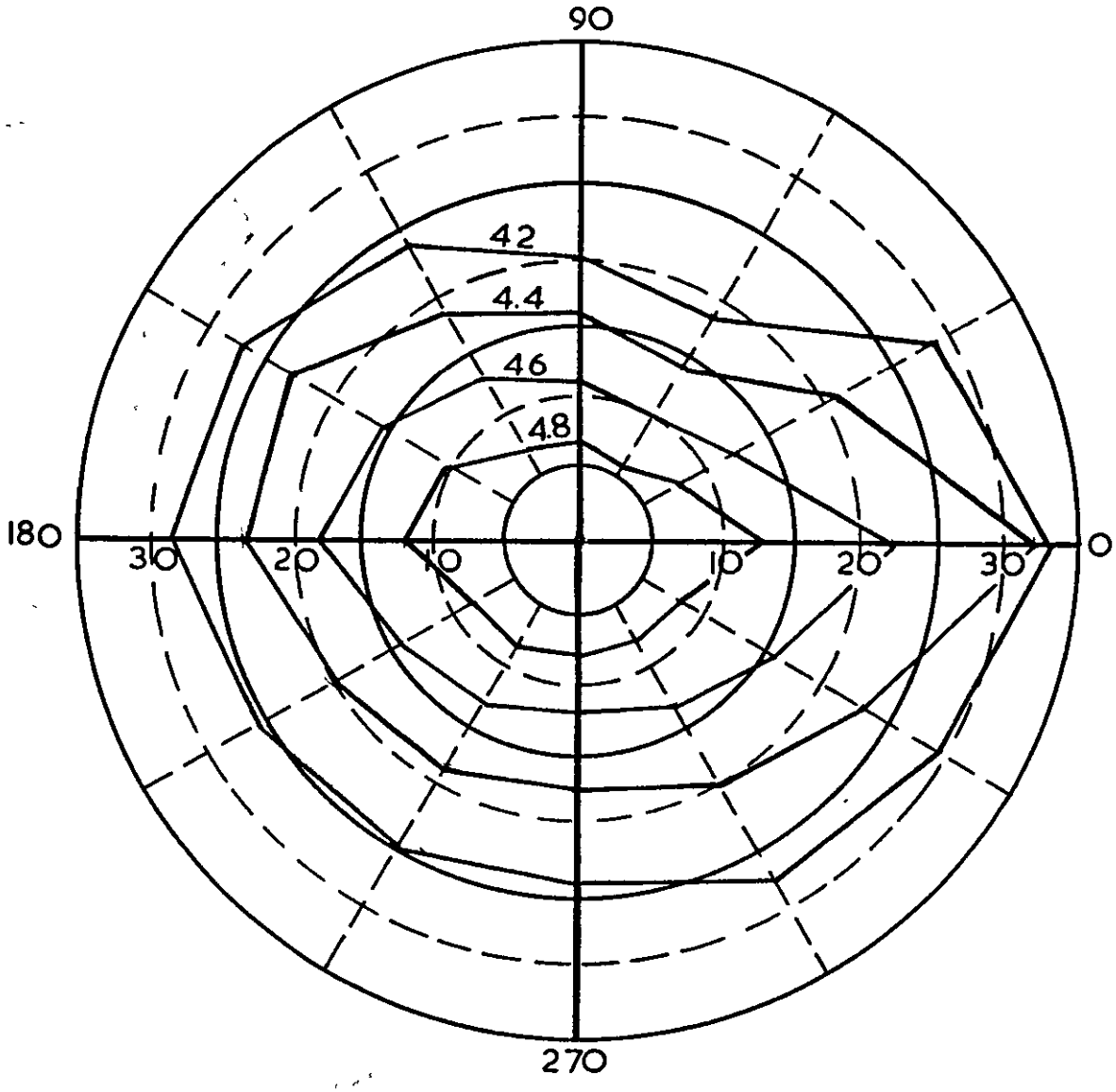
N.D.F.	Meridian.	Mean reading.	Standard deviation.
4.0	0	38.0	7.1
4.0	30	36.8	6.6
4.0	60	32.0	7.5
4.0	90	28.0	7.6
4.0	120	32.0	6.6
4.0	150	33.7	6.1
4.0	180	35.5	4.5
4.0	210	33.7	7.0
4.0	240	35.9	6.5
4.0	270	36.4	5.6
4.0	300	36.6	6.4
4.0	330	36.4	7.4

MEAN CONTOURS OR ISOPTERS OF

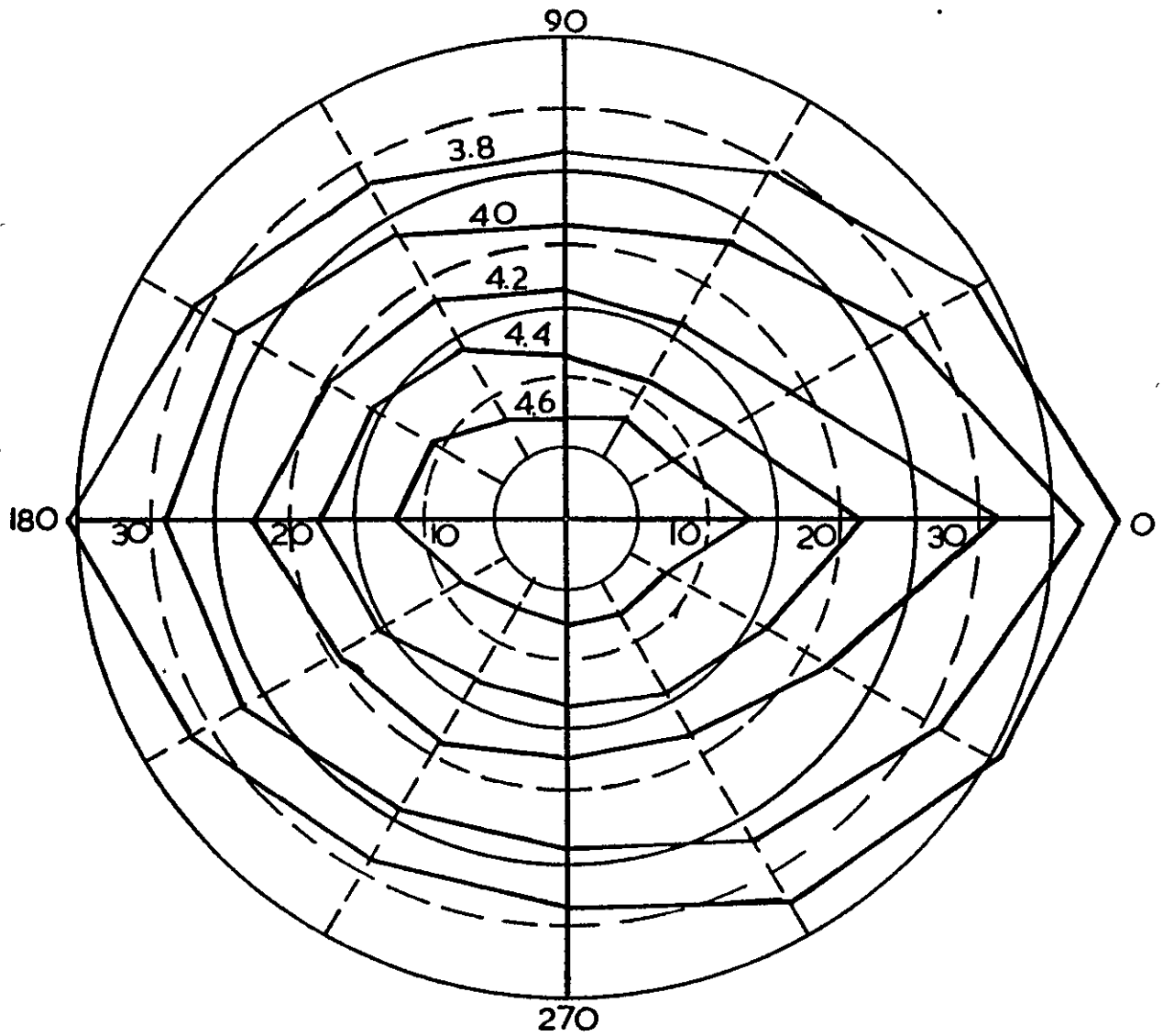
DIFFERENTIAL THRESHOLD CONTRAST.



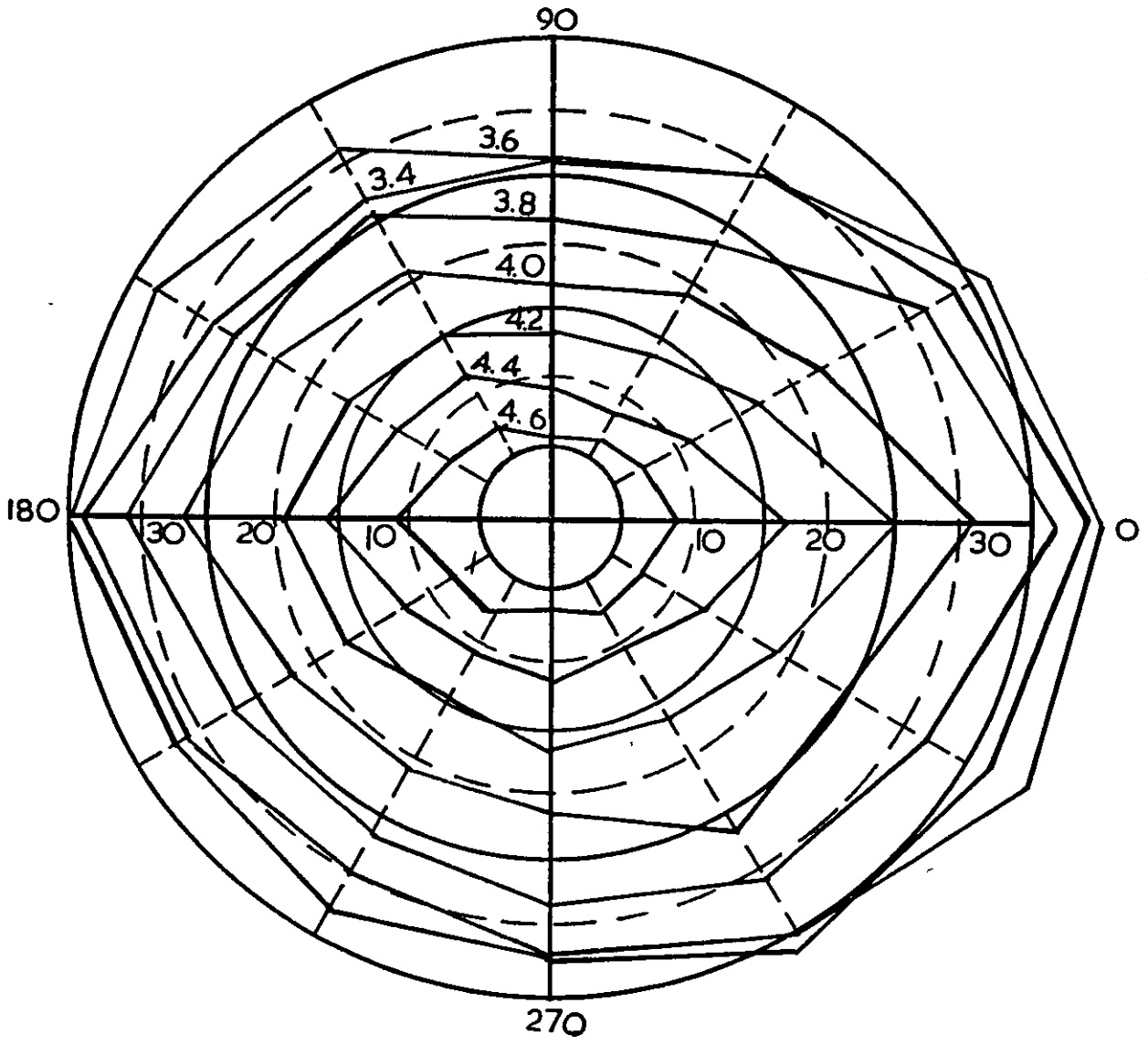
Mean isopters of differential threshold contrast for 12' stimulus at 0.1 milli-lamberts background luminance.



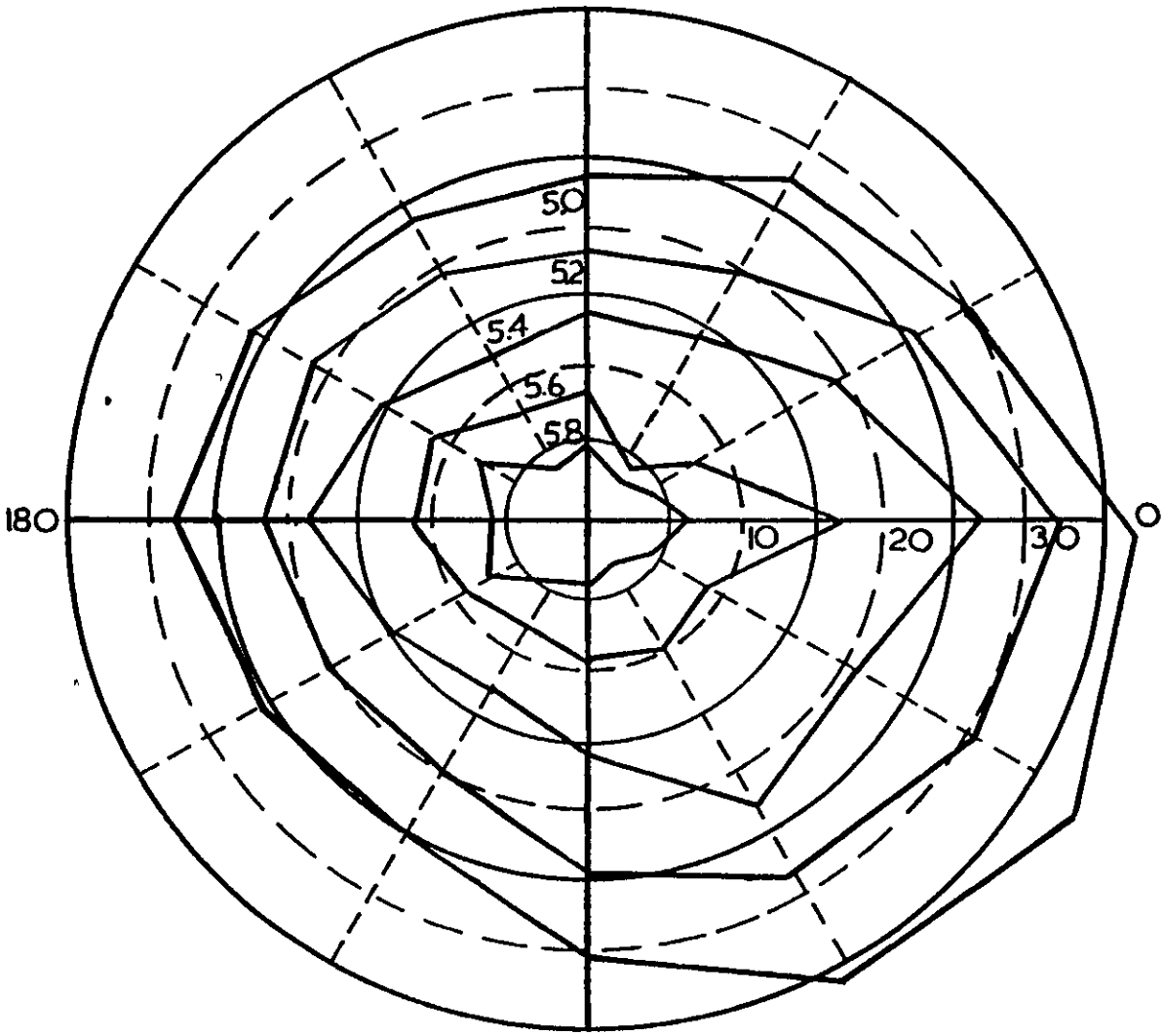
Mean isopters of differential threshold contrast for 12' stimulus at 0.5 milli-lamberts background luminance.



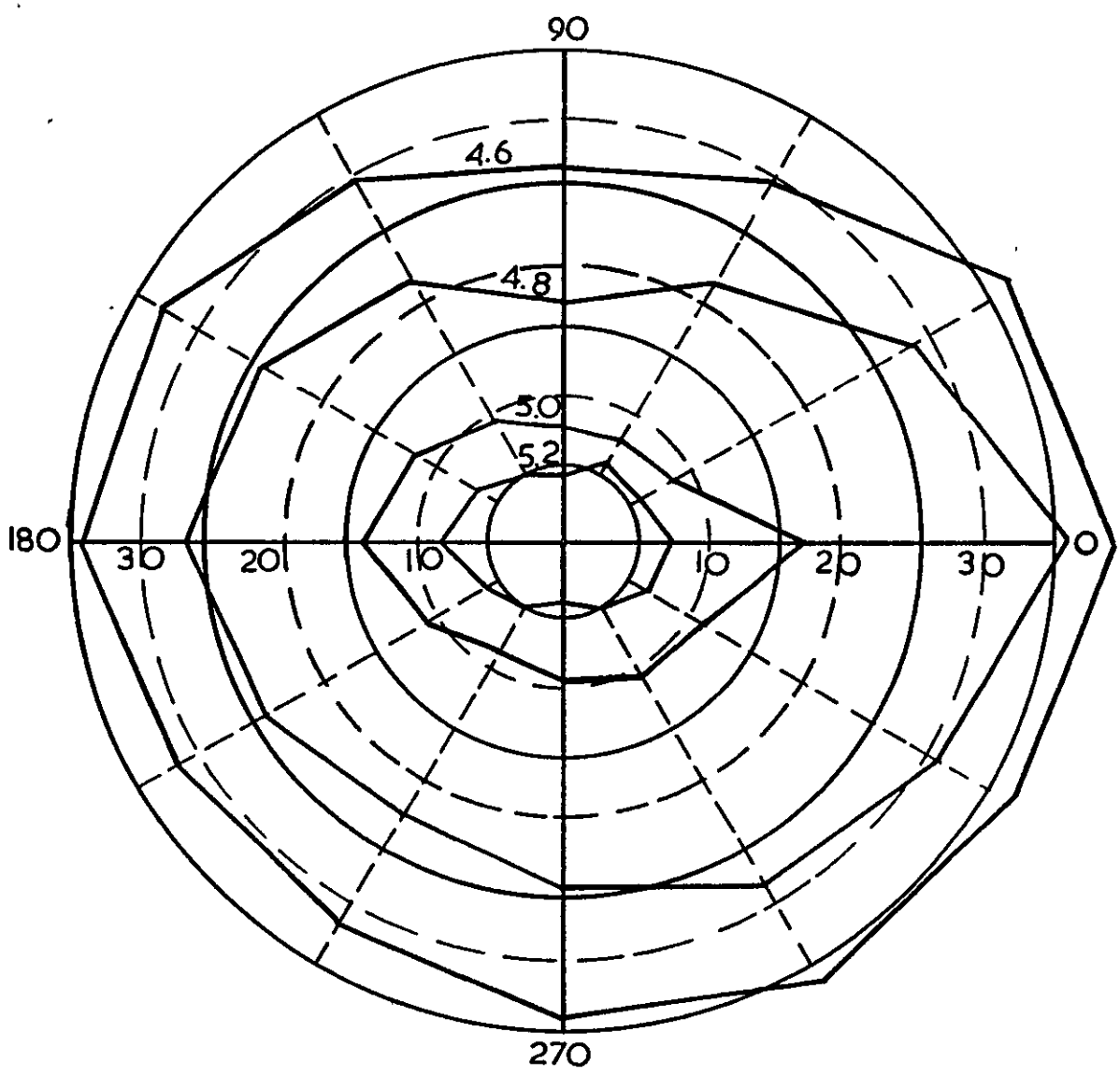
Mean isopters of differential threshold contrast for 12' stimulus at 1.0 milli-lamberts background luminance.



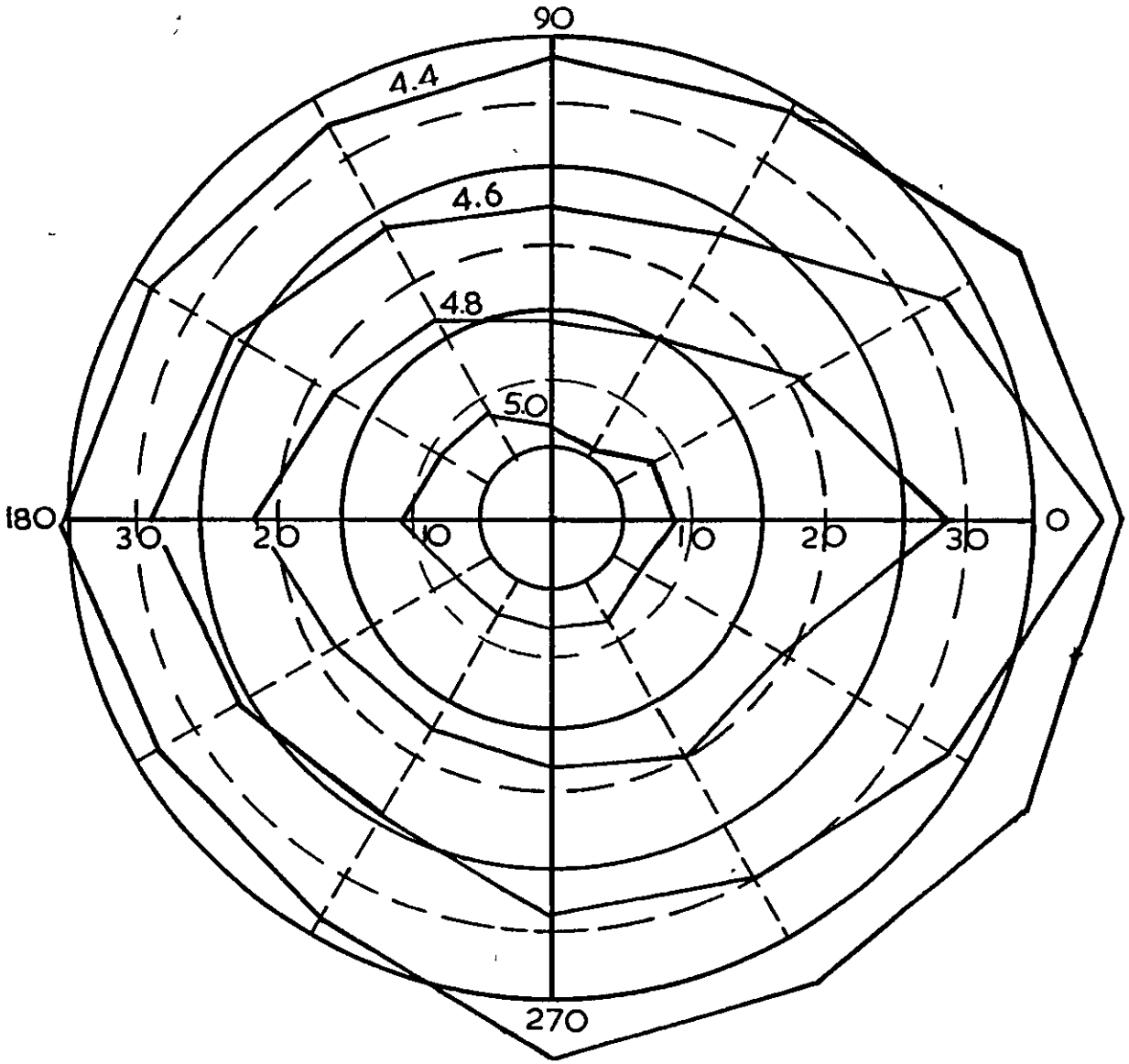
Mean isopters of differential threshold contrast for 12' stimulus at 1.5 milli-lamberts background luminance.



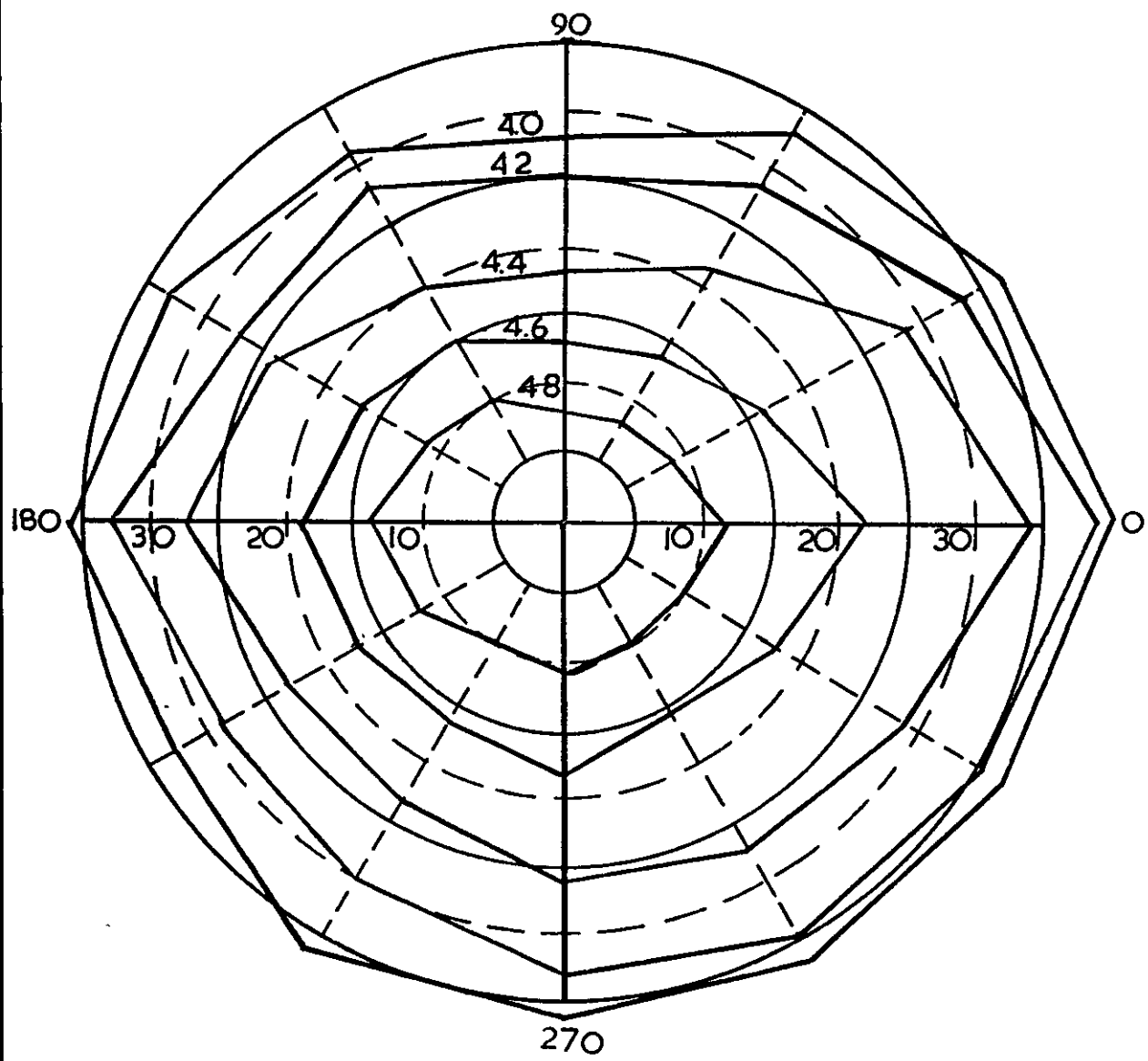
Mean isopters of differential threshold contrast for 24' stimulus at 0.1 milli-lamberts background luminance.



Mean isopters of differential threshold contrast for 24' stimulus at 0.5 milli-lamberts background luminance.



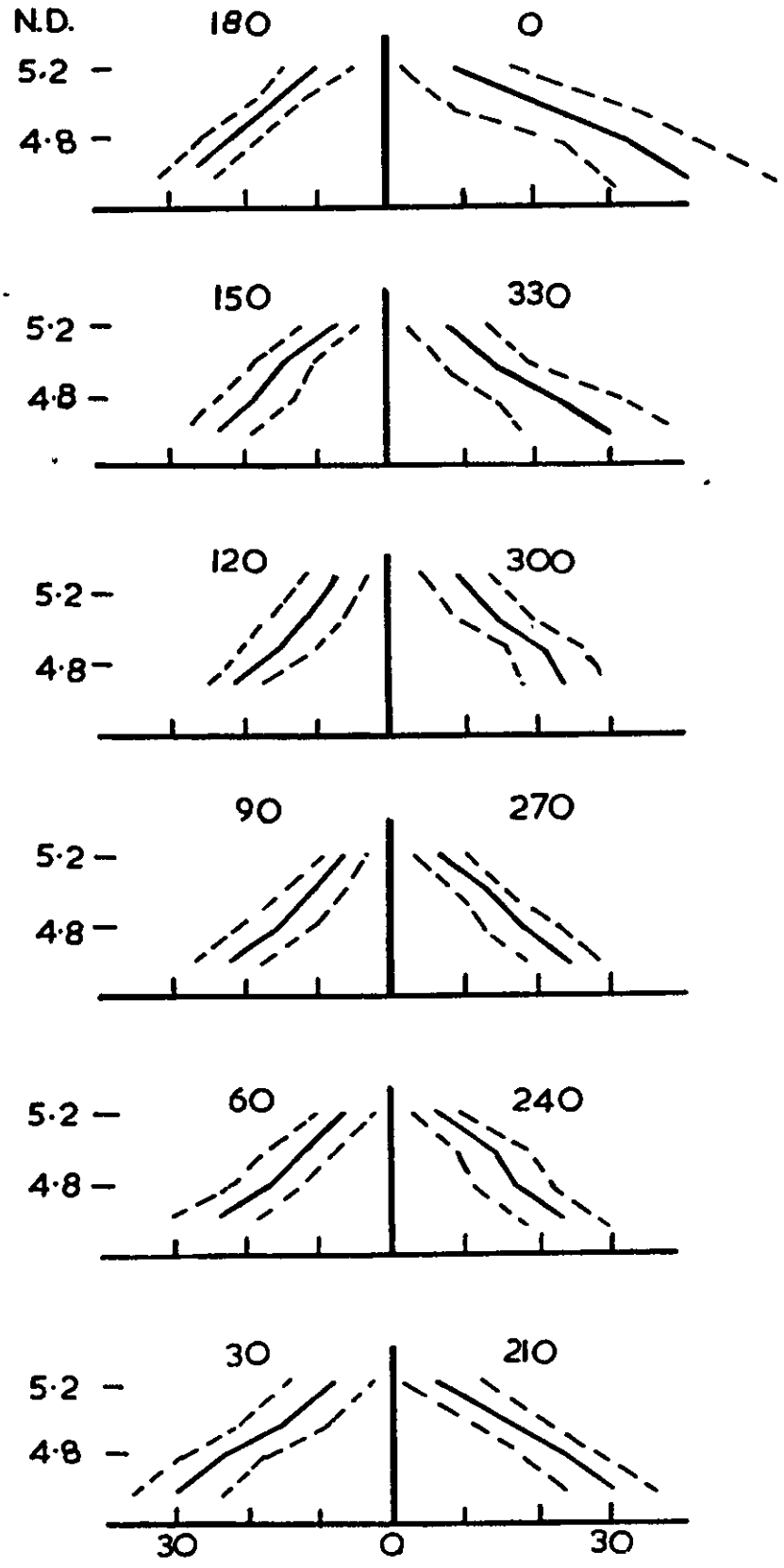
Mean isopters of differential threshold contrast for 24' stimulus at 1.0 milli-lamberts background luminance.



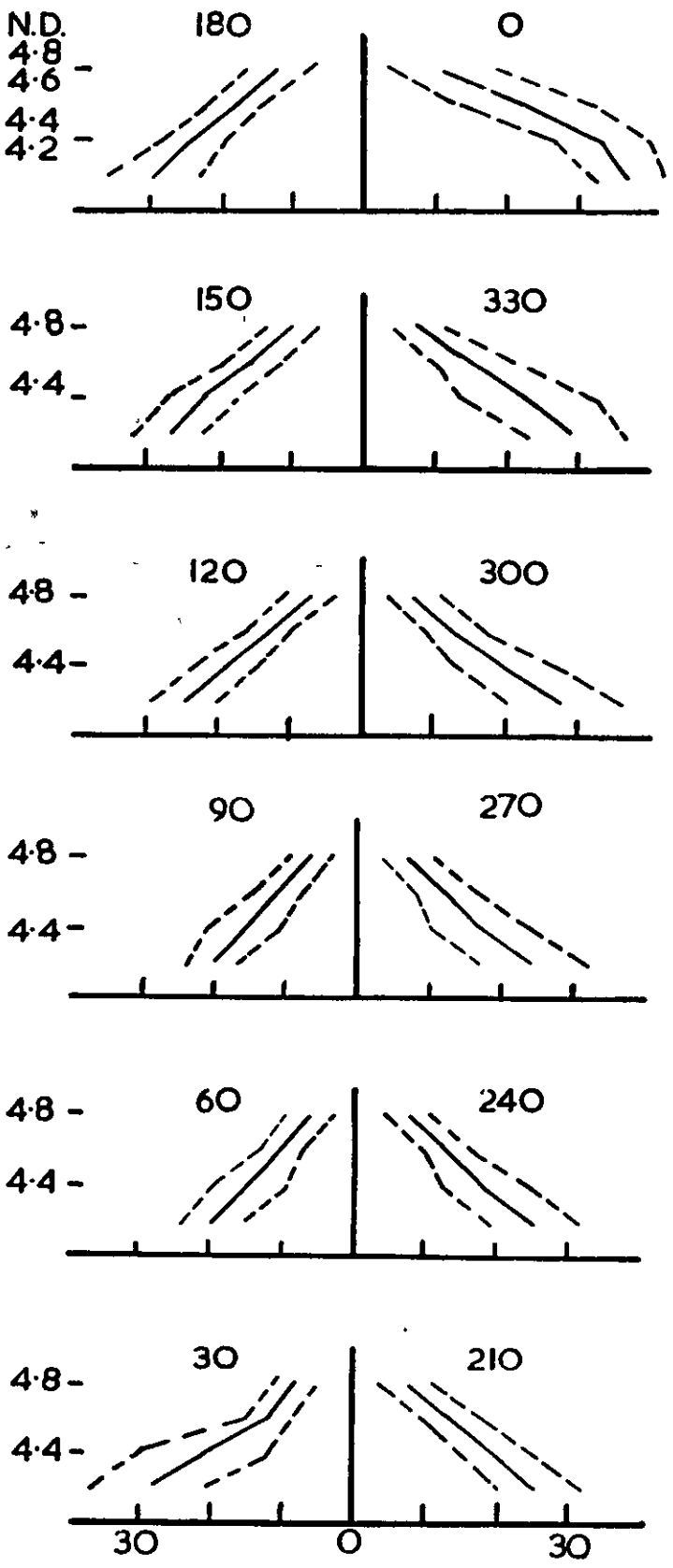
Mean isopters of differential threshold contrast for 24' stimulus at 1.5 milli-lamberts background luminance.

MEAN GRADIENTS AND STANDARD DEVIATIONS

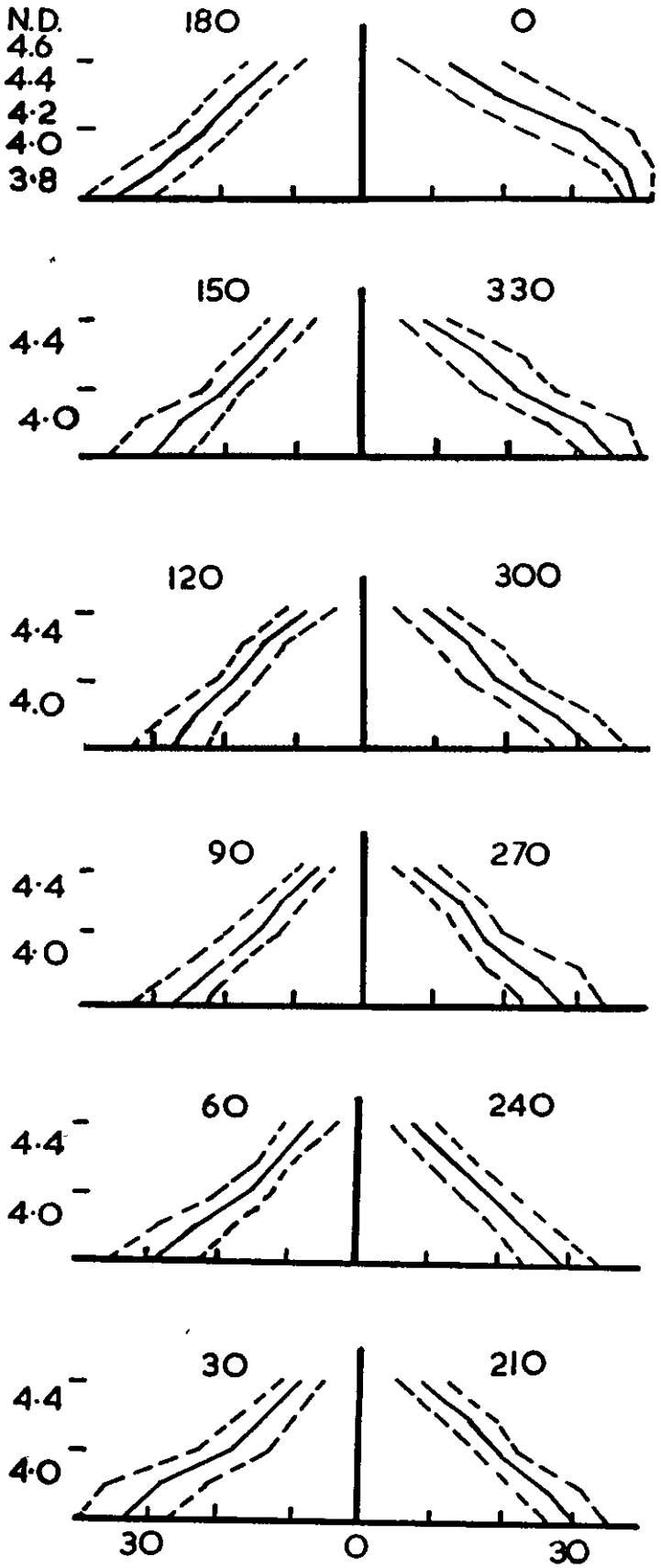
OF DIFFERENTIAL THRESHOLD CONTRAST.



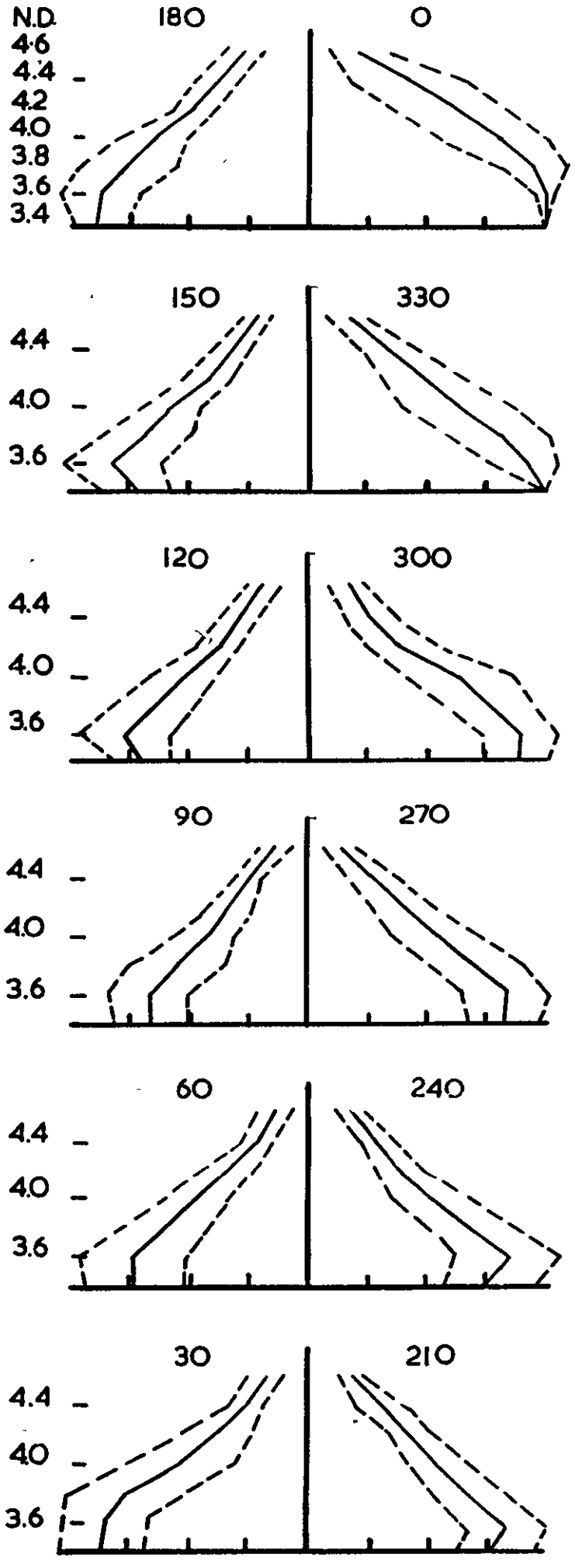
Mean gradients and standard deviations of differential threshold contrast for 12' stimulus at 0.1 milli-lamberts background luminance.



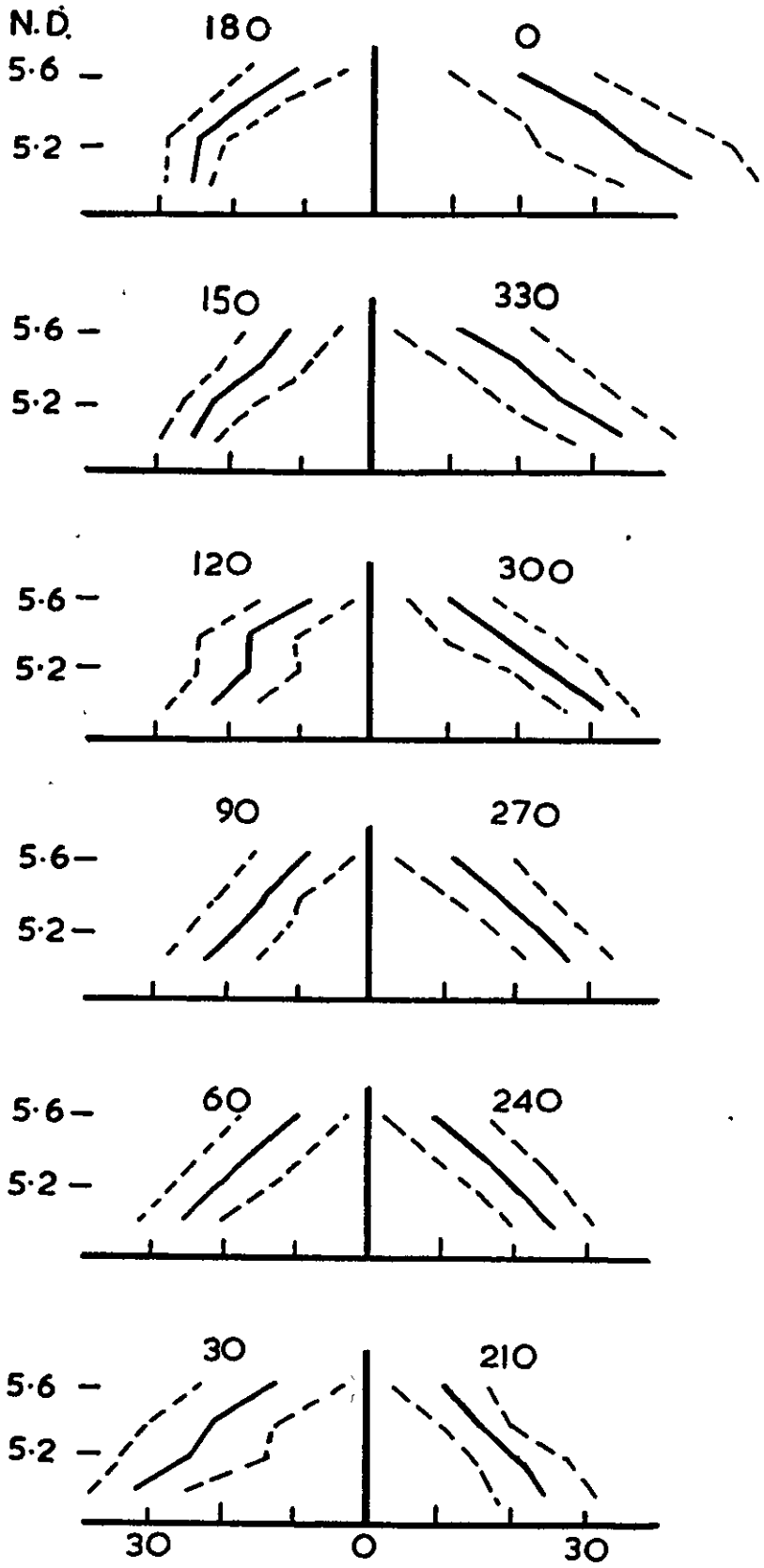
Mean gradients and standard deviations of differential threshold contrast for 12' stimulus at 0.5 milli-lamberts background luminance.



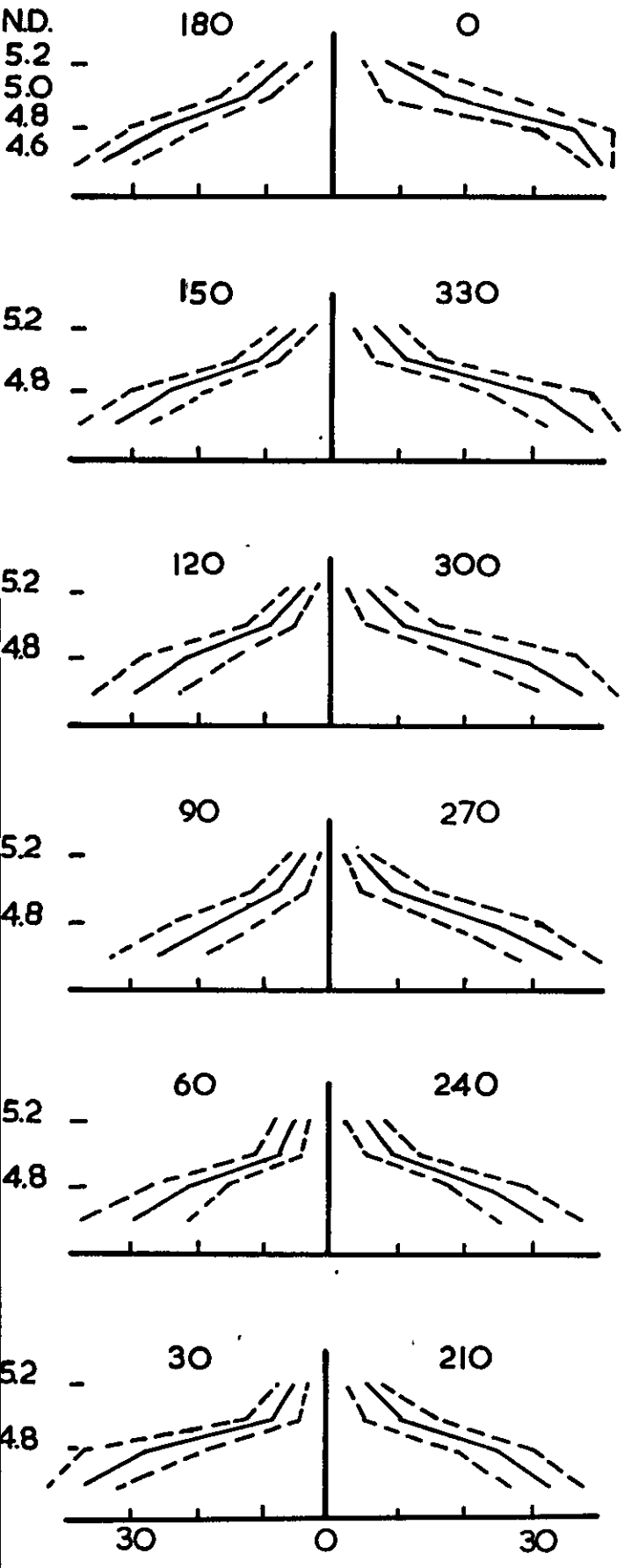
Mean gradients and standard deviations of differential threshold contrast for 12' stimulus at 1.0 milli-lamberts background luminance.



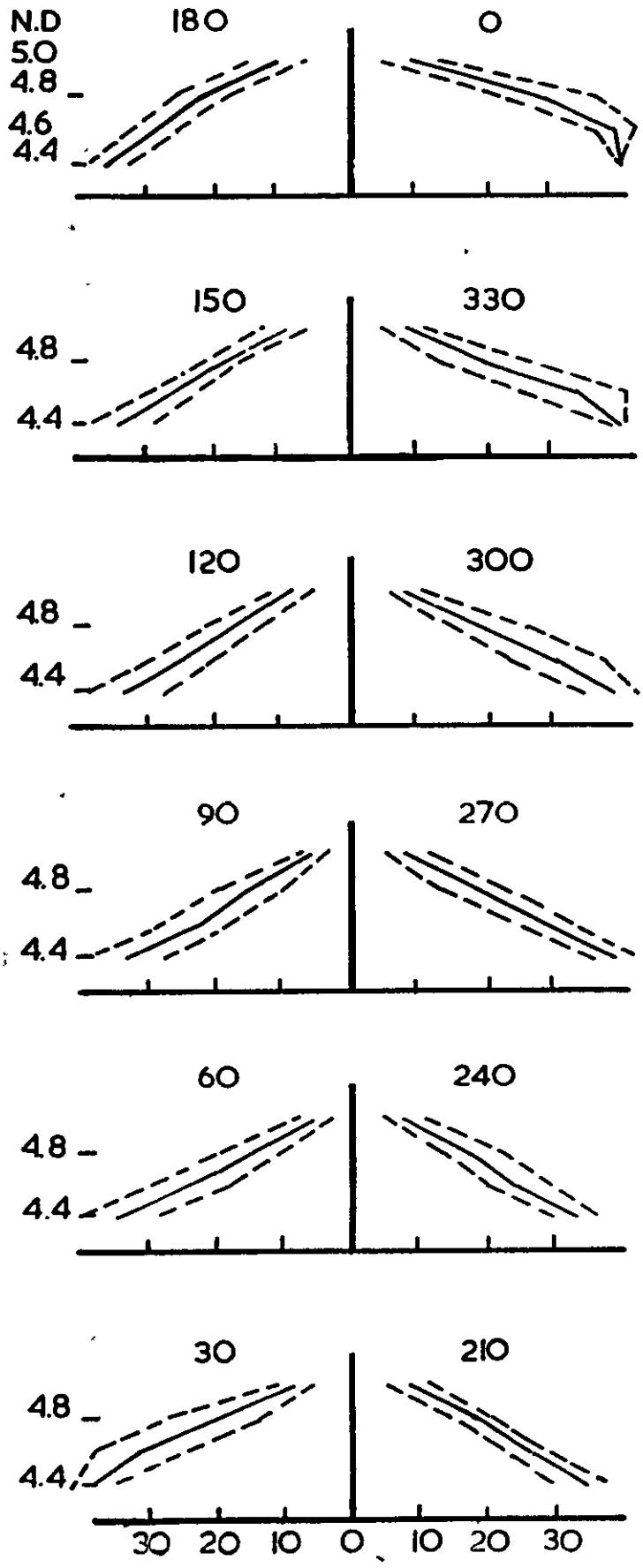
Mean gradients and standard deviations of differential threshold contrast for 12' stimulus at 1.5 millilamberts background luminance.



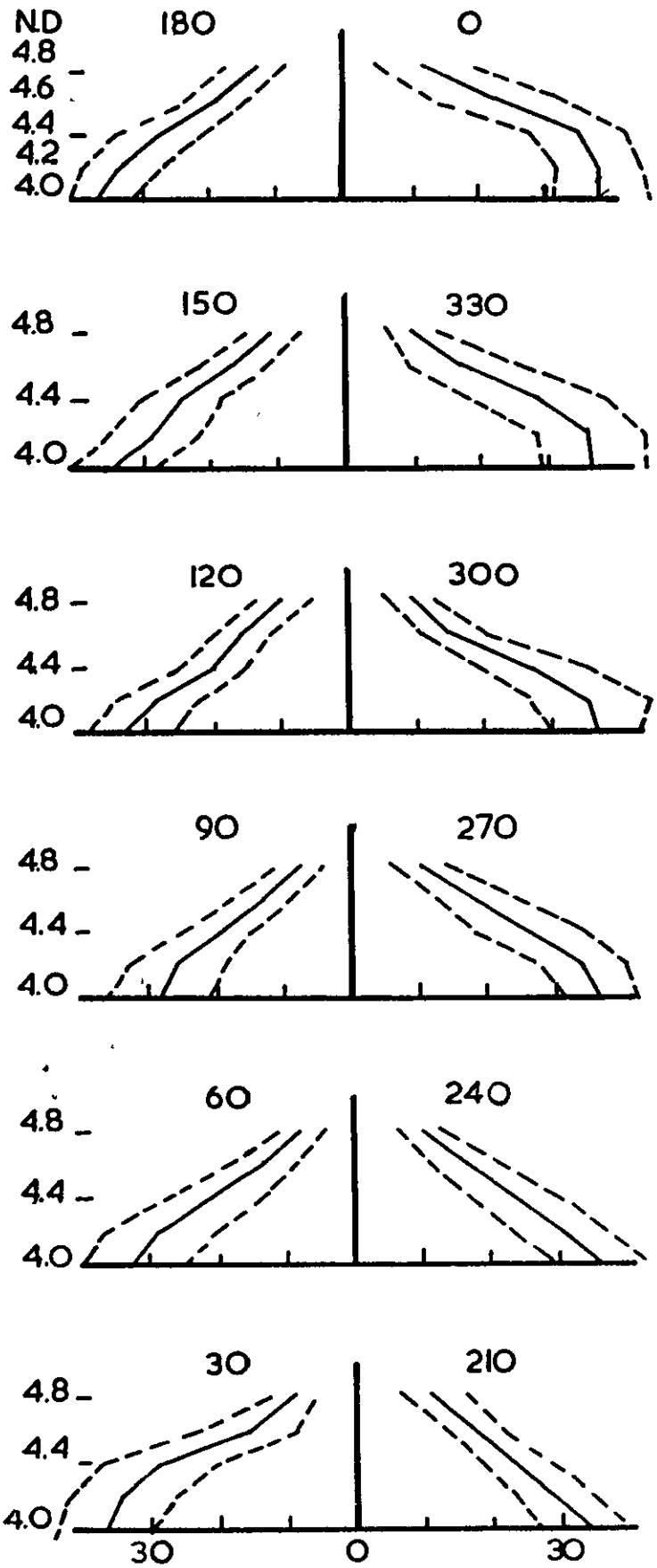
Mean gradients and standard deviations of differential threshold contrast for 24' stimulus at 0·1 milli-lamberts background luminance



Mean gradients and standard deviations of differential threshold contrast for 24' stimulus at 0.5 milli-lamberts background luminance.



Mean gradients and standard deviations of differential threshold contrast for 24' stimulus at 1.0 milli-lamberts background luminance.

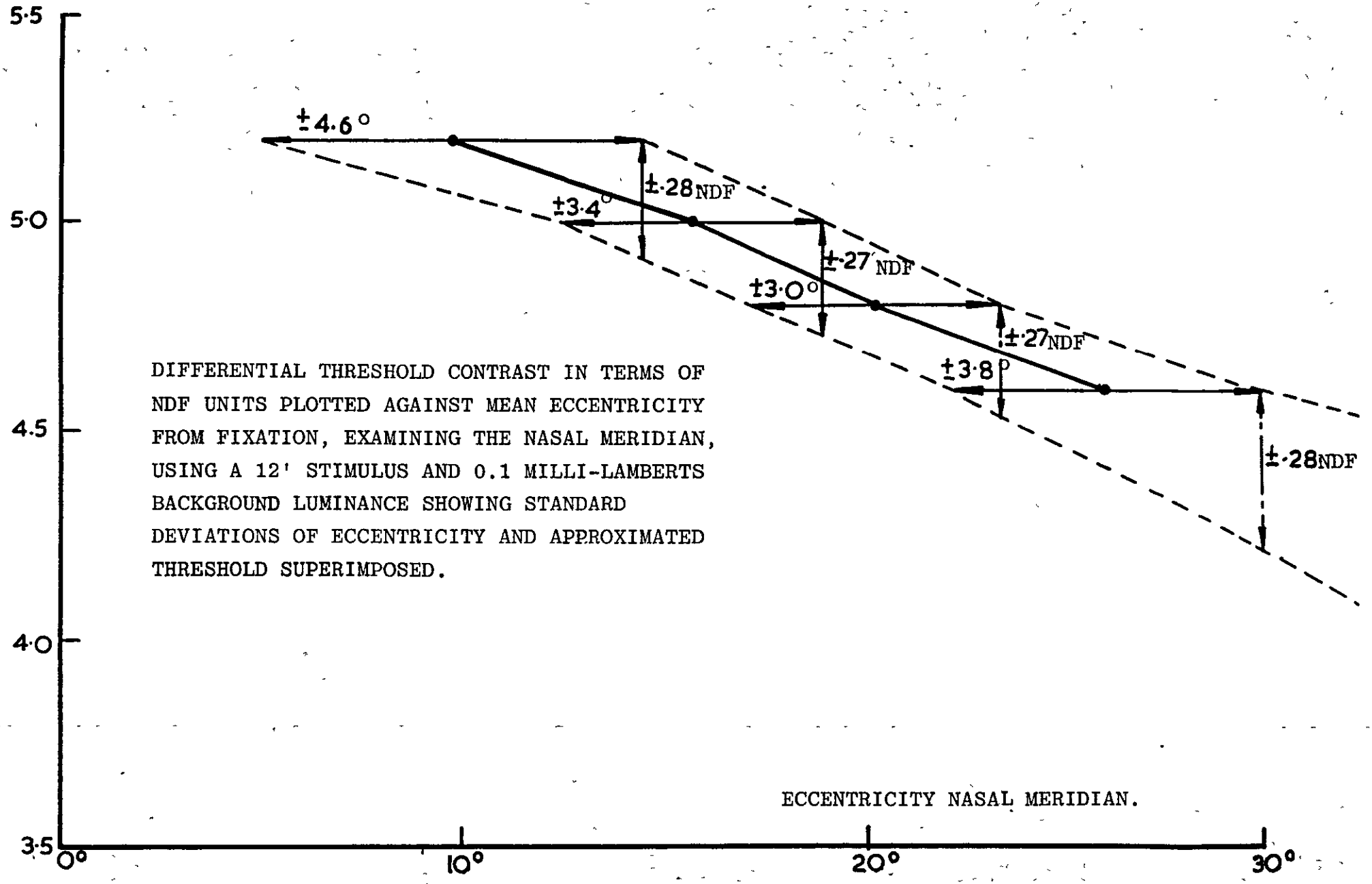


Mean gradients and standard deviations of differential threshold contrast for 24' stimulus at 1.5 milli-lamberts background luminance.

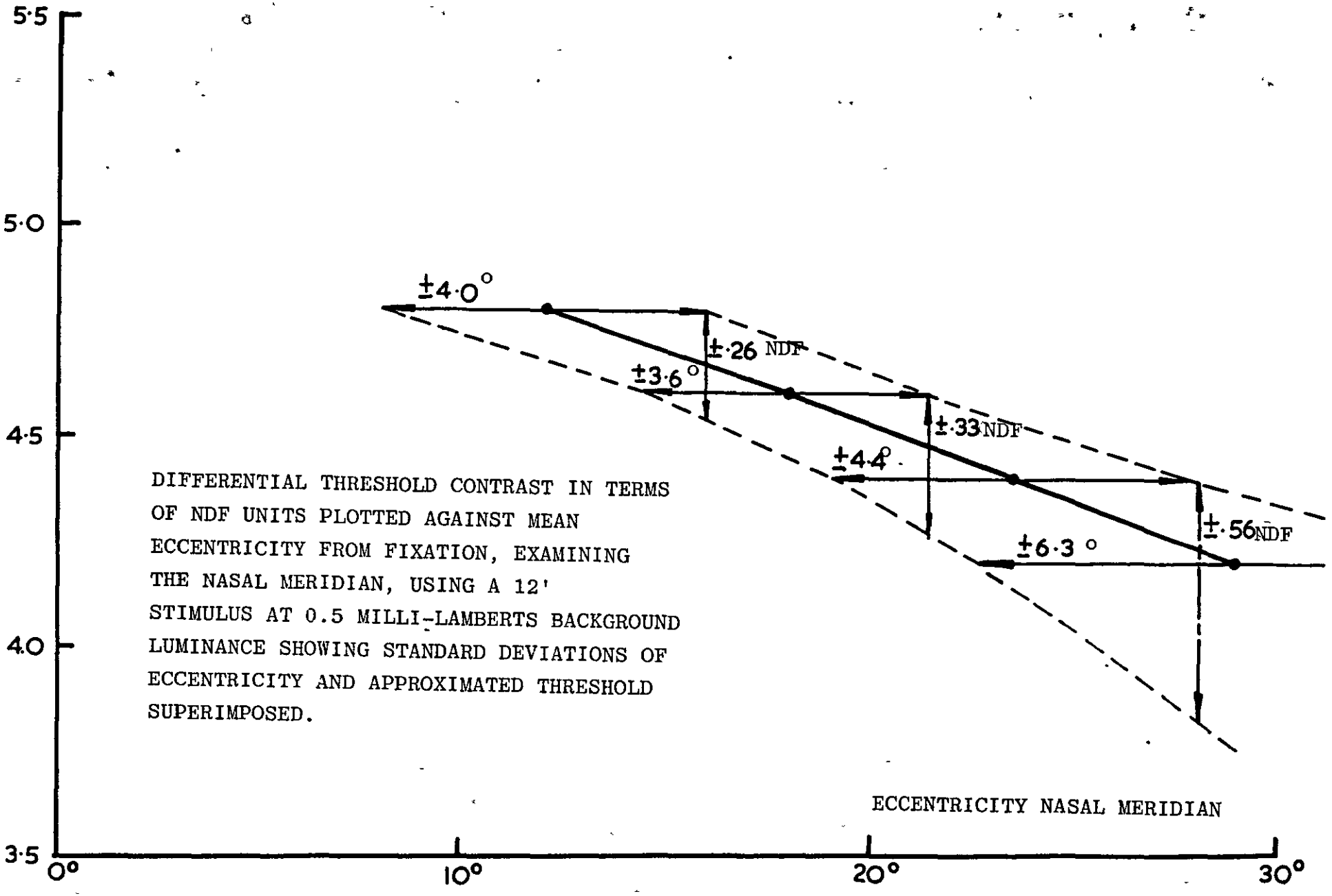
TABLES AND GRAPHS SHOWING, FOR THE NASAL MERIDIAN, THE RELATION BETWEEN DIFFERENTIAL THRESHOLD CONTRAST AND THE MEANS AND STANDARD DEVIATIONS OF ECCENTRICITY.

12' STIMULUS.

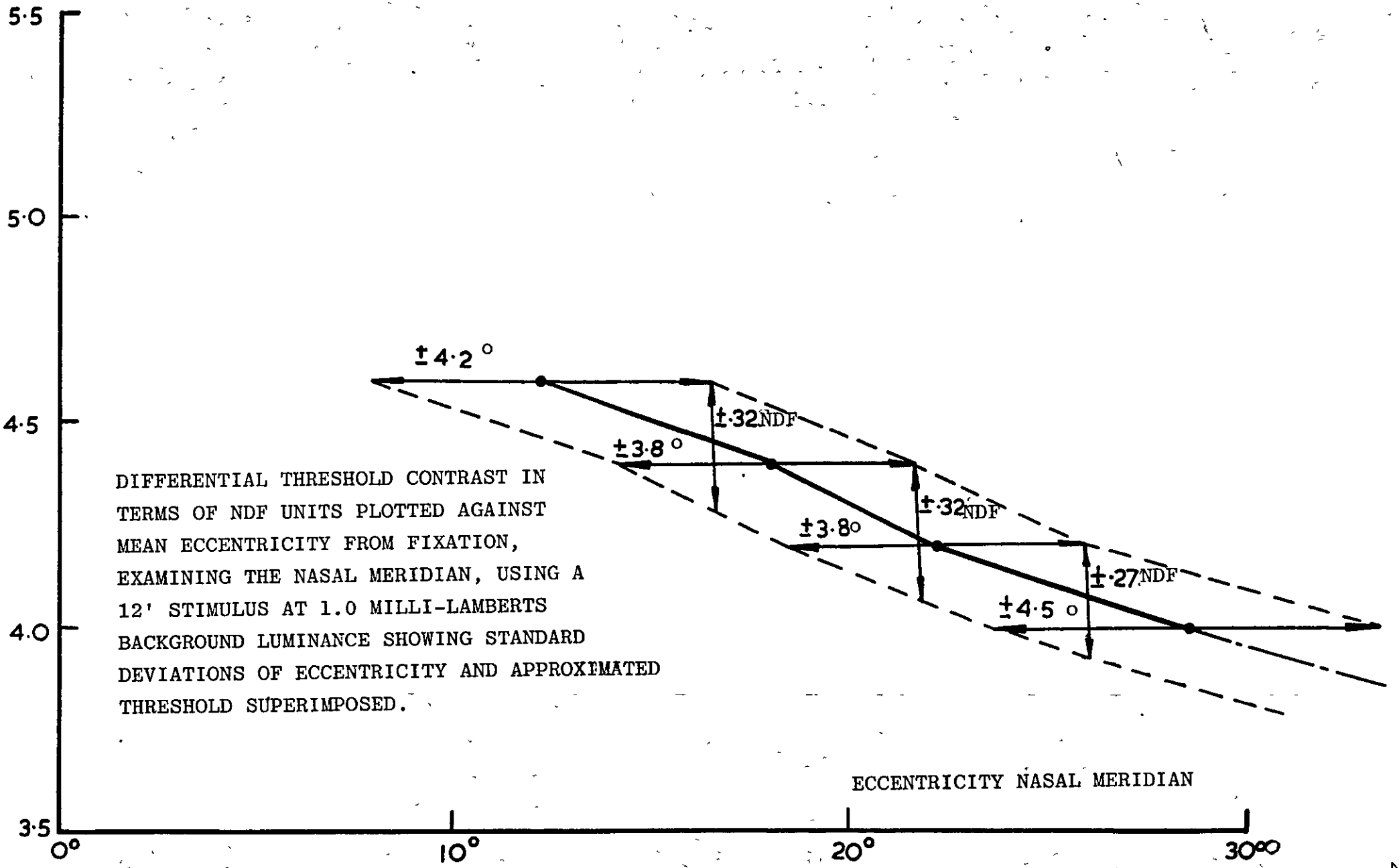
N.D.F.	Mean Eccentricity.	S/Dev.	Approx. Equiv. S/Dev. N.D.F.	Background Luminance.
5.2	9.7	4.6	.28	0.1 mL
5.0	15.7	3.4	.27	
4.8	20.2	3.0	.27	
4.6	26.0	3.8	.28	
4.8	12.0	4.0	.26	0.5 mL
4.6	17.9	3.6	.33	
4.4	23.5	4.4	.56	
4.2	29.0	6.3		
4.6	12.2	4.2	.32	1.0 mL
4.4	18.0	3.8	.32	
4.2	22.2	3.8	.27	
4.0	28.6	4.5		
4.6	11.1	3.1	.32	1.5 mL
4.4	15.5	3.6	.35	
4.2	19.7	3.5	.32	
4.0	25.9	6.0		
3.8	30.6	6.0		



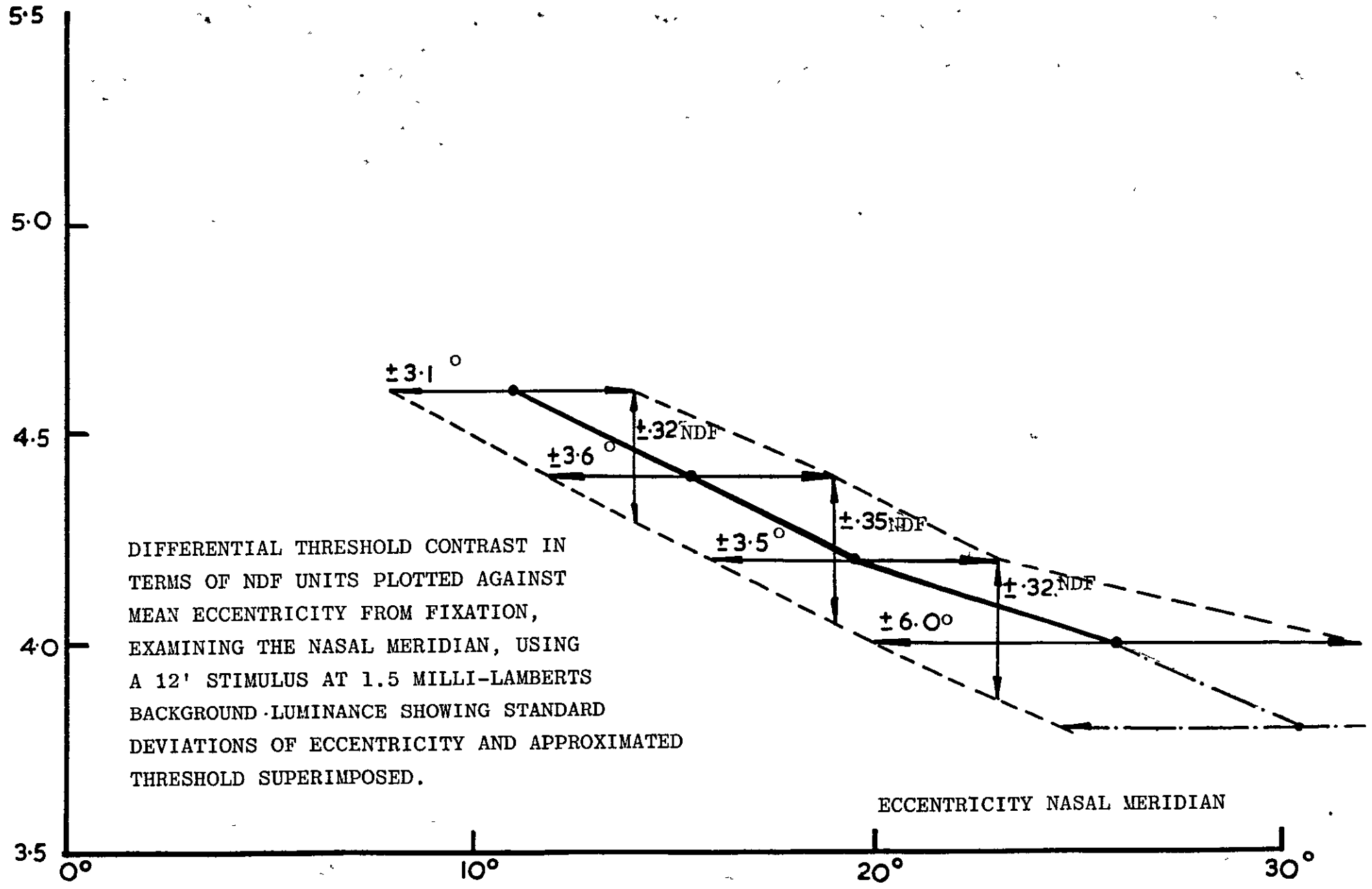
DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN, USING A 12' STIMULUS AND 0.1 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.



DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN, USING A 12' STIMULUS AT 0.5 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.



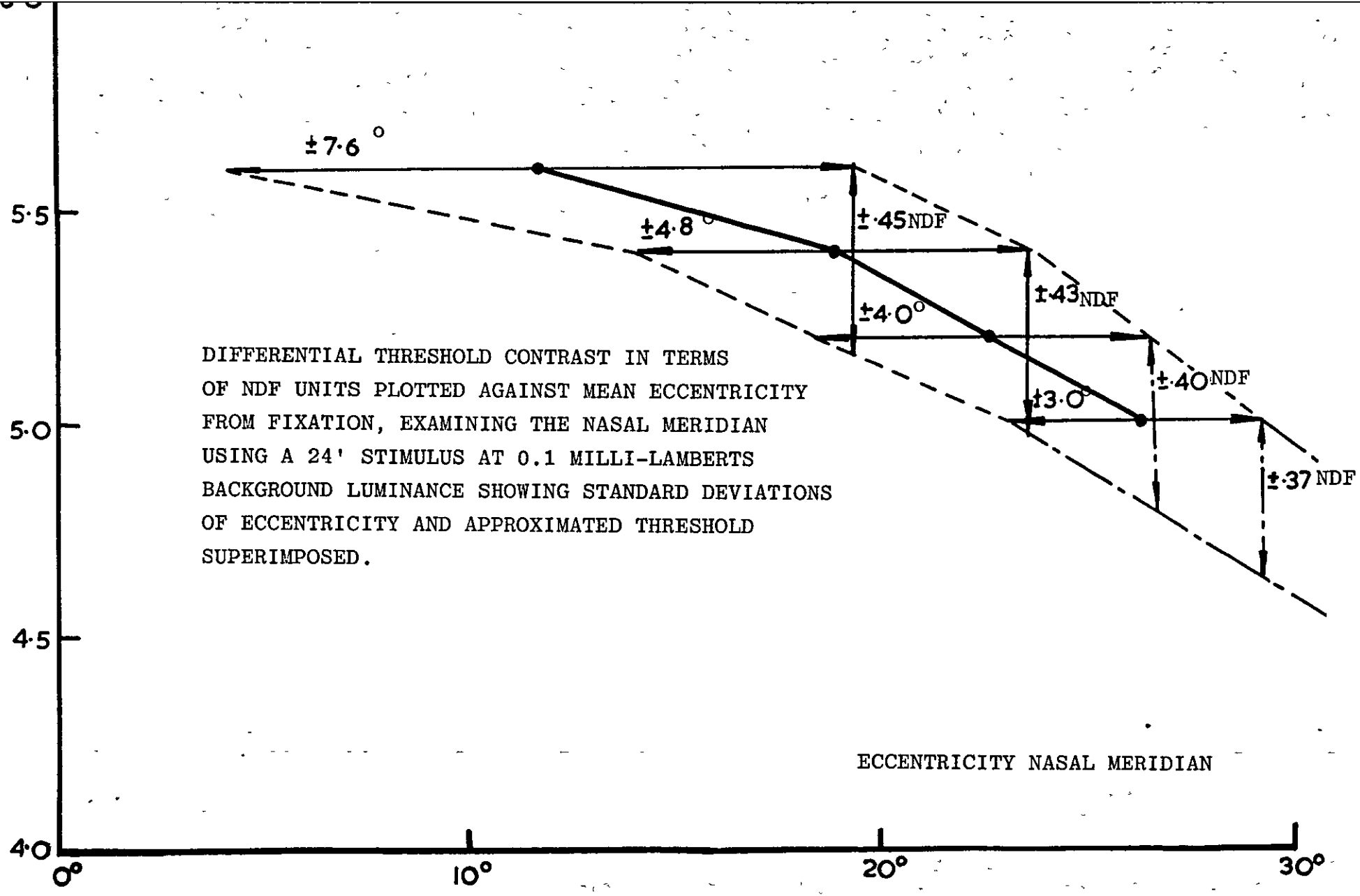
DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN, USING A 12' STIMULUS AT 1.0 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.



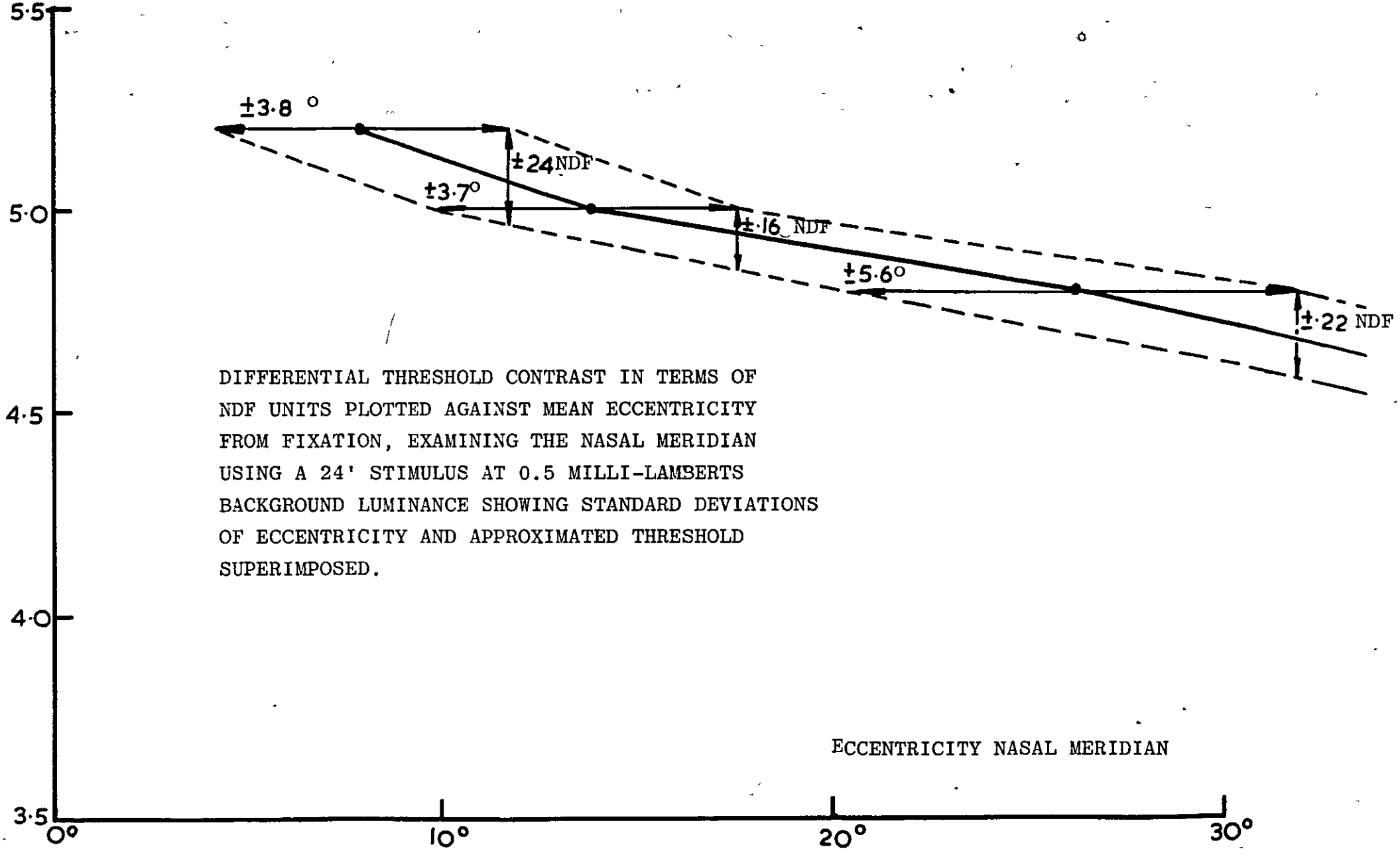
DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN, USING A 12' STIMULUS AT 1.5 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.

24' STIMULUS.

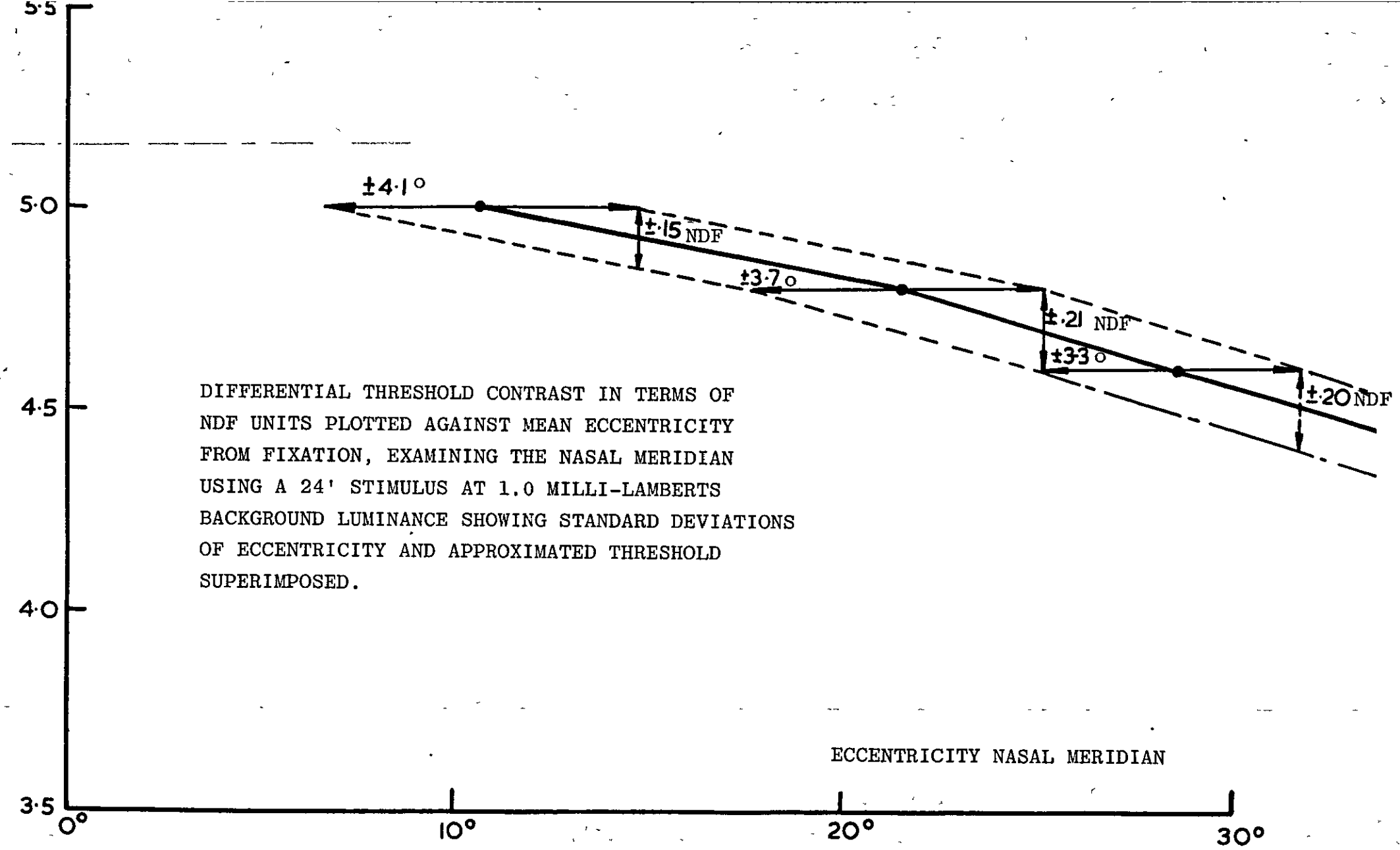
N.D.F.	Mean Eccentricity.	S/Dev.	Approx Equiv. S/Dev. N.D.F.	Background Luminance.
5.6	11.7	7.6	.45	0.1 mL
5.4	19.0	4.8	.43	
5.2	22.5	4.0	.40	
5.0	26.4	3.0	.37	
5.2	8.1	3.8	.24	0.5 mL
5.0	13.7	3.7	.16	
4.8	26.0	5.6	.22	
5.0	10.8	4.1	.15	1.0 mL
4.8	21.4	3.7	.21	
4.6	28.6	3.3	.20	
4.8	13.1	4.2	.31	1.5 mL
4.6	18.7	4.4	.30	
4.4	26.5	6.1	.50	
4.2	32.5	5.5		



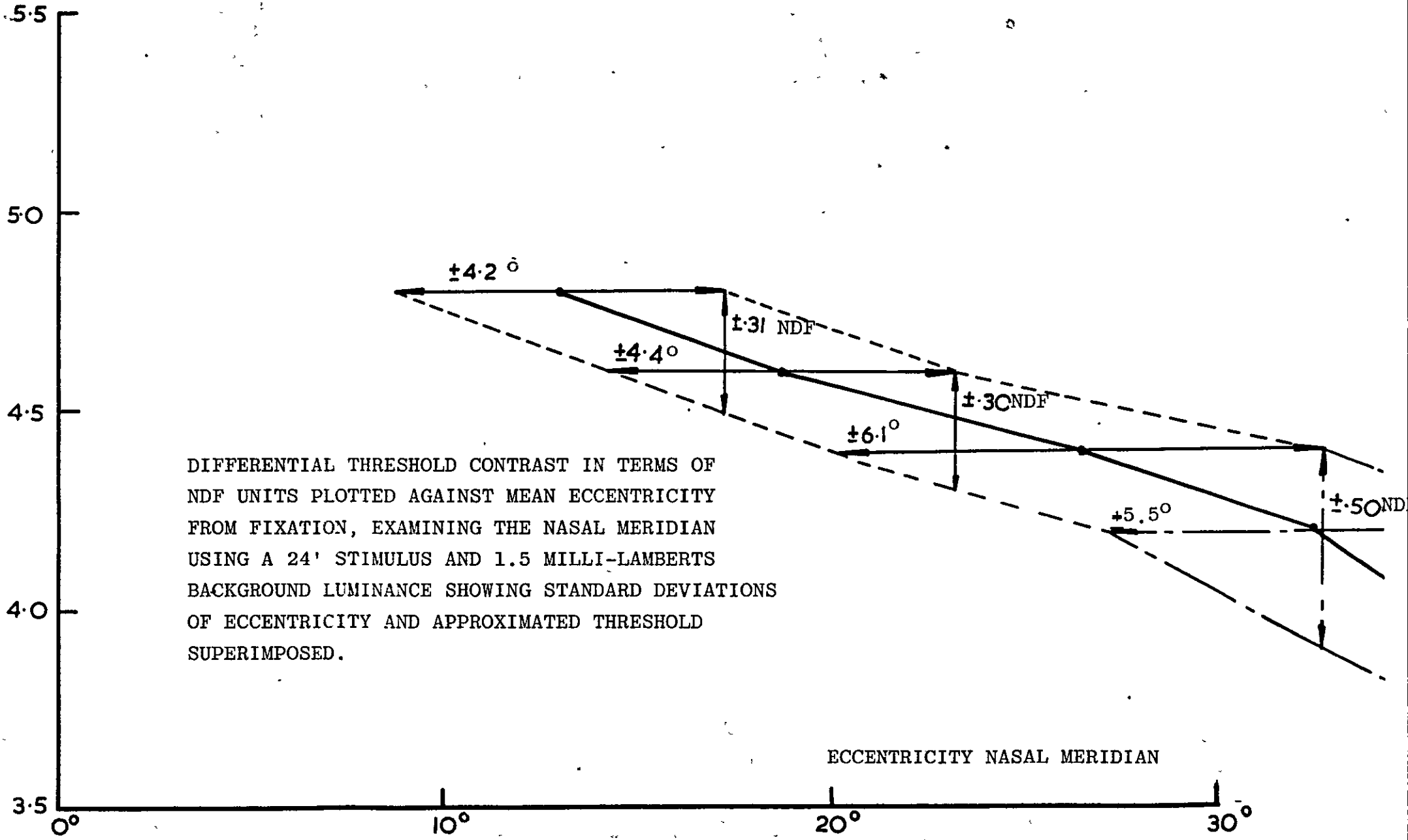
DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN USING A 24' STIMULUS AT 0.1 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.



DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN USING A 24' STIMULUS AT 0.5 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.



DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN USING A 24' STIMULUS AT 1.0 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.



DIFFERENTIAL THRESHOLD CONTRAST IN TERMS OF NDF UNITS PLOTTED AGAINST MEAN ECCENTRICITY FROM FIXATION, EXAMINING THE NASAL MERIDIAN USING A 24' STIMULUS AND 1.5 MILLI-LAMBERTS BACKGROUND LUMINANCE SHOWING STANDARD DEVIATIONS OF ECCENTRICITY AND APPROXIMATED THRESHOLD SUPERIMPOSED.

APPENDIX D.

THE DIFFERENTIAL THRESHOLD CONTRAST RESPONSE FOR EACH OF THE 46 STIMULI POSITIONS OVER THE FRONT PLATE OF THE VISUAL FIELD ANALYSER FOR 26 NORMAL RIGHT EYES OF YOUNG ADULTS.

Individual neutral density filter settings for differential threshold contrast for each of the 46 stimuli positions, examining the right eyes of 26 normal young adults.

	1	2	3	4	5	6	7	8	9	10	11	12
A1	2.4	2.4	1.8	2.2	2.4	2.4	2.4	2.2	2.4	2.2	2.4	2.4
A2	2.4	2.4	2.0	2.2	2.4	2.4	2.4	2.4	2.4	2.2	2.4	2.4
A3	2.4	2.4	2.2	2.2	2.4	2.4	2.2	2.4	2.4	2.2	2.4	2.4
A4	2.4	2.4	2.6	2.4	2.4	2.4	2.4	2.4	2.4	2.2	2.4	2.4
B1	2.2	2.4	2.2	2.2	2.4	2.4	2.2	2.4	2.4	2.4	2.4	2.4
B2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
C1	2.4	2.4	2.6	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
C2	2.2	2.4	1.8	1.8	2.0	2.4	2.0	2.4	2.2	2.2	2.4	2.2
C3	2.2	2.4	2.0	2.2	2.2	2.4	2.2	2.4	2.2	2.4	2.2	2.0
D1	-	2.4	2.0	2.2	2.4	2.4	2.2	2.4	2.2	2.2	2.2	2.4
D2	-	2.4	2.4	2.4	2.4	2.4	2.2	2.4	2.4	2.2	2.4	2.4
E1	2.4	2.2	2.4	2.4	2.4	2.4	2.2	2.4	2.4	2.2	2.2	2.4
E2	2.4	2.4	2.0	1.8	2.4.	2.2	2.2	2.4	2.4	2.4	2.0.	2.2
E3	2.4	2.4	2.4	2.2	2.4	2.4	2.2	2.4	2.4	2.4	2.2	2.4
F1	2.2	2.4	2.0	2.4	2.4	2.2	2.2	2.2	2.2	2.0	2.0	2.2
F2	2.2	2.4	1.8	2.0	2.2	2.0	2.2	2.2	2.4	2.0	2.0	2.0
F3	2.4	2.4	2.0	2.2	2.4	2.2	2.2	2.4	2.4	2.4	2.2	2.4
F4	2.4	2.4	1.8	2.2	2.4	2.2	2.2	2.4	2.4	2.0	1.8	2.0
G1	2.2	2.4	2.0	2.0	2.2	2.2	2.2	2.2.	2.2	2.0	2.2	2.2
G2	2.4	2.4	2.6	2.2	2.4	2.4	2.2	2.2	2.4	2.0	2.0	2.2
H1	2.4	2.4	2.6	2.2	2.2	2.4	2.2	2.2	2.2	2.0	2.0	2.2
H2	2.4	2.4	1.8	1.8	2.0	2.4	2.2	2.2	2.2	2.2	2.2	2.2
H3	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.2	2.2	2.4
J1	2.4	2.4	2.4	2.2	2.4	2.4	2.2	2.2	2.2	2.2	2.2	2.2
J2	2.4	2.4	2.4	2.2	2.4	2.4	2.2	2.2	2.4	2.2	2.2	2.2
K1	2.2	2.4	2.0	2.0	2.4	2.4	2.4	2.2	2.2	2.2	2.0	2.0
K2	2.4	2.4	2.6	2.0	2.4	2.4	2.4	2.4	2.4	2.4	2.2	2.4
K3	2.4	2.4	2.6	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.0	2.2
L1	2.4	2.4	2.4	2.2	2.4	-	2.2	2.4	2.4	2.4	2.4	2.2
L2	2.4	2.4	1.8	1.8	2.0	-	2.2	2.2	2.0	2.2	2.2	2.2
L3	2.4	2.4	2.4	2.2	2.4	-	2.4	2.4	2.4	2.4	2.2	2.2
L4	2.4	2.4	2.0	1.8	2.4	-	2.4	2.2	2.2	2.2	2.0	2.2
M1	2.4	2.4	2.6	2.2	2.4	2.4	2.4	2.4	2.4	2.2	2.4	2.4
M2	2.4	2.4	2.4	2.0	2.4	2.4	2.4	2.4	2.2	2.0	2.0	2.2
N1	2.4	2.4	2.4	2.4	2.2	2.4	2.4	2.4	2.4	2.4	2.2	2.4
N2	2.4	2.4	2.4	2.2	2.4	2.4	2.4	2.2	2.4	2.2	2.4	2.2
N3	2.4	2.4	2.4	2.2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
N4	2.4	2.4	2.4.	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.2	2.2
O1	2.2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.0	-
O2	2.2	2.4	2.4	2.2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	-
O3	2.2	2.4	2.4	2.4	2.2	2.4	2.4	2.4	2.4	2.4	2.2	-
O4	2.2	2.4	2.4	2.2	2.4	2.4	2.4	2.4	2.4	2.4	2.2	-
P1	2.4	2.4	2.6	2.6	2.4	2.4	2.4	2.4	2.4	2.4	2.2	-
P2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.2	-
P3	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	-
P4	2.4	2.6	2.6	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	-

	13	14	15	16	17	18	19	20	21	22	23	24
A1	2.0	2.4	2.2	2.4	2.6	2.2	2.4	2.4	2.4	2.4	2.4	2.2
A2	2.2	2.4	2.2	2.4	2.4	2.2	2.4	2.4	2.4	2.6	2.2	2.4
A3	2.0	2.4	2.0	2.4	2.6	2.2	2.4	2.4	2.4	2.6	2.2	2.4
A4	2.2	2.4	2.2	2.4	2.6	2.2	2.4	2.4	2.4	2.6	2.2	2.4
B1	2.4	2.4	2.4	2.2	2.4	2.4	2.2	2.4	2.4	2.6	2.4	2.6
B2	2.0	2.4	2.4	2.4	2.6	2.4	2.4	2.4	2.4	2.6	2.4	2.6
C1	2.4	2.4	2.4	2.4	2.4	2.4	2.6	2.4	2.4	2.6	2.4	2.6
C2	2.4	2.2	1.8	2.4	2.4	2.2	2.2	2.0	2.4	2.6	2.2	2.4
C3	2.4	2.4	2.4	2.2	2.4	2.4	2.4	2.4	2.4	2.6	2.4	2.4
D1	2.4	2.4	2.4	2.4	2.2	2.0	2.2	2.4	2.4	2.4	2.2	2.6
D2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.0	2.4	2.4	2.2	2.6
E1	2.4	2.2	2.2	2.4	2.2	2.4	2.4	2.4	2.4	2.4	2.4	2.4
E2	2.2	2.4	2.4	2.2	2.0	2.0	2.2	2.0	2.2	2.4	2.2	2.2
E3	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.6
F1	2.2	2.2	2.2	2.2	2.4	2.4	2.2	2.4	2.4	2.4	2.4	2.4
F2	2.0	2.4	2.2	2.2	2.2	2.0	2.2	2.4	2.4	2.6	2.0	2.2
F3	2.0	2.2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
F4	2.4	2.4	2.2	2.2	2.2	2.2	2.4	2.4	2.4	2.6	2.4	2.4
G1	2.4	2.2	2.4	2.2	2.2	2.2	2.2	2.2	2.2	2.4	2.0	2.6
G2	2.4	2.2	2.4	2.4	2.2	2.2	2.4	2.2	2.2	2.4	2.4	2.4
H1	2.4	2.4	2.2	2.4	2.2	2.4	2.2	2.2	2.4	2.4	2.2	2.2
H2	2 2	2.4	2.2	2.0	2.2	2.2	2.2	2.0	2.4	2.4	2.2	2.4
H3	2.6	2.4	2.4	2.4	2.4	2.4	2.6	2.4	2.4	2.4	2.4	2.4
J1	2.4	2.4	2.2	2.4	2.2	2.4	2.2	2.2	2.2	2.4	2.4	2.4
J2	2.4	2.4	2.2	2.4	2.4	2.2	2.4	2.0	2.2	2.2	2.4	2.4
K1	2.4	2.4	2.2	2.4	2.2	2.2	2.2	2.2	2.2	2.4	2.2	2.4
K2	2.4	2.4	2.2	2.4	2.2	2.4	2.4	2.0	2.2	2.4	2.4	2.4
K3	2.2	2.4	2.2	2.4	2.4	2.4	2.2	2.0	2.2	2.4	2.2	2.4
L1	2.2	2.4	2.4	2.4	2.4	2.4	2.6	2.2	2.4	2.4	2.6	2.4
L2	2.2	2.4	2.4	2.2	2.2	2.4	2.2	2.4	2.4	2.4	2.2	2.4
L3	2.4	2.4	2.4	2.2	2.4	2.4	2.6	2.4	2.4	2.4	2.6	2.4
L4	2.2	2.4	2.4	2.0	2.0	2.4	2.2	2.2	2.4	2.4	2.2	2.4
M1	2.2	2.4	2.6	2.4	2.4	2.4	2.6	2.4	2.6	2.4	2.4	2.4
M2	2.2	2.4	2.6	2.2	2.2	2.4	2.2	2.4	2.6	2.6	2.2	2.4
N1	2.4	2.4	2.6	2.4	2.6	2.4	2.4	2.4	2.6	2.4	2.6	2.4
N2	2.2	2.4	2.6	2.4	2.2	2.4	2.4	2.4	2.6	2.4	2.4	2.4
N3	2.4	2.4	2.6	2.4	2.6	2.2	2.6	2.4	2.6	2.4	2.6	2.4
N4	2.2	2.4	2.6	2.4	2.4	2.6	2.6	2.4	2.6	2.4	2.6	2.4
O1	2.4	2.4	2.6	2.6	2.6	2.6	2.6	2.4	2.4	2.4	2.6	2.4
O2	2.4	2.4	2.6	2.6	2.4	2.4	2.4	2.2	2.4	2.6	2.2	2.4
O3	2.4	2.4	2.6	2.6	2.2	2.4	2.4	2.6	2.4	2.4	2.4	2.4
O4	2.4	2.4	2.6	2.6	2.4	2.6	2.6	2.4	2.4	2.6	2.6	2.4
P1	2.4	2.4	2.6	2.6	2.6	2.4	2.6	2.6	2.4	2.6	2.6	2.4
P2	2.4	2.4	2.6	2.6	2.6	2.4	2.6	2.6	2.4	2.4	2.6	2.4
P3	2.6	2.4	2.6	2.6	2.6	2.4	2.4	2.6	2.4	2.6	2.6	2.4
P4	2.4	2.4	2.6	2.4	2.6	2.4	2.6	2.6	2.4	2.4	2.6	2.4

	25	26	Aver.	S.Dev.	Min.	Max.
A1	2.0	2.2	2.30	.16	1.8	2.6
A2	2.4	2.2	2.34	.12	2.0	2.6
A3	2.2	2.2	2.32	.14	2.0	2.6
A4	2.4	2.2	2.38	.11	2.2	2.6
B1	2.2	2.2	2.35	.11	2.2	2.6
B2	2.4	2.2	2.40	.11	2.0	2.6
C1	2.4	2.2	2.42	.08	2.2	2.6
C2	2.2	2.2	2.21	.02	1.8	2.6
C3	2.0	2.2	2.31	.14	2.0	2.6
D1	2.4	2.2	2.30	.14	2.0	2.6
D2	2.4	2.2	2.36	.11	2.0	2.6
E1	2.6	2.0	2.34	.12	2.0	2.6
E2	2.4	2.0	2.21	.17	1.8	2.4
E3	2.4	2.2	2.37	.08	2.2	2.6
F1	2.2	2.0	2.25	.13	2.0	2.4
F2	2.2	2.0	2.17	.18	1.8	2.6
F3	2.2	2.0	2.31	.13	2.0	2.4
F4	2.4	2.4	2.28	.19	1.8	2.6
G1	2.4	2.2	2.22	.13	2.0	2.6
G2	2.4	2.4	2.31	.13	2.0	2.6
H1	2.2	2.0	2.26	.14	2.0	2.6
H2	2.2	2.0	2.19	.17	1.8	2.4
H3	2.4	2.4	2.40	.07	2.2	2.6
J1	2.4	2.2	2.30	.10	2.2	2.4
J2	2.4	2.0	2.29	.12	2.0	2.4
K1	2.4	2.0	2.24	.14	2.0	2.4
K2	2.2	2.2	2.33	.13	2.0	2.6
K3	2.4	2.4	2.33	.13	2.0	2.6
L1	2.4	2.2	2.36	.10	2.2	2.6
L2	2.4	2.0	2.22	.18	1.8	2.4
L3	2.4	2.2	2.38	.10	2.2	2.6
L4	2.4	2.4	2.25	.17	1.8	2.4
M1	2.4	2.4	2.41	.10	2.2	2.6
M2	2.4	2.4	2.32	.16	2.0	2.6
N1	2.4	2.2	2.41	.10	2.2	2.6
N2	2.4	2.4	2.37	.10	2.2	2.6
N3	2.4	2.2	2.41	.11	2.2	2.6
N4	2.6	2.4	2.42	.11	2.2	2.6
O1	2.4	2.2	2.41	.13	2.0	2.6
O2	2.6	2.2	2.39	.12	2.2	2.6
O3	2.4	2.4	2.39	.10	2.2	2.6
O4	2.6	2.2	2.42	.13	2.2	2.6
P1	2.6	2.4	2.47	.11	2.2	2.6
P2	2.4	2.2	2.43	.10	2.2	2.6
P3	2.6	2.4	2.46	.09	2.4	2.6
P4	2.4	2.2	2.45	.10	2.2	2.6

APPENDIX E.

ANALYSIS OF VISUAL LOSS IN TERMS OF LOCAL REDUCTION OF DIFFERENTIAL THRESHOLD CONTRAST.

GLAUCOMA CASES

RIGHT EYES.

Case No.	1	2	3	4	5	6	7	9
AGE.	48	57	42	48	68	67	73	48
NDF Guide for age.	1.8	1.6	1.8	1.8	1.4	1.4	1.4	1.8
A1	1.8	1.8	1.4	0.	0.	0.2	1.0	0.
A2	1.4	1.8	0.6	1.8	0.	0.2	1.4	1.0
A3	1.4	1.8	0.6	1.8	0.	1.0	1.4	1.8
A4	0.2	1.8	0.6	1.8	0.	1.0	1.4	1.8
B1	0.6	1.8	1.4	0.	0.	0.6	1.4	1.0
B2	0.2	1.8	1.0	1.8	0.	0.	1.4	1.8
C1	0.	1.8	0.6	0.	0.	0.	0.	1.8
C2	1.8	1.0	0.	1.8	0.	1.0	1.4	1.0
C3	1.4	1.8	0.	1.8	0.	1.0	1.4	1.8
D1	0.6	1.8	1.4	0.	0.	0.2	1.4	1.8
D2	0.6	1.8	0.	1.8	0.	1.4	1.4	1.8
E1	1.0	1.8	0.	0.	0.	0.6	1.0	0.
E2	1.4	1.8	1.4	0.6	0.	1.0	1.4	1.8
E3	1.0	1.8	0.	1.8	0.	1.4	1.4	1.8
F1	1.0	1.0	1.4	0.	0.	1.0	1.0	0.2
F2	1.4	1.0	0.	0.	0.	0.2	1.4	0.6
F3	1.0	1.0	0.	1.8	0.	0.	1.0	1.0
F4	0.0	1.0	0.	1.8	0.	1.0	1.4	1.8
G1	0.0	1.8	0.	0.	0.	1.0	1.4	0.
G2	0.0	1.8	0.	1.8	0.	0.	1.4	1.8
H1	1.8	1.0	0.	0.	0.	1.4	1.4	0.2
H2	0.0	1.0	0.	0.	0.	1.0	1.4	0.2
H3	1.8	1.8	0.	1.8	0.	1.4	1.4	0.2
J1	0.2	1.0	0.	0.	0.	1.0	1.4	0.
J2	0.2	1.8	0.	1.8	0.	1.0	1.0	1.8
K1	1.0	1.8	0.	0.	0.	1.0	1.4	1.8
K2	1.0	1.0	0.	1.8	0.	1.0	1.4	1.8
K3	1.0	1.8	0.	1.8	0.	0.	1.4	1.8
L1	0.6	1.8	0.	0.	0.	1.4	1.4	1.8
L2	0.6	1.8	0.	0.6	0.	0.2	1.4	1.8
L3	0.6	1.8	0.	1.8	0.	1.0	1.0	0.6
L4	0.6	1.8	0.	1.8	0.	0.2	0.2	1.8
M1	1.8	1.0	1.0	1.8	0.	1.0	1.4	1.8
M2	1.8	1.0	0.	1.8	0.8	1.4	1.4	1.8
N1	0.2	1.8	0.	0.	0.	1.4	0.6	0.2
N2	0.2	1.8	0.	0.	0.8	1.4	1.4	1.8
N3	1.8	1.8	0.	1.8	0.	1.4	0.6	1.8
N4	1.8	1.8	0.	0.6	0.	1.4	1.4	1.8
O1	1.8	1.8	0.	1.8	0.	1.4	0.	1.8
O2	0.	1.8	0.	0.	0.	1.4	1.0	1.8
O3	1.8	1.8	0.	1.8	0.8	1.4	1.4	1.8
O4	1.8	1.8	0.	1.8	0.	1.4	1.4	0.6
P1	1.4	1.8	0.6	0.6	0.4	1.4	0.	0.
P2	1.8	1.8	0.	1.8	0.8	1.4	1.4	1.8
P3	1.8	1.8	0.	0.6	0.4	1.4	1.4	1.8
P4	1.8	1.8	0.	1.8	0.4	1.4	1.4	1.8

GLAUCOMA CASES

RIGHT EYES.

Case No.	10	11	12		
AGE.	79	78	45		
NDF Guide for Age.	1.4	1.4	1.8	Mean	S.Dev.
A1	1.4	0.2	1.6	0.83	0.71
A2	1.0	1.0	1.2	1.01	0.53
A3	1.0	0.2	1.6	1.15	0.62
A4	1.4	1.0	1.6	1.15	0.62
B1	1.4	1.0	1.6	0.98	0.59
B2	1.4	0.6	1.6	1.05	0.70
C1	1.4	0.	1.6	0.65	0.78
C2	1.0	0.6	1.6	1.16	0.63
C3	1.4	1.0	1.6	1.20	0.63
D1	1.0	1.0	1.6	0.73	0.64
D2	1.4	0.6	1.6	1.13	0.67
E1	1.0	0.6	1.6	0.69	0.62
E2	1.0	1.0	1.6	1.18	0.57
E3	1.4	0.6	1.6	1.16	0.65
F1	1.4	0.6	1.6	0.84	0.54
F2	1.0	1.0	1.2	0.62	0.50
F3	1.4	0.	1.2	0.73	0.62
F4	1.0	0.2	0.4	0.78	0.67
G1	1.4	1.0	1.6	0.75	0.71
G2	1.4	0.6	1.6	0.85	0.73
H1	1.8	0.2	0.8	0.79	0.70
H2	1.0	0.2	1.6	0.58	0.59
H3	1.0	0.6	1.6	1.05	0.70
J1	1.4	1.0	1.6	0.60	0.64
J2	1.0	0.2	1.2	0.91	0.68
K1	1.4	0.2	1.6	0.87	0.67
K2	1.0	1.0	1.2	0.96	0.49
K3	1.4	0.6	1.6	1.04	0.72
L1	1.4	0.2	1.6	1.05	0.67
L2	1.0	0.6	1.6	0.85	0.68
L3	1.4	0.	1.6	0.89	0.67
L4	1.0	0.	1.6	0.89	0.76
M1	1.4	0.	1.8	1.13	0.81
M2	1.4	1.0	1.6	1.21	0.52
N1	1.4	0.2	1.6	0.67	0.69
N2	1.4	0.	1.6	0.95	0.72
N3	1.0	0.	1.6	0.98	0.72
N4	1.4	1.0	1.6	1.16	0.65
O1	1.4	0.	1.6	1.05	0.81
O2	1.4	0.	1.6	0.82	0.77
O3	1.4	1.0	1.6	1.35	0.53
O4	1.4	0.2	1.6	1.09	0.71
P1	1.4	0.	1.2	0.80	0.63
P2	1.4	1.0	1.2	1.31	0.53
P3	1.4	1.0	1.2	1.16	0.58
P4	1.4	1.0	1.2	1.27	0.57

GLAUCOMA CASES

LEFT EYES.

Case No.	2	3	5	7	8	9
AGE.	57	42	68	73	73	48
NDF guide for AGE.	1.6	1.8	1.4	1.4	1.4	1.8
A1	1.8	0.6	1.6	1.4	1.4	1.8
A2	1.8	1.8	0.	1.4	0.	1.8
A3	1.8	1.8	1.6	1.4	1.4	0.
A4	1.8	1.0	0.	1.4	0.	1.8
B1	1.6	1.8	1.6	1.4	1.4	1.8
B2	1.8	1.8	1.6	1.4	1.4	1.8
C1	1.8	1.0	1.6	1.4	1.4	1.8
C2	1.8	1.8	1.6	1.4	0.	1.8
C3	1.8	1.8	1.6	0.	1.4	1.0
D1	1.8	1.8	1.6	1.4	0.6	1.8
D2	1.8	1.8	1.6	1.4	0.6	1.8
E1	1.8	1.8	1.6	1.4	1.4	1.0
E2	0.2	1.8	1.6	1.4	0.	0.2
E3	1.8	1.8	1.6	1.4	1.4	1.8
F1	1.8	1.8	1.6	1.0	1.4	1.8
F2	1.8	1.8	1.6	1.4	0.	1.8
F3	1.8	0.2	1.6	1.4	0.6	1.8
F4	1.8	1.0	1.6	1.0	0.	0.6
G1	0.6	1.8	1.6	1.4	1.4	1.8
G2	1.8	0.6	1.6	0.2	1.4	1.0
H1	1.8	1.8	1.6	1.4	1.4	1.0
H2	1.8	1.8	1.6	1.4	0.	1.0
H3	1.8	0.6	1.6	0.	0.6	1.8
J1	1.8	1.8	1.6	1.4	1.4	1.8
J2	1.8	0.6	1.6	1.4	1.4	1.8
K1	1.8	1.8	1.6	1.4	1.4	1.8
K2	1.8	0.6	1.6	0.	1.4	1.8
K3	1.8	0.6	1.6	0.	0.	1.0
L1	1.8	1.8	1.6	1.0	1.4	1.8
L2	0.2	1.0	1.6	1.4	0.	1.8
L3	1.8	1.8	1.6	1.0	1.4	1.8
L4	1.8	0.6	1.6	0.	0.	1.8
M1	1.8	1.8	1.6	1.4	1.4	1.8
M2	1.8	1.8	1.6	0.2	0.	1.8
N1	1.8	1.0	1.6	1.4	1.4	0.
N2	0.0	1.8	1.6	1.4	0.	1.8
N3	1.8	1.8	1.6	0.6	1.4	1.8
N4	1.8	0.	1.6	1.0	0.	1.8
O1	1.8	1.8	1.6	1.0	1.4	1.8
O2	1.8	1.8	1.6	1.4	0.6	0.
O3	1.8	1.8	1.6	1.0	0.2	1.8
O4	1.8	1.8	1.6	1.4	1.4	1.8
P1	1.8	1.8	1.6	1.4	1.4	1.8
P2	1.0	1.8	1.6	1.4	1.4	1.8
P3	1.8	1.8	1.6	1.4	1.4	1.8
P4	1.0	1.8	1.6	1.4	1.4	1.8

GLAUCOMA CASES.

LEFT EYES.

Case No.	10	11		
AGE.	79	78		
NDF guide for AGE.	1.4	1.4	Mean	S.Dev.
A1	1.0	1.0	1.33	0.40
A2	1.0	1.0	1.10	0.71
A3	1.4	0.6	1.10	0.71
A4	1.4	0.	1.17	0.70
B1	1.4	1.0	1.50	0.24
B2	1.4	1.0	1.52	0.26
C1	1.4	0.6	1.37	0.38
C2	1.0	1.0	1.30	0.58
C3	1.4	0.	1.12	0.69
D1	1.4	1.0	1.42	0.40
D2	1.4	0.6	1.30	0.47
E1	1.0	1.0	1.38	0.30
E2	1.4	0.	0.79	0.71
E3	1.4	0.2	1.42	0.49
F1	1.4	1.0	1.47	0.32
F2	1.4	1.0	1.35	0.57
F3	1.4	0.	1.10	0.68
F4	1.4	0.	0.89	0.67
G1	1.4	1.0	1.37	0.38
G2	1.4	0.6	1.07	0.53
H1	1.4	0.2	1.32	0.49
H2	1.4	0.2	1.15	0.65
H3	1.4	0.2	1.00	0.69
J1	1.4	0.6	1.47	0.37
J2	1.4	0.	1.21	0.59
K1	1.4	1.0	1.52	0.26
K2	1.4	0.	1.07	0.71
K3	1.4	0.	0.80	0.71
L1	1.0	0.	1.30	0.58
L2	1.4	1.0	1.05	0.61
L3	1.0	0.	1.30	0.58
L4	1.0	1.0	0.97	0.69
M1	1.4	1.0	1.52	0.26
M2	1.4	0.	1.07	0.79
N1	1.4	0.2	1.10	0.62
N2	1.4	0.2	1.02	0.76
N3	1.4	0.	1.22	0.59
N4	1.4	0.	1.02	0.80
O1	1.4	1.0	1.40	0.26
O2	1.4	0.	1.07	0.71
O3	1.4	0.	1.16	0.68
O4	1.4	0.2	1.30	0.58
P1	1.4	1.0	1.49	0.30
P2	1.4	0.	1.30	0.55
P3	1.4	1.0	1.49	0.30
P4	1.4	0.2	1.30	0.55

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THE DESIGN OF INSTRUMENTATION FOR THE EFFICIENT INVESTIGATION OF THE VISUAL FIELDS*

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INTRODUCTION

Since the time of von Graefe (1856), the importance of the clinical investigation of the visual field has been realized more and more[1]. The earliest known instrument for this purpose was the perimeter designed by Aubert and Forrester (1857). From this beginning, until the present day, numerous instruments have been designed to improve the techniques available, for example, the perimeter of Goldmann[2], employing quantitative control of adaptation and stimulus variables. Of necessity, the

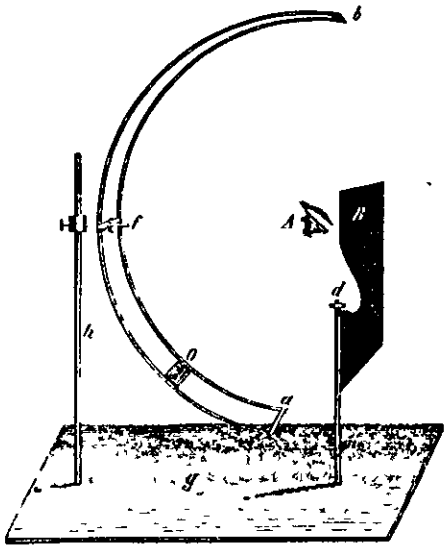

Fig 1 The Aubert and Foerster Perimeter

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Fig 2 The Goldmann Bowl Perimeter

methods of investigation tend to be laborious, and the results obtained vary considerably according to the conditions under which they are undertaken, and to the unavoidable variations in technique between investigators Figures 1, 2 and 3

Because of the time taken to investigate the visual fields by conventional means, interest has been taken in instruments which could be used quickly to "screen" these fields Through limitation in design and usage, they are not intended to replace existing methods If any variation from normal is found, then the fields have to be explored by laborious conventional techniques The main difficulty in the application of these instruments has been in the lack of control over the essential variables, and in insuring adequate sensitivity without undue trouble from false positives and negatives

REQUIREMENTS FOR VISUAL FIELD INVESTIGATION

Before considering the detailed design of any new instrument, it is essential to understand and to evaluate those factors which are considered clinically essential, and to decide over what variables there should be adequate control It is desirable that the technique of operation of the instrument should have as little influence as possible on the recorded results, and that data obtained at different times should be readily comparable

Fig. 3 The Goldmann Bowl Perimeter

Visual perception in the whole field of vision is a complex process, and unfortunately there are still few factors which are fully understood The clinical investigation of the visual fields is essentially a method of trying to assess whether there is any loss of visual function The basis of commonly employed techniques is the visual perception, at differential threshold, of the presence of a stimulus, or stimuli, at a certain position,

Fig. 4 The Harrington-Flocks Visual Field Screener

or positions, on the retina, against an illuminated background The actual contrast required for perception is influenced by the angle subtended by the stimulus at the eye, the luminance and duration of exposure of the stimulus, the shape of the stimulus, the position at which it falls on the retina, and the number and type of receptors that are stimulated The degree of inter-connection between neurones influences the effect of summation In addition to the effect of the stimuli and the background, the adaptation of the eye will be influenced by the luminance of any ambient light, for example, room lighting The spectral quality of the stimulus light as well as its quantity, are important, as they may influence the degree of the rod and/or cone stimulation.

It is also necessary to consider whether the stimulus is fixed or moving, as movement will involve the stimulation of successive receptors Very important is the duration of exposure of the stimulus as this not only determines the total quantity of light incident on the eye, but also can affect the degree of summation that occurs Since it is impractical to control pupil size the latter will be determined initially by the luminance of the adapting field

If more than one stimulus is exposed at one time, it is probable that the threshold contrast required for perception may not be the same as that for a single stimulus The actual amount by which the threshold may be altered will depend on the number and size of stimuli exposed, and the relative positions at which they fall on the retina

The ability to hold steady central fixation can also introduce vagaries in the recorded data of differential threshold With a constantly

Fig 5 The Fincham-Sutcliffe Visual Field Screener.

exposed stimulus, steady fixation is much more difficult, and this difficulty decreases as exposure time is reduced.

EXISTING VISUAL FIELD SCREENERS

Visual field screeners mostly use a series of patterns of multiple stimuli, which are exposed in suitable sequence. These patterns are designed to allow exploration of these parts of the visual field where defects are most likely to be met

The Harrington-Flocks Visual Field Screener

Harrington and Flocks[1] were the first to make a major contribution in this field, and their instrument is based on a set of ten test cards for each eye, made of white card, on each of which is printed, in fluorescent ink, a series of patterns These patterns are practically invisible under visible light, but glow green on exposure to long-wave ultra-violet light They are designed to be viewed at ⅓ of a meter at a suggested room illuminance of approximately 7 lumens ft^2 of tungsten light, and are exposed for 0.25 seconds Figure 4

Unfortunately with this system there is no control over adaptation or over stimulus brightness. It is therefore not possible to allow for different sensitivities of visual perception found in different age groups or to make any adequate assessment of loss of sensitivity in physical terms

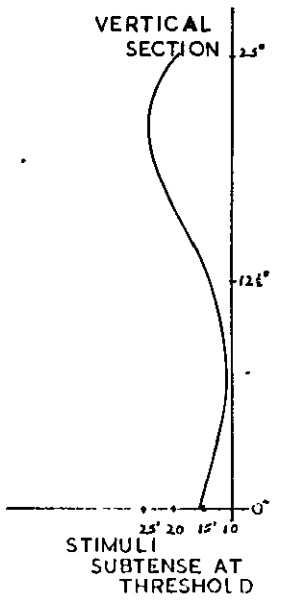

Fig 6 Diagram of angular subtense of stimuli through 90 meridian giving same threshold difference at the observer's eye

The Fincham-Sutcliffe Visual Field Screener

The Fincham-Sutcliffe visual field screener, described by Sutcliffe and Binstead[4], employs a flat grey Bjerrum screen containing small apertures placed in suitable positions, and behind which are placed small low-voltage tungsten filament lamps Stimuli patterns are controlled by a multi-way switch, and are exposed for approximately 0 25 seconds A rheostat is used to set the luminance of the stimuli to an average normal threshold contrast, and any defects found are investigated by normal methods using stimuli projected optically on to the same screen Unfortunately, no external illuminance device is available to control adaptation, spectral quality is altered when the lamps are dimmed, and there is no calibration for changes in stimulus brightness Figure 5

Other instruments on similar principles to the Fincham-Sutcliffe have been designed, including the Roberts Visual Field Screener[5], the more recent Feedback Screening Scotometer of Burns[6], and the single-stimuli instrument with automatic recording of Buchanan-Gloster[7]. All of these instruments have in their way made a valuable contribution, but have left unanswered a number of problems, and their effectiveness is to some extent limited, because of the lack of full control of the physiological and physical factors involved

DESIGN OF THE VISUAL FIELD ANALYSER

When contemplating the design of a new instrument, it was considered essential to be able to control both the luminance of the background and of the stimuli and, also, that the duration of exposure of the latter should be constant and short

To achieve these aims it was thought desirable to employ a system of presenting either single or multiple patterns from a single source to avoid individual differences between sources It was also felt that this source should emit light of known intensity and spectral quality and that it should produce light as near as possible to the color temperature of daylight A xenon discharge lamp has been used, with neutral density filters to vary luminance in known intensities, to ensure constancy and to avoid variations in spectral quality The short exposure time possible minimizes problems due to eye movement

To overcome difficulties of producing varying patterns from a single source, a patented system devised by A I Friedmann, employing a fixed front and a rear rotating plate, is used to produce patterns of stimuli, with an electronic flash to produce the stimuli

DETERMINATION OF STIMULI POSITIONS AND COMBINATIONS

The choice of stimulus positions has been determined largely by appreciation of the areas in the visual field where defects are most likely

to occur, and of the characteristics likely to be expected in each case For example, those areas of the visual field representing the projection of the arcuate retinal nerve fiber bundles are particularly important as regards the early field changes in glaucoma. In lesions beyond the retinal level, any changes of visual perception on either side of the vertical midline through the fixation point are particularly important In addition, for example, patterns are included to detect lesions around the macular area and between the macula and the disc When employing multiple-pattern stimuli it is possible to make use of "the phenomenon of extinction," whereby any possible difference of threshold contrast between each of two stimuli is intensified if they are simultaneously exposed, one on an area of retina, say with normal response along the visual pathway, and the other on an adjacent area where there may be reduced sensitivity.

In determining the position of stimuli, a number of physiological factors must be allowed for. Precautions must be taken against slight difference of size and of position of the physiological blind spot, and also against slight displacement caused by any small variations in central fixation Also, in the region of the projection of the arcuate nerve fiber

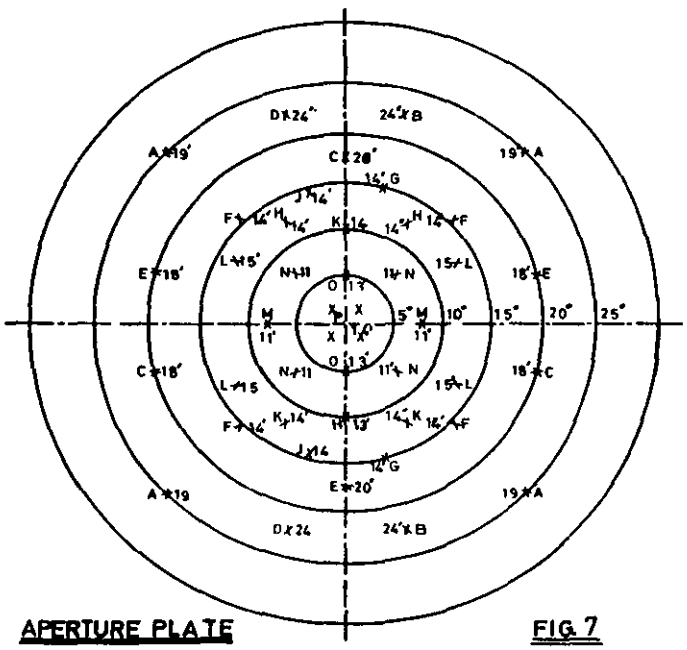

Fig 7. Map of the front plate of the Analyser indicating stimulus positions and their angular subtense at the observer's eye

bundles it is possible to have difficulty during visual field investigation due to angioscotomata, because of the presence of retinal vessels in this region. Their effect can be minimized by the choice of suitable sizes of stimuli, and also by a reasonable distribution of stimulus positions. When determining stimulus positions and sizes, it also must be remembered that the nerve fiber bundles take an oval course, major axis horizontal, and not a truly circular course

In general it is advisable to bear in mind the normal span of attention and to limit the number of stimuli exposed at any one time to not more than four, and, where possible, to vary the number of stimuli seen at any one time.

THE DETERMINATION OF STIMULUS SIZE

It is possible to produce a visual stimulus at differential threshold contrast with suitable combinations of areas and luminance Though small stimuli are desirable, difficulties are introduced if they are too small, particularly as regards the effect due to increase of the retinal image, because of blurred margins due to aberrations and refractive errors Furthermore, with very small stimuli greater trouble is experienced with angioscotomata On the other hand, too large a stimulus may overlap a small field defect or its edge.

In deciding on stimulus sizes and brightnesses, several problems are involved. Little work has been done concerning the visual perception of stimuli incident on the retinal area when duration of exposure (a very important variable) is controlled The position is complicated by the fact that the individual relationships between intensity, area, and dura-

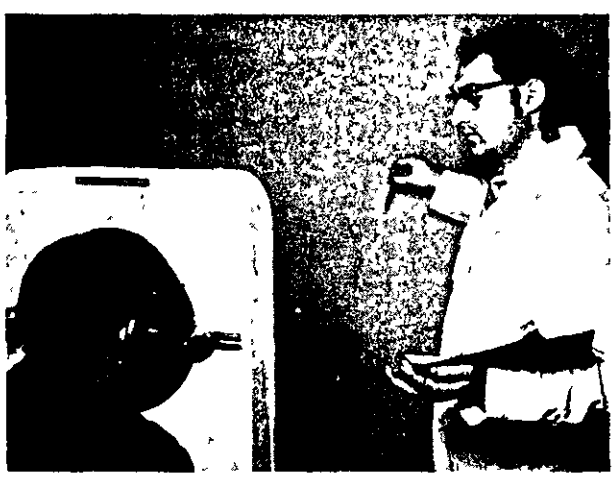

Fig 8 Illustration of apparatus for research on visual fields showing central stimulus

tion, can vary for equal threshold difference for different values of these quantities, as well as with the state of adaptation In addition, little is known of the effect of visual perception of multiple stimuli as opposed to a single stimulus. If the investigation is to be satisfactory, it is essential to try to achieve approximately equal threshold difference between stimuli and background over the whole of the area of the visual field being examined; otherwise false positives or false negatives will result. After consideration of the various factors involved, a stimulus subtending an angle of approximately 14 min (1 4 mm at 33 cm) at the eye, was chosen, and then calculations made to allow for oblique viewing and any tunnelling effect due to the thickness of the front plate Apertures over the area of the central field could then be determined, which, when made in the front plate, would all have the same effective area at the eye. It is then necessary to make allowances for the difference in visual perception across the retinal area so that the apertures can be modified to produce equal threshold difference over the central area of the field Since no data were available on these variations of threshold in the visual field, it was necessary to determine them experimentally Initially it was assumed that the isopters varied in the central field approximately linearly

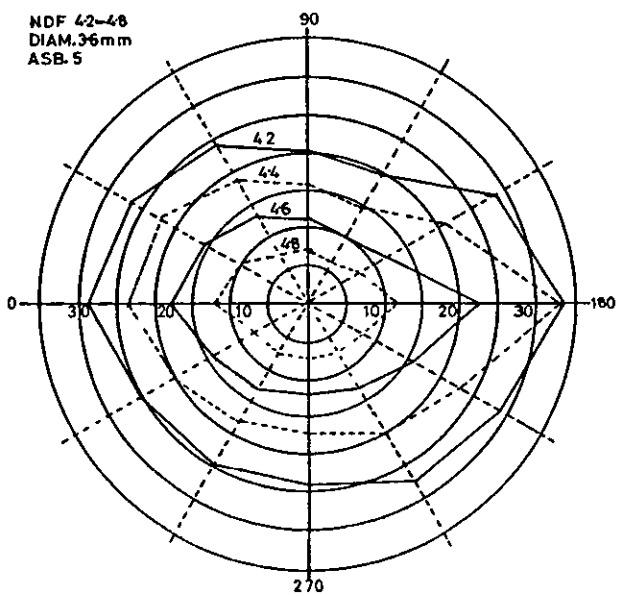

Fig 9. One of a series of isopters in terms of neutral density filters required to produce similar differential threshold contrast over the central field The stimulus was 3 6 mm diameter and was viewed at 1 meter It was exposed for 200μ sec against a background luminance of approximately 0 5 ft/Lamberts

to logarithmic changes in luminance As a commencement it was decided to employ, by suitable illuminance of the front plate, an adaptation level of 0 075 foot lamperts (prior to the exposure of the stimuli). This adaptation level allowed investigation as near as possible to the mesopic condition and should ensure adequate sensitivity of investigation for vision involving all receptors The subjects had to view different fixation points over the visual field and at each point the sizes of aperture, positioned centrally to produce threshold difference for the same stimuli luminance, were noted These differences of area of stimulus necessary for physiological reasons were superimposed on to those necessary, because of geometrical considerations of viewing, to produce an initial front plate of approximately even physiological response Using 30 normal observers from 16 to 73 years and commencing with a stimulus

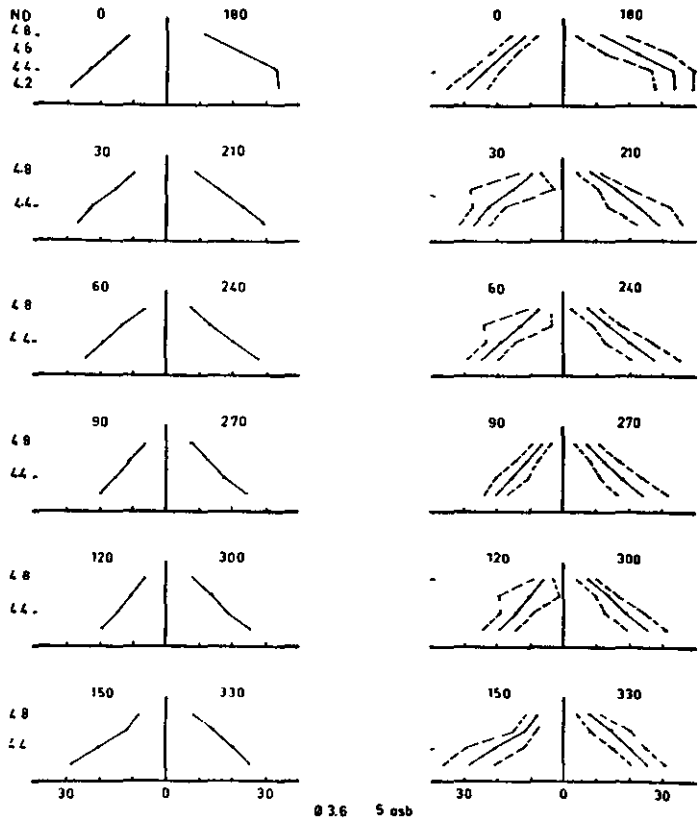

Fig 10 Individual meridians through these isopters showing average threshold contrast difference in relation to eccentricity from the fovea On the right are also shown the standard deviations in broken lines

below threshold, each pattern was exposed in turn and the threshold examined for each stimulus position and for each pattern sequence for both the right and left eyes.

After statistical analysis, the apertures were adjusted in size to produce an equal average threshold difference Subjects of different age groups were examined so that the effect of age on threshold could be investigated. The resulting data could then be used to determine stimulus intensity when the instrument was used clinically. These intensities are slightly higher than those used to obtain threshold to avoid false positives Figures 6 and 7

FUNDAMENTAL RESEARCH ON THRESHOLD CONTRAST

In view of the lack of data on threshold in the visual field for constant duration of exposure of stimuli, it was decided to obtain this information To remedy a gap in the literature concerning luminance difference threshold for a controlled exposure time, data are being obtained by H. Obstfeld, in conjunction with the author, at the City University. Figures 8, 9 and 10.

The present method is an extension of the one employed for determining aperture sizes for the visual field analyser In a dark room a single stimulus at the center of a large screen is viewed at 1 meter The source for the stimulus is a xenon flash tube, the luminance of which can

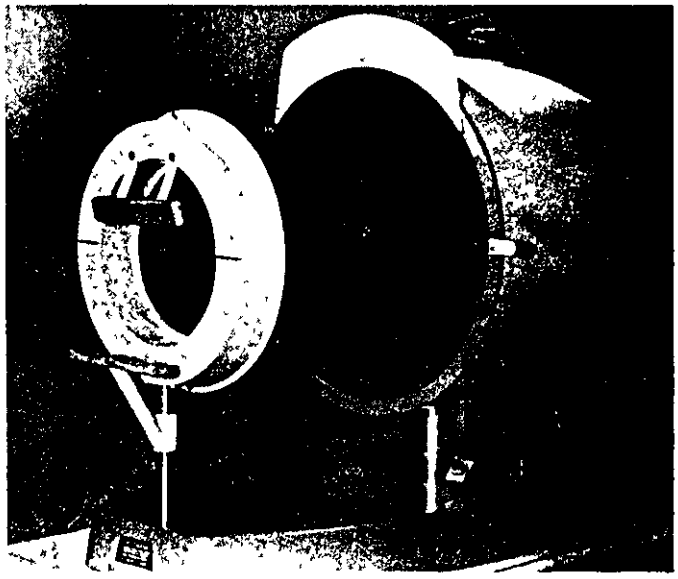

Fig 11 General view of the Visual Field Analyser

be controlled by neutral density filters The sizes of the stimulus can be altered by an aperture disc with holes which increase in area logarithmically. Illuminance on the screen, and therefore adaptation, is controlled by a circular Bjerrum screen illuminator In use the isopters are obtained in terms of luminance difference, for a constant size of stimulus, in the central field. Data are being obtained initially under low photopic and mesopic states of adaptation for different sizes of stimuli.

DESCRIPTION OF THE VISUAL FIELD ANALYSER

The aim in design of the analyser was to produce an instrument that would allow quick, accurate, and yet sensitive, quantitative visual field investigation that was convenient to use clinically and that was in keeping with modern trends in instrumentation Figure 11

With small stimuli employing short duration of exposure, there is no need to employ the customary one meter working distance Therefore, a third of a meter viewing distance was chosen so that a compact instrument would result which could be used easily in conjunction with other stand instruments and on multiple-position instrument tables.

The instrument consists essentially of a base carrying a housing containing an integrating bowl hemisphere, the light source and its ac-

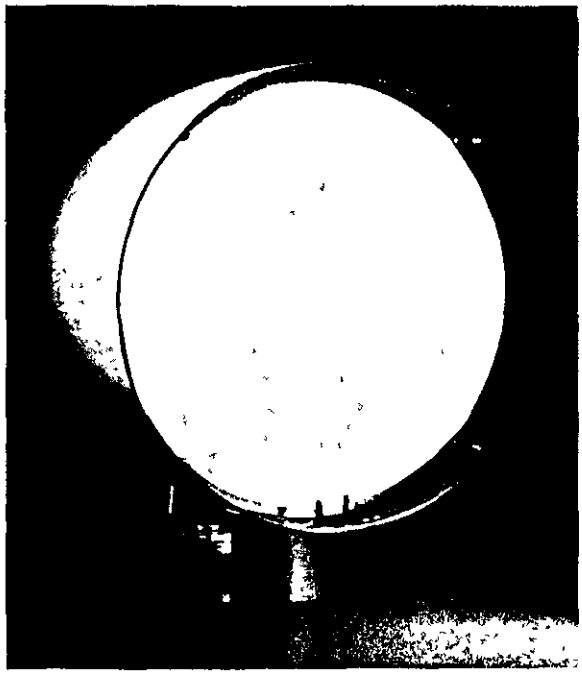

Fig 12 Illustration of the Analyser with the front plate detached

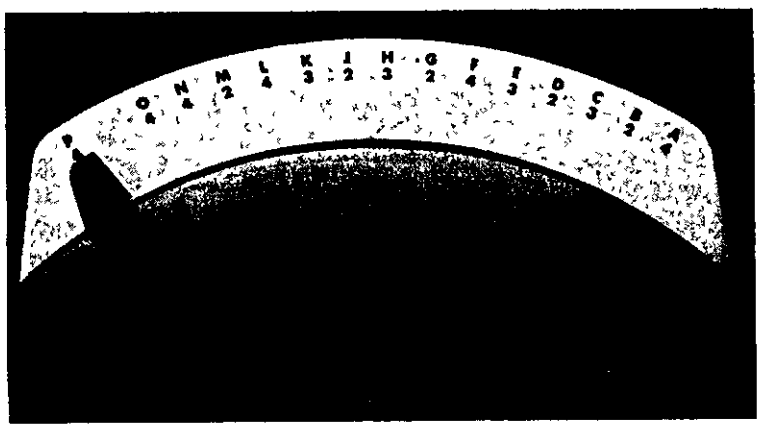

Fig. 13. The operator's view of the translucent scale and the 15-position lever of the Analyser.

cessories, and the front-plate assembly for exposing the patterns on the front of this housing. At the other end of the base is carried the external illuminator, on which is also mounted an adjustable double-position chin rest for right and left eye examination. The major part of the instrument is constructed in glass-fiber for strength and lightness.

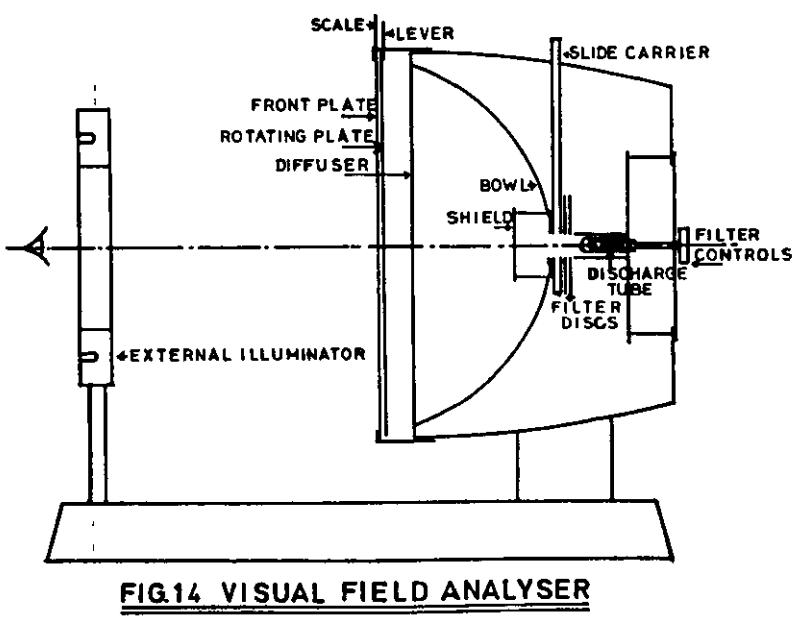

FIG.14 VISUAL FIELD ANALYSER

Fig. 14. A vertical section through the Visual Field Analyser to illustrate its main components.

The Front Plate Assembly and Integrating Bowl Illuminator

The front plate assembly, carrying the multiple pattern apertures, is readily detachable from the integrating bowl assembly so that the Analyser can be used easily for assessment of dark adaptation The front plate is fixed and carries the 46 apertures to produce the patterns of stimuli. It is of black rigid matt vinyl sheet with a reflection factor of approximately 7.5%. Reasonably low levels of adaptation can be achieved combined with a workable level for the operator. The external illumination device also acts as a shield, limiting the total visual field to approximately that of the screen. Figure 12

The indexing for the multiple pattern divisions is achieved by moving a lever running in a light-tight slot at the top of the rim carrying the front plate On a translucent hand-shield, illuminated by light from the external illuminator, and in front of this lever, is a scale on which are marked letters indicating the individual patterns; below these are

Fig 15. The rear control panel of the Analyser showing the neutral density filter indicators

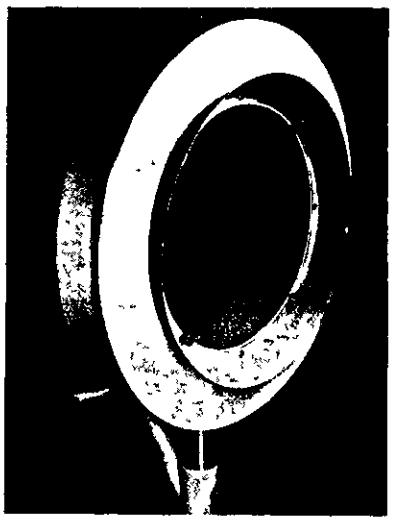

Fig 16 A view of the external illuminator

numerals indicating the number of stimuli in each pattern Figure 13.

The bowl integrator consists of a hemisphere finished matt white inside, across the front of which is a diffuser of opal plastic. At the rear of the bowl is an aperture covered by a disc of diffusing plastic allowing entry of light into the bowl. Spaced between the rear opening and the front diffuser is a matt-white circular shield, to allow inter-reflection

Fig. 17. The filter slide carrier

FILTER SETTING & AGE			
UP TO 40	41–50	51–60	OVER 61
2·0	1·8	1·6	1·4

Fig 18. Suggested settings of neutral density for different age groups These settings are those for which all normal subjects examined were able to see all the stimuli Where some good observers can see all the stimuli easily at this setting they should be examined at a 0 2 higher setting especially if some abnormality is suspected

but to prevent direct light from being transmitted to the front By this means even illuminance can be obtained over the whole surface of the front of the bowl Figure 14.

The light source is a xenon flash tube permitting light of a constant quantitative and qualitative output. The luminance can be varied by two sets of neutral density filters one in steps of 0, 1 0, 2 0, 3 0 and 4.0 (log units) and the other in steps of 0, 0 2, 0 4, 0 6, 0 8 (log units), the two sets of filters are additive. Illuminated dials at the rear of the bowl on the control panel indicate the filters in use through small windows, and click-stops also give indication of the position by feel The tube is supplied by a fully-insulated electronic power supply with components especially selected to ensure long life and freedom from breakdown. Figure 15.

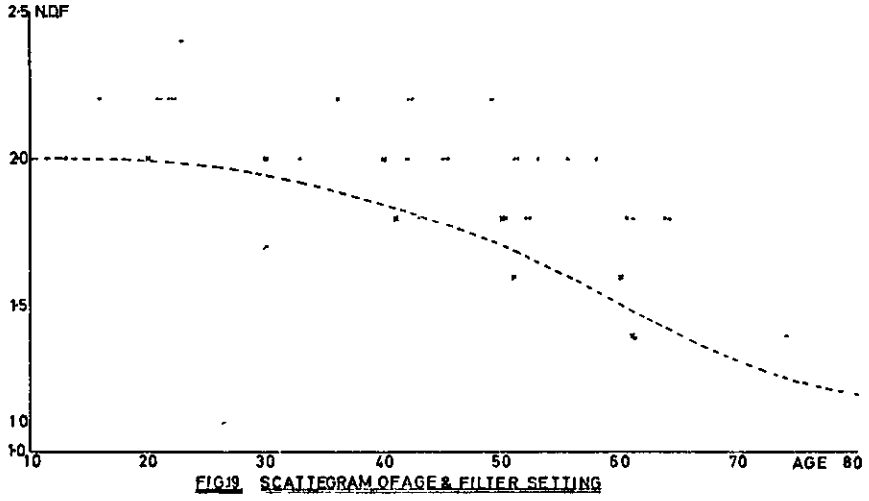

Fig. 19. A typical scattergram obtained in ophthalmic practice by the author on a group of over 100 normal subjects relating age to the neutral filter density setting at which all the stimuli in each of the fifteen patterns could just be seen The curve was taken just below the lowest of the settings to avoid difficulties due to false positives. It compares well with the table of age and neutral filter settings in Fig 18

Without the neutral density filters the average integrated light output across the front of the diffuser of the bowl is 1.5 lumen/seconds per ft^2.

The External Illuminator

To demonstrate defects in the early stages of a pathological condition, the visual fields should be investigated under low levels of adaptation[8]. Since the rods, as well as the cones, are very much concerned with perception over the visual field it is desirable that the level of adaptation should be at least low photopic; if possible as near as possible mesopic. By using material for the front plate which has a low reflection factor (7.5%) it has been possible to approximate this condition and yet

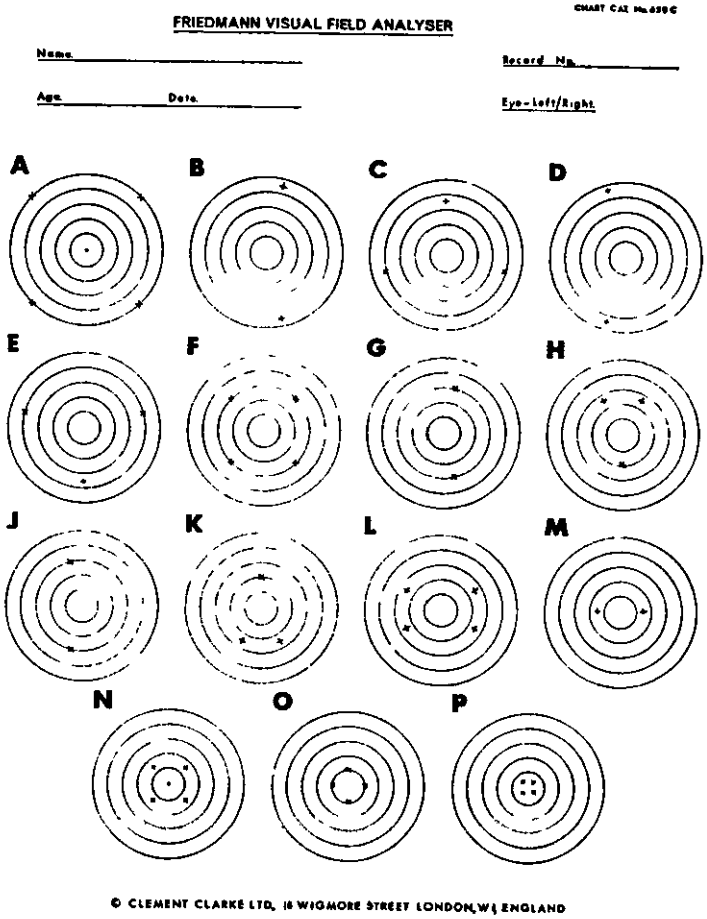

Fig 20a Recording charts 15—position

to allow reasonable clinical working levels of illuminance by special design of the illuminator.

An external illuminator is provided with eight small tungsten lamps intentionally under-run to give longer life, and to minimize the effect of main voltage fluctuations on light output. These lamps are covered by a diffuser of opal plastic and the housing also acts as a visual shield for the patient.

The illuminance on the front plate of the analyser is approximately 1.0 lm/ft^2. At the position of the eye the luminance of the front is approximately 0 075 ft/L (0.8 ASB) Figure 16

The Filter Slide Carrier

At the top of the outer casing of the bowl is a slide carrier for employing colored and/or auxiliary neutral density filters. These filters are mounted in simple self-adhesive cardboard mounts so that the user can readily make up his own when special filters are required, for example, during assessment of adaptation or investigating the visual fields with colored stimuli Figure 17

CLINICAL USE OF THE VISUAL FIELD ANALYSER

In the past, with other visual field screening instruments, it has been very difficult for the ophthalmic consultant to interpret the significance of the results obtained and also to make adequate allowance for variations in perception due to age Large numbers of normal and also pathological visual fields have therefore been investigated during the past

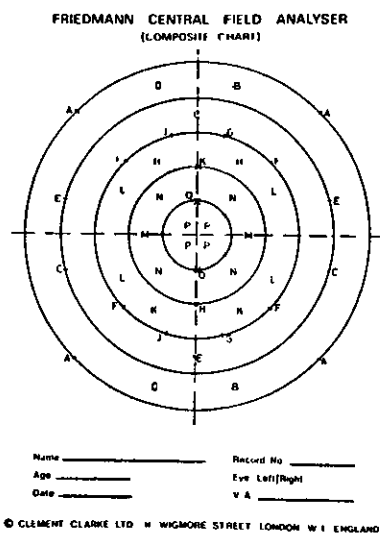

Fig 20b Recording charts—composite

three years at the Royal Eye Hospital on prototype instruments under normal clinical conditions. In consequence it has been possible to assess the settings required for different age groups and to assess when sensitivity is reduced by a pathological condition.

It will be found that with some good observers the patterns of stimuli will be seen very easily at the average setting and that 0 2 (log units) better could be obtained In these cases this higher setting should be used as the patient's normal In general if a setting of the neutral density filters is made at which all of the patterns can just be seen, then an increase of neutral density filter of 0 2 will usually cause some of the stimuli to be missed, while a setting of 0 2 lower will ensure that they are seen very readily. The average neutral density filter setting required may be a little lower when there are changes in the media such as lens changes

So that the patient can readily understand the test, it is usually best to set the filters at one whole unit lower than the threshold for his age, and then expose patterns O and A for him to understand what he is expected to see The neutral filters are then set for his age, and the patterns exposed in turn; the patient is requested to state the number of stimuli that he can see and the answer is checked on the trans-illuminated scale. It is easiest to start from the central set of patterns, i e , pattern P and gradually work out to the peripheral pattern A Figures 18 and 19

Two types of recording charts are provided, one consists of a series of individual diagrams, the fifteen position chart, indicating separately each of the stimuli pattern positions—the other is a composite

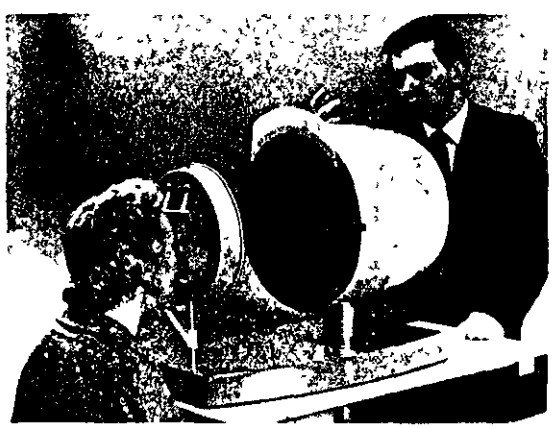

Fig 21 The Visual Field Analyser in use

chart containing all the stimuli on one chart. When the first chart is completed, the findings can be transferred to the second chart. One can then tell at a glance the shape and degree of any visual field defect Figures 20a and 20b.

It is suggested that the following routine be employed when using the Visual Field Analyser

(1) The patient's response to the patterns at the fifteen positions should be examined at the filter setting for his age; if some are missed, the appropriate point on the chart should be underlined

(2) At a 0.4 lower filter setting any of the positions previously missed, but which are now seen, are marked with the new filter density setting.

(3) Any stimuli still missed, are tested with a further reduction of 0 4 filter setting, if now seen the positions are marked with the filter density.

(4) This process is repeated for all stimuli still not seen until 0 0 filter setting is in use. Stimuli not seen at this setting are indicative of a dense visual field defect

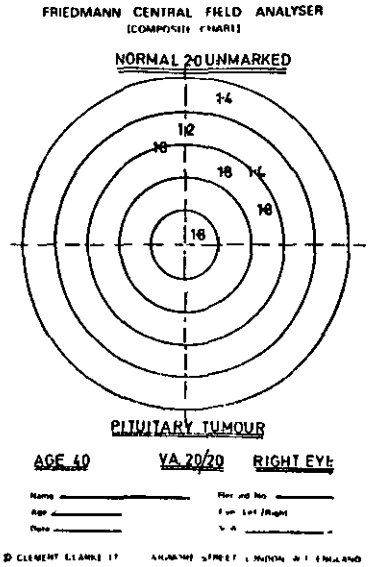

Fig 22 *Pituitary Tumour—Right Field* Case record of patient (male, aet 40) with pituitary tumor Right and left fields Very slight upper temporal defect (junction scotoma), typical of the condition, could not be demonstrated on the tangent screen Initial X-rays of the pituitary fossa revealed no abnormality and diagnosis was made on these field examinations By courtesy of Mr A. I Friedmann F R C S, and the Royal Eye Hospital

If at step (2), i.e., after reducing filter density by 0.4 less than the normal for age, all the stimuli are seen set the filter density at 0.2 less than the normal for age. If any stimuli are missed at this setting they should be considered very slightly abnormal and the patient re-examined after a period of a few weeks If the field defect has not changed the patient should be re-examined after a further period, but if the defect has become denser the patient should be referred. (Stimuli that can now only be seen with a lower field intensity indicate a worsening of the condition)

When viewing the upper peripheral stimuli, particular care must be taken that they are not obscured by the top rim of any spectacles or by the upper eyelid. In the latter case it is usually advisable to request the patient to open his eyes wide while the peripheral stimuli are being viewed.

If, when both eyes have been examined, the neutral density filter setting is within 0.2 of the average setting for the patient's age and is the same for both eyes, the visual fields can be considered within normal limits In these cases it is not really necessary to record the results on a chart and it is quite adequate to make a note of the neutral density filter setting on the patient's record If stimuli are missed at a filter setting of 0.2 or more lower than the patient's average threshold the result should be recorded on the charts With the complete chart in front of one it is

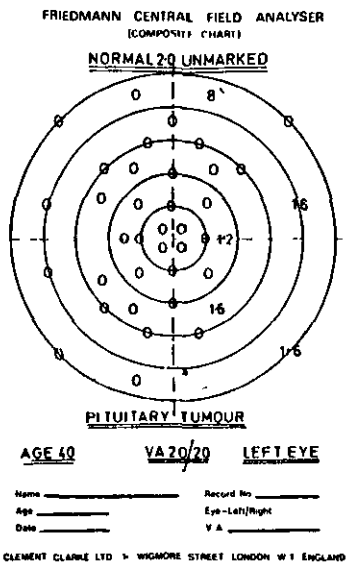

Fig 23. *Pituitary Tumour—Left Field.* Same patient as in Fig 22

fairly easy to assess the extent and amount of any deterioration present. Knowing the characteristics of field defects for different types of conditions, it is easy to obtain a good idea of the cause unless the field defect is very complicated The patient can be referred with a copy of these findings for further medical investigation without undertaking any of the classical laborious methods of visual field investigation Figure 21

It is possible to insert in the filter slide carrier colored filters which will give monochromatic blue or red light for specialized receptor investigation. However, in normal routine practice white-light stimuli are adequate

In some cases in ophthalmic practice it is helpful to be able to investigate macular function For example, central visual acuity may be slightly reduced or the patient may complain of slight distortion for no readily apparent reason though the central visual field is within normal limits outside the fovea The macular function of the two eyes can be compared by setting the indexing lever to stimuli position A and requesting the patient to fixate a central hole—purposely made larger—in the front plate after the fixation target has been removed. The neutral density filter control is then set to approximately 3 0 log units and the patient asked to say "yes" each time he can see the central stimulus At this setting it is unlikely that he will see the peripheral stimuli at position A The neutral density filter setting is then reduced until the patient can just see the center stimulus and a note made of the setting It is advisable to repeat this test at a 0 2 higher neutral filter setting until the examiner has determined at which setting the subject can see 10 out of 10 stimuli If this setting is increased by 0 2, the stimuli should not be seen at ten of all the exposures The other eye is then examined and if the difference between the neutral density setting is greater than 0 2 log units there is a disparity in macular function

A typical case record is included in this paper to illustrate the use of a Analyser. In a subsequent paper it is hoped to describe further types of clinical investigation which can be undertaken with this instrument and how it can be used also for research purposes Figures 22 and 23.

ACKNOWLEDGMENTS

The author would like to acknowledge the helpful cooperation of Mr A I Friedmann F R C S The Royal Eye Hospital London in this joint project also for his help with the case records obtained with the assistance of Miss K Graham Also Professor R J Fletcher The City University London Mr H Obstfeld, The City University, London for cooperation with the author on fundamental research and the Technical Staff of the Department of Ophthalmic Optics The City University The author would also like to extend his thanks to Mr H C Binstead and Mr G Babbs for their help in the design and production of prototypes also to Mr L Wray,

B Sc , and to Mr A T Wagstaff of Clement Clarke, Ltd , for his help and encouragement in making the instrument generally available *

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*The Visual Field Analyser is being marketed by Messrs Clement Clarke, Limited, 16, Wigmore Street, London, W 1

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OBITUARY

DR. EUGENE G WISEMAN 1885 - 1967

Dr. Eugene Wiseman, 81, Buffalo, New York died during August. He was one of the founders of the Academy and was elected its second president in 1923, serving until 1927. He practiced optometry in Buffalo for nearly 60 years Dr. Wiseman also served as president of the Buffalo Optometric Society and vice-president of the A O.A He made many contributions to the literature and his outstanding work *Building Optometry* was one of the early practice building books that ran into many editions and had marked effect upon the profession.

CAREL C. KOCH

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Technology and the prevention of blindness

by Mr C H Bedwell
Department of Ophthalmic Optics

Mr C H Bedwell describes a new instrument, the Visual Field Analyser, developed with Mr A I Friedmann* of the Royal Eye Hospital. This new instrument, for the early detection of loss of vision, allows, for the first time, a sensitive, yet speedy, quantitative assessment of visual loss over the central field of vision, under controlled conditions. It is suitable both for professional clinical use and in visual and medical mass-screening surveys by technicians.

Just as our eyes and vision provide our main link with the world around us, so does any anomaly of the eyes or vision often provide the first indication of a serious pathological condition lurking in us. It is interesting but somewhat sinister that considerable parts of the vision of the outside world can be lost (called loss of field vision or visual loss) without the subject noticing. This may seem odd, until one realises that the presence of the physiological blind spot is not normally obvious, and does not appear as a black spot superimposed on our field of vision. Early detection of visual loss, both as part of routine eye examination and during a medical screening, is therefore of vital importance.

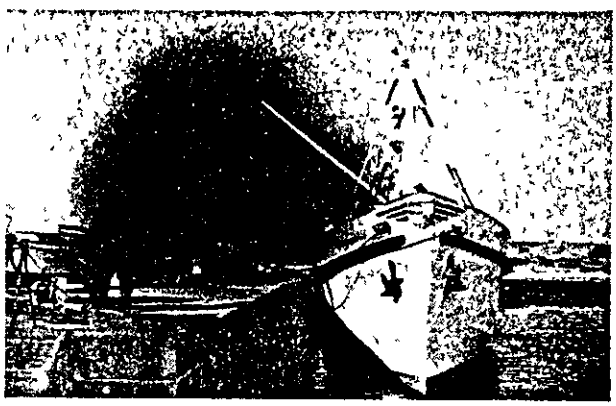
The first case is a typical instance where a serious condition would have passed undetected, until a much later and more serious stage, had not a visual field examination formed part of a routine eye examination. The other illustration shows what can happen if this aspect of examination is neglected.

Mrs J had come for a routine examination for a new pair of spectacles.

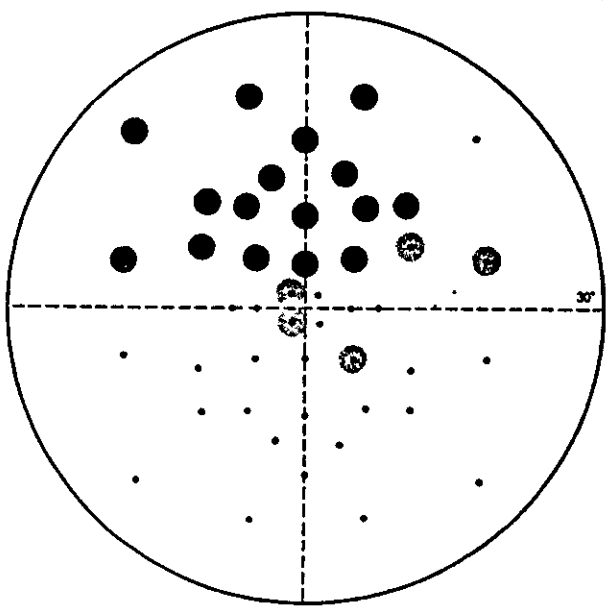
She had not realised that a considerable loss of vision had developed—this was because it had come on slowly, and had not yet affected her central vision.

It was in fact a case of simple chronic glaucoma. This is an insidious condition where there is an obstruction of the outflow of the aqueous fluid produced in the eye, causing higher internal pressure and consequent atrophy of the retinal nerve fibres—the sensitive 'seeing' layer of the eye. The resultant loss of vision is irreversible. (Note—In this and subsequent illustrations, loss of vision is shown relatively,

Mr C H Bedwell is a Lecturer in the Department of Ophthalmic Optics



1 Mrs J's visual loss superimposed on a view seen by her right eye.

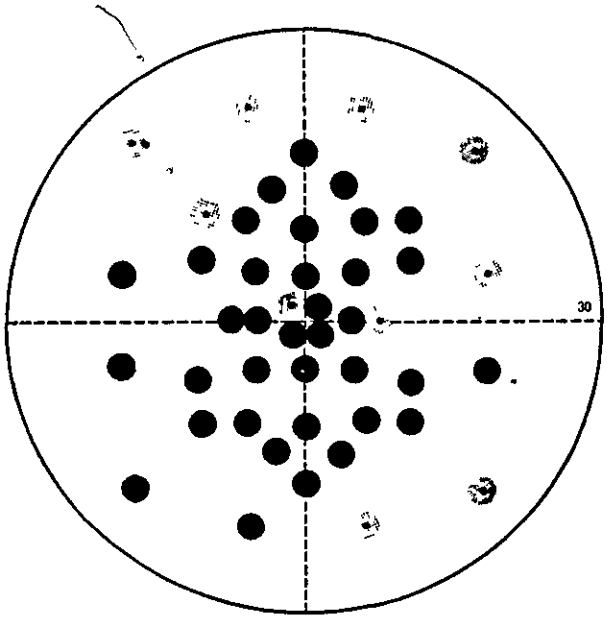


2 Mrs J's relative visual loss assessed quantitatively by the Visual Field Analyser over the central field of her right eye. The vision is within normal limits over the other points examined.

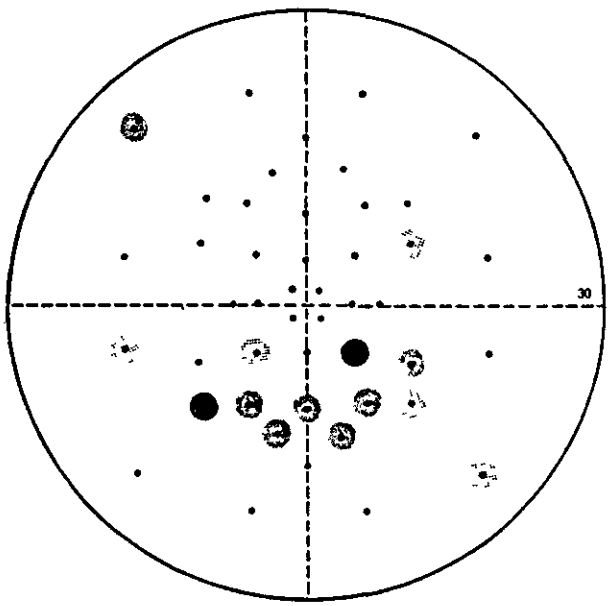
rather than in numerical log units, as in normal clinical practice)

Mr D, aged 42, came for an eye examination because he was

* Mr A I Friedmann, FRCS, Reader in Ophthmology. The Royal College of Surgeons, London, with whom the author jointly developed the Visual Field Analyser from an original design of Mr Friedmann's



3 Extensive visual loss due to glaucoma in Mr D's right eye



4 Visual loss commencing in Mr D's left eye

during the last two years. When examined previously he had worried that the vision in his right eye had become worse been told that the slight blur in his vision was 'nothing to worry about'.

This was also due to glaucoma and if his visual fields had been examined previously as a routine it is unlikely that the condition would have been left undetected. His sight in this eye would then have been saved.

Visual field examination

When we look straight ahead at an object we are vaguely aware visually of objects seen out of the 'corner of the eye'. Also, in a normal person, there is a large central area over which the fields of vision of both eyes overlap. Unfortunately early visual loss does not often occur over the point of immediate central regard, but in the more peripheral areas of vision. Because of these factors, we are not, therefore, usually aware of gradual encroaching visual loss until it has become serious, and involves central vision. Unfortunately, too, when we lose vision in this way it is usually a permanent loss. In some cases the primary cause may be in the eye itself, or, in others, a manifestation of a serious cerebral new growth in the brain. In many cases blindness will result unless treatment is instituted at an early stage.

The classical method of examination of the central visual fields is for the patient to look at a white spot at the centre of a black screen, and for the examiner to move in a white stimulus on the end of a wand, until the patient says he can just see it. Though some aspects of this investigation of the visual fields have been instrumented, and made under more controlled conditions, it is still a laborious procedure and requires skill and knowledge on the part of the examiner.

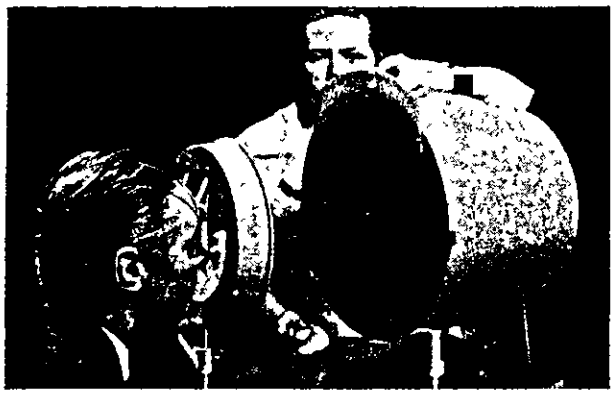
Since 1950, attempts have been made to design instruments employing patterns of stimuli which can be exposed in sequence, to enable the more rapid screening of the visual fields. Unfortunately, because of inadequate control of variables, and no provision for quantitative assessment, these attempts have not proved very satisfactory.

The Visual Field Analyser

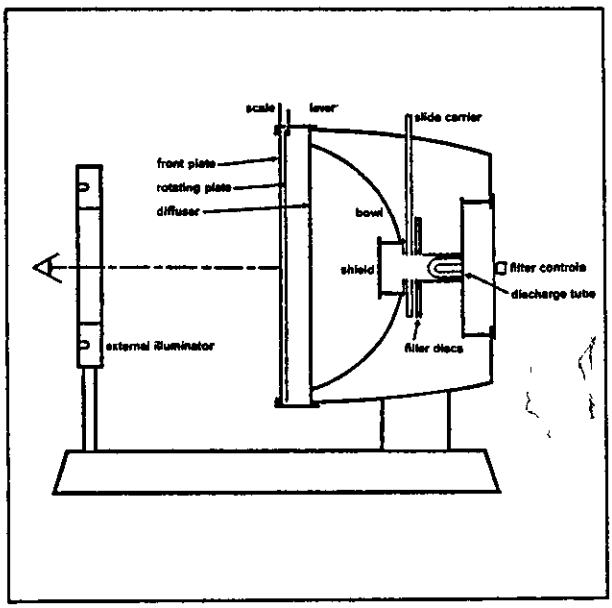
It was felt that the main clinical need was an instrument which would detect and record quantitatively any reduction of visual function present in the central field of vision, but which would reduce to a minimum over-referrals because of inadequate allowance for physiological variations in individuals. Carefully chosen multiple patterns of stimuli are presented in sequence to the eye, under controlled conditions of adaptation to light, stimuli brightness, and duration of exposure Any visual loss detected can be recorded quantitatively An assistant can quite easily screen sensitively the visual fields of both eyes in approximately 1¼ minutes, after simple instruction. There is no need to resort subsequently to laborious classical methods of visual field investigation.

To achieve these aims, considerable experimental work was necessary to ensure, for example, that allowance was made for difference of response over different areas of the retina Again allowance had to be made for the deterioration of threshold contrast with age, so that the correct setting of stimuli brightness could be made for different age levels. It was also necessary to determine how much change in threshold contrast could be regarded as being within normal physiological limits, and how much should be regarded as abnormal To provide these data, large numbers of patients had to be examined using prototypes of the instrument, and comparing the results with existing methods.

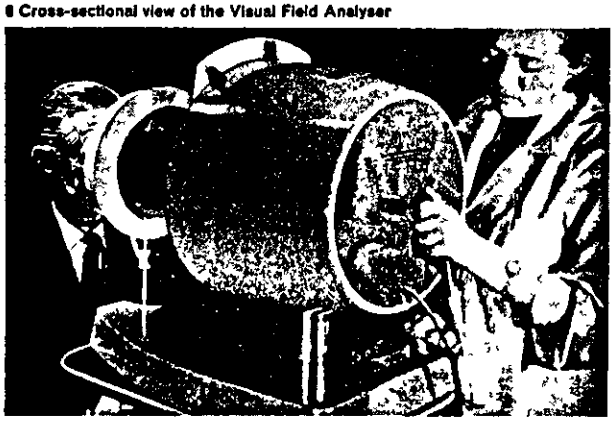
It was also felt desirable to incorporate in this instrument facilities for the early detection of the loss of central vision.



5 The Visual Field Analyser being used as part of the clinical routine in The City University's Ophthalmic Clinic



6 Cross-sectional view of the Visual Field Analyser



7 Rear view of Analyser

The instrument can also be used for assessment of dark adaptation for the early detection of conditions exhibiting an initial night blindness. Additional adaptors are also being developed, for example, to enable the use of a single stimuli where very detailed analysis is required.

The design of the Visual Field Analyser

Essentially the instrument consists of a base which carries the main body of the instrument, with means of presenting small light stimuli to the eye, and an external illuminator to provide controlled adaptation of the eye to light during the investigation. In order to construct a compact instrument, advantage was taken of the fact that, with small stimuli employing a short duration of exposure, a viewing distance of one-third of a metre could be employed. The main body of the Analyser carries the front-plate assembly and indexing system, in order to expose fifteen patterns of stimuli in sequence. The patterns were carefully selected so that an adequate number of stimuli could be exposed over the areas of the central visual fields most likely to exhibit early loss, and yet provide general coverage over the whole central field. For example, the area 10–20 degrees above and below the centre of fixation, is a critical area for early visual field loss in glaucoma, the most common ocular condition exhibiting visual field loss. Allowance, too, had to be made for individual variations in the position and size of blind spot to avoid unnecessary referrals.

The fixed, matt black, front plate carries the forty-six apertures necessary to produce the fifteen patterns of stimuli. These are exposed successively by moving the index lever which rotates the rear plate. The individual pattern, and the number of stimuli in each pattern, are indicated on a translucent scale illuminated by light from the external illuminator. The operator can then know immediately whether the patient can see the full numbers of stimuli in each pattern.

Stimuli illumination

To avoid the variations in stimuli brightness which could occur if individual lamps were employed for each stimulus, a single xenon discharge light source is used to illuminate all the apertures. A constant quantity of light of a quality approximating to that of natural daylight is therefore produced on each discharge. To ensure long life the tube is considerably under-run. The stimuli brightness can be varied, without alteration to spectral quality, by using neutral density filters. These are in two additive sets, from 0 to 4 8 Log Units in steps of 0 2. The filters are controlled by knobs at the rear of the instrument, indication being both by illuminated dial and click stops

The front plate assembly carrying the stimuli apertures is evenly illuminated by means of a bowl integrator, in the form of a hemisphere, painted matt-white inside, across the front of which is a diffuser of opal plastic. Placed between the rear opening in the bowl and the front diffuser, is a matt white circular shield, the purpose of which is to allow inter-reflection, but to prevent light from being transmitted directly onto the front. By this means a uniform brightness can be obtained over the whole surface of the diffuser at the front of the bowl. Though this requirement necessitated considerable experimentation, it was important to design the instrument so that apertures could be designed which initially presented to the eye stimuli of similar light output, on which could then be superimposed variations dictated by local retinal sensitivity. The xenon flash tube is placed behind the aperture in the rear of the hemisphere, with the two sets of neutral density filters operating in between. A slide carrier is also incorporated, which enables coloured and/or auxiliary neutral density filters to be used.

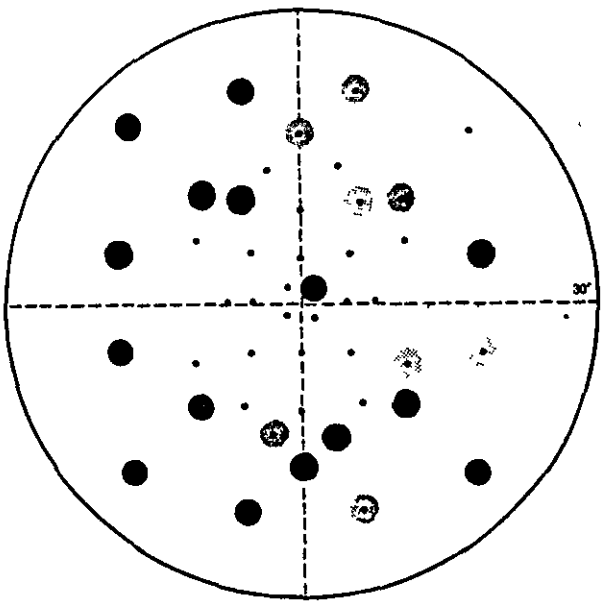
The control of light adaptation

Various investigators, including the designers, have found that, at least for glaucoma detection, visual field defects in their early stages can best be demonstrated by employing a level of adaptation as near as possible to that of twilight (mesopic) vision. This allows a more satisfactory investigation of both rod and cone light sensitive receptors in the retina which are operative at night time and in the day time respectively. By using a material of a low reflection factor for the front plate, it has been possible to approximate this condition, and yet allow reasonable clinical working levels of illumination provided by the front illuminator.

The clinical use of the Visual Field Analyser

As the state of adaptation of the eye has a marked effect on threshold contrast, it is desirable that the Visual Field Analyser be used in as dark a room as possible using only the light provided by the external illuminator. As threshold contrast gradually deteriorates with age, allowance is made for this factor by setting the neutral density filters to the correct age group of the patient. One eye is occluded, and the head suitably positioned so that the patient's other eye is at the centre of the illuminator. The patterns are then exposed in turn, and the patient requested to state the number of stimuli that he sees in each case.

Considerable clinical trials have shown that if any of the stimuli missed at the age level setting are seen at a brighter setting of 0.2 log units less than the normal for age, their response can be regarded as within physiological limits. If, however, stimuli are not seen within 0 4 log units of their age setting, their response can be regarded as abnormal. If any stimuli are missed at this setting, the filter setting is reduced by another 0.4 log units, and this level recorded if they can be seen. The process is repeated until the brightest setting has been reached, which would indicate a very marked visual loss. From the completed composite chart, the position, extent, and depth of any field defect present can be assessed, and its significance determined. The assessment is quantitative, and



8 The relative visual loss in Miss T's right eye

the extent of visual loss can be compared at intervals, using different operators, and in different units, if necessary.

As an interesting final illustration of the Visual Field Analyser in use, let us consider the following case. Miss T, aged 46, was referred by her local doctor for an eye examination because she was complaining of very slight blurring of vision for reading in her right eye, and had been experiencing headaches recently.

Though she appeared otherwise to be within normal ocular limits, an extensive mid-central visual field loss was detected in the right eye on the Visual Field Analyser. After considerable investigation, an extensive new growth of the meninges lining of the brain was found. This new growth was successfully treated by surgery and radiotherapy, but it was a year before she was able to return to her office. If the condition had been left undetected much longer, the consequences would have been tragic.

This instrument is now being employed in this country and in many parts of the world, and results have indicated that it tends to be more sensitive than classical methods of detecting visual loss, in addition to being much quicker in use. By paying attention to the main variables concerned in visual field investigation, it has been possible to keep to a minimum unnecessary referrals, and yet allow early detection of visual loss. By this means sensitive visual field screening can be incorporated as part of an ophthalmic and medical screening routine, without overloading specialist clinical investigation units. For example, this instrument is now being employed in automated medical screening centres.

In this article the author has attempted to show the value of co-operation between those of different disciplines, experience, and skills, and of collaboration with industry, in the common interest of applying technology to the service of mankind.

The author would like to acknowledge the helpful co-operation of Mr A I Friedmann in this joint project, and of Messrs Instrumedic Ltd in the design and construction of prototypes Thanks are due also to the staff of the Ophthalmic Department, including Mr C Longhurst and Miss S Johnson, and Mr C Wilson, the Departmental Photographer, for assistance in the preparation of this article.

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THE APPLICATION OF FLASHING LIGHT STIMULI TO THE DETECTION AND QUANTITATIVE ASSESSMENT OF EARLY PATHOLOGICAL VISUAL LOSS

C. H. BEDWELL

The City University, London.

INTRODUCTION

Most people are usually aware if there is any reduction of immediate central vision in either eye, whereas any visual loss outside this small central area usually passes unnoticed unless it happens to be very extensive. If detected, however, reduction of vision in the periphery is often the first sign of some serious pathological condition. Typical instances are glaucoma, where there is gradual atrophy of the retinal nerve fibres, or a cerebral new growth. Unfortunately these visual losses are usually progressive and irreversible, and blindness, or possibly death in the case of a brain lesion, can result.

Early detection of visual loss, both as part of a routine eye examination, and during a medical screening, is therefore of vital importance. Classical methods of visual field investigation are laborious and time consuming, require knowledge and skill on the part of the investigator, and are unsuitable for routine screening.

In the last 15 years attempts have been made to devise instruments employing multiple patterns of light stimuli as a method of screening for visual field defects.[1,2,3,4] In this technique, a series of patterns of spots of light are presented to the patient in sequence, and he is asked to indicate whether he can see them correctly. Unfortunately, such methods have been relatively unsophisticated, with inadequate control of variables. As a result, the test is either too insensitive to be safe, or results in a high proportion of over-referrals, which then have to be investigated by formal classical techniques.

THE EMPLOYMENT OF FLASHED STIMULI FOR VISUAL FIELD INVESTIGATION

Classical methods of visual field investigation require the patient to fixate centrally a small white target, and then to say when he can just see a small white stimulus on the end of a wand, which the examiner moves gradually from the periphery to the centre of a screen, arc or bowl. This method of kinetic visual field investigation is usually under-

taken with very little control of variables, and its effectiveness depends very much on the skill and knowledge of the examiner. In static perimetry, a stimulus is placed in different parts of the visual field, and then its size or luminance adjusted until it can just be seen. This technique is commonly employed with bowl perimeters, where better control of adaptation and stimuli luminance and size is possible (see Plate 2).

In instruments employing multiple patterns of stimuli, these are presented to the eye in sequence over the visual field, with two, three, or four, stimuli exposed at a time. Unfortunately, because of inadequate control of the variables involved, and lack of provision for quantitative assessment of any visual loss, these earlier attempts have not proved very satisfactory.

If a visual field screening instrument is to be designed so that it is adequately sensitive, yet avoids unnecessary referrals for further investigation, and the investigation is to be complete in itself, a number of factors need to be considered and allowed for. For instance, for a given retinal location and state of adaptation, the visibility of a stimulus will depend on its area and luminance, and also, within limits, on the duration of exposure. The location on the retina of the image of the stimulus will determine the type, or types, of receptors stimulated, their density, and the density of the ganglion cells to which they are connected. Therefore, if a given stimulus is to be just visible, retinal location will affect stimuli specification because of these receptor variations, and because of the summation effects produced by their interconnections.

In addition to these general physiological effects, there are also some differences in visual responses between different individuals, variations in minimum discernible luminance difference being relevant to our present considerations. This function is also affected by observer age, in such a way that stimuli luminance needs to be increased with age.

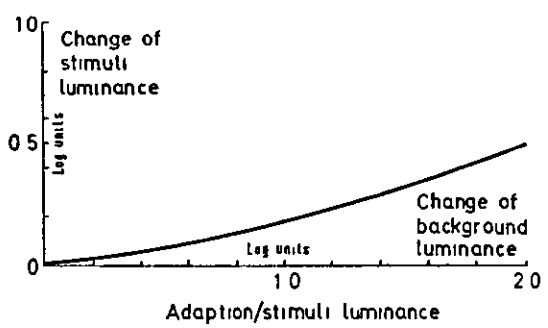

FIG. 1. Adaptation and stimuli luminance (approximate relationship over the central field).

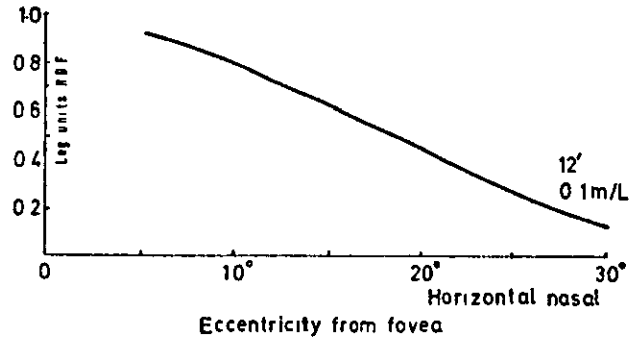

FIG 2. Stimuli luminance and eccentricity from the fovea for a stimulus subtending 12′ at the eye and for a background luminance of 0·1 millilamberts

If, therefore, predetermined settings for the variables concerned are to be used in a visual field screening instrument, it is necessary to know what tolerances can be regarded as being within physiological limits both for an average subject, and for subjects in different age groups. When these data have been obtained, it is then necessary to know what degree of reduction in vision is to be regarded as abnormal, and thus indicating a pathological change.

THE DESIGN OF A CLINICAL INSTRUMENT EMPLOYING FLASHED LIGHT STIMULI

Light adaptation and its control

It is possible to investigate visual fields under different adaptation levels, but clinical research, e.g., Marlowe,[5] Jayle and others,[6,7] Endo,[8] and individual clinical work by Friedmann,[9,10] and also by Bedwell,[11,12] have indicated that, at least in the case of glaucoma, visual field defects appear to be demonstrated earlier when levels of adaptation as near as

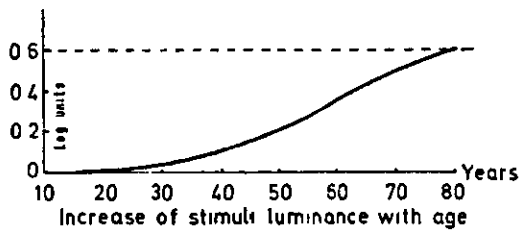

FIG 3 Increase of stimuli luminance with age for short duration of exposure of stimuli 200 μs)

possible to the mesopic state are employed. In this way, examination may be carried out under conditions of similar sensitivity for both cone-type and rod-type receptors. (It must be remembered that, outside the immediate central or macular area, the rods are the most dominant type of receptor.) Because the needs of clinical practice make it difficult to allow very long dark adaptation, an adaptation level of approximately 0·1 millilamberts (3·18 candelas/m^2) appears to be a suitable compromise. The illumination for this adaptation is provided in the case of the Visual Field Analyser by a separate external illuminator, which provides an illumination of 10 lux on a black screen.[9,11,12] This screen contains the apertures for the stimuli, and has a reflection factor of approximately 10 per cent (see Plate 3)

The light source

Unlike previous attempts in this field, the present apparatus uses a single light source to illuminate the stimuli, which are exposed through apertures in the front plate assembly. All the stimuli are contained in the front plate, and presented in sequence by rotation of a rear plate. By this means variation between individual light sources is avoided A xenon electronic discharge lamp was chosen as the light source, because it gives light of a spectral quality approximately equivalent to daylight, has a very long lamp life when under-run, and emits a reasonably constant amount of light.

The short exposure of the stimuli, in this case approximately 200 μs, helps to ensure that the pupil size is largely dependent on the adaptation level employed, and is not affected by exposure time. In addition, the short exposure of the stimuli reduces the problem of wandering of fixation during the test, and greatly facilitates the examination of cases with lenticular changes and reduced visual acuity.

Stimuli illumination

The visual field extends, in its extreme, to about 60° eccentric from the fovea, except on the temporal side where it goes out to slightly beyond 90°. If the investigation is sensitive, the more common conditions for which visual field screening is desirable usually produce defects within 25° eccentric from fixation. For this extent of field, it is possible to employ a flat screen, making instrument construction easier Also the greater the eccentricity of the visual field investigated, the greater are the individual variations in minimum discernible luminance difference, and the more difficult it becomes to use sensitive predetermined settings, and at the same time avoid too many unnecessary referrals.

If a single source is employed for stimuli illumination, an initial uniform luminance has to be provided behind the apertures of the front plate assembly over this 50° field. To achieve this, an integrating

PLATE 3. The visual field analyser in clinical use (*see page* 64).

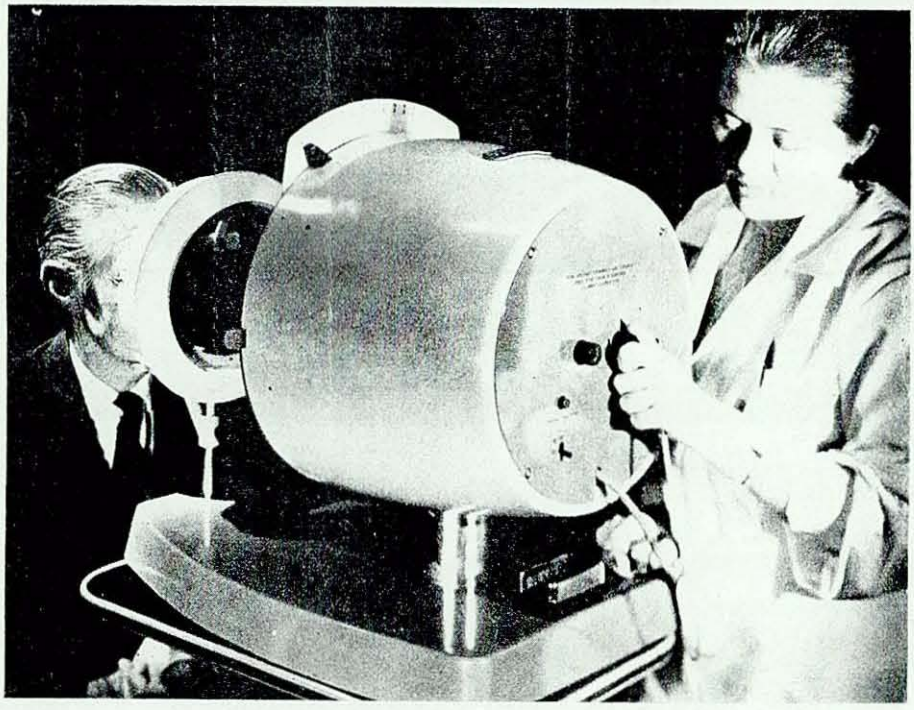

PLATE 4. Rear view of visual field analyser (*see page* 65).

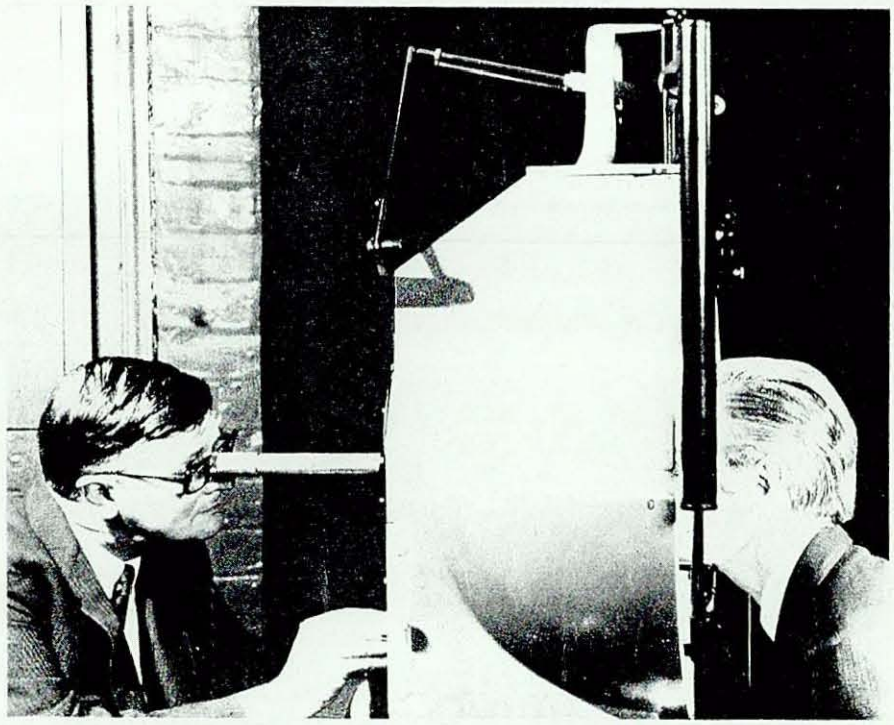

PLATE 2. The Goldmann Haag-Streit bowl perimeter (*see page* 62).

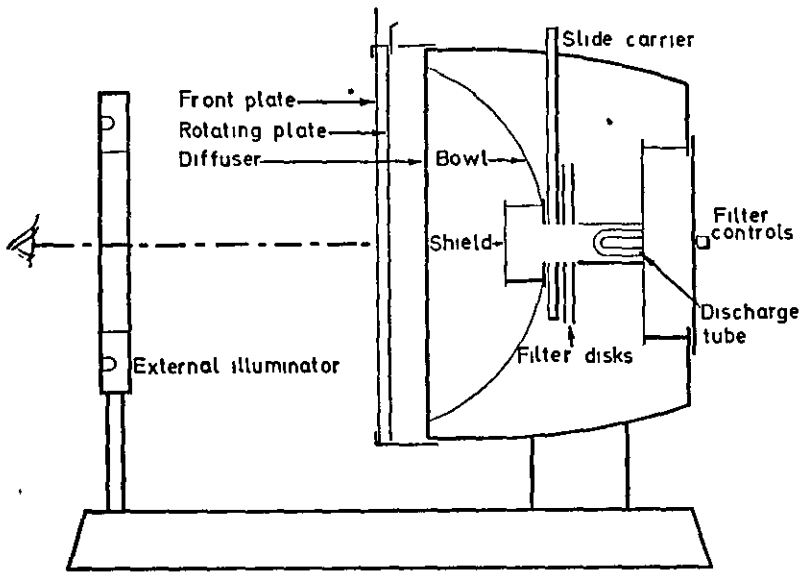

FIG. 4. Cross-section view of the visual field analyser.

hemisphere is used, with the light entering the bowl at its rear. The light output from the discharge lamp is kept constant, but the light input to the bowl, and hence the illumination of the stimuli, is controlled by employing neutral density filters, these being held in two disks controlled by knobs at the rear of the instrument. These filters provided a variation from 0 to 4·8 log units, in steps of 0·2 log units (Plate 4).

For a given adaptation level, visibility of the stimulus will vary according to the retinal location of the image [13,14] It was therefore necessary to determine, for a reasonable number of individuals, how much tolerance should be allowed for physiological factors, so that when a final plate was made, all the stimuli provided approximately the same minimum discernible luminance difference for a normal individual. A guide to the necessary tolerance was provided by regarding the eye as responding approximately linearly to logarithmic changes of stimulus area.

The actual placing of the patterns was determined largely by the requirements of the most likely areas in which visual field defects were likely to be found. For example, in the case of glaucoma, an important area is that represented by the arcutate nerve fibre bundles, approximately 10–20° eccentric above and below fixation. In the case of cerebral lesions, reduction of vision on either side of a vertical line through fixation

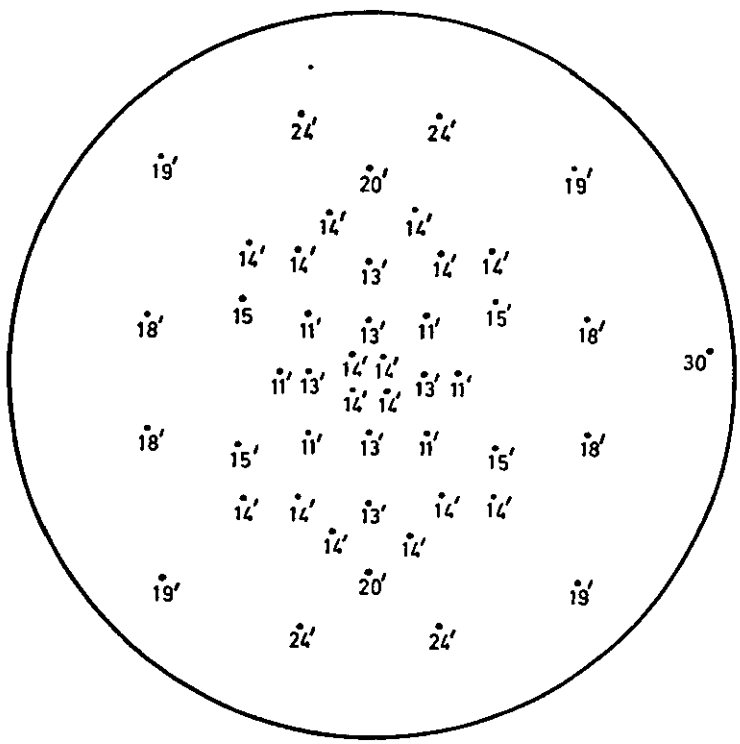

FIG 5. Subtense at the eye of stimuli of similar luminance that give approximately the same minimum discernible luminance difference for an average observer, for a background luminance of 0 1 millilamberts

is particularly important. In some areas of the retina, for example, around and just temporal to the blind spot (representing the optic nerve), there are greater variations in visibility. Therefore caution must be exercised in placing the stimuli near these areas; otherwise unnecessary referrals from false positives can result.

Differentiation between the normal and the abnormal

Before considering what minimum discernible luminance difference might be regarded as abnormal, and therefore of pathological implication, it is necessary to obtain average results for different normal individuals in different age groups, and the normal spread above and below these figures. In terms of logarithmic units of luminance difference, this appears to be approximately ± 0.2 log units of the

average value of neutral density filter at which all patterns can just be seen. In some local areas, such as the field temporal to the blind spot, the variations can be slightly greater. However these areas involve only a small part of the visual field up to the 25° eccentric isopter, and are therefore of less clinical importance in this case.

With increase of age, from 40 to 60 years, there is an average decrease in minimum discernible luminance difference of 0·6 log units, for these short duration stimuli. Therefore the curve of age against neutral density filter setting (to give a satisfactory setting for minimum discernible luminance difference for age) needs to be placed just below the lower limit of these results, otherwise too many unnecessary referrals will result. Some good observers, however, may be able to see all the patterns of stimuli using a 0 2, or possibly 0·4, log unit neutral density filter setting greater than the average for age setting. In these cases a setting of 0·2 log units, or in a few cases 0·4 log units, dimmer

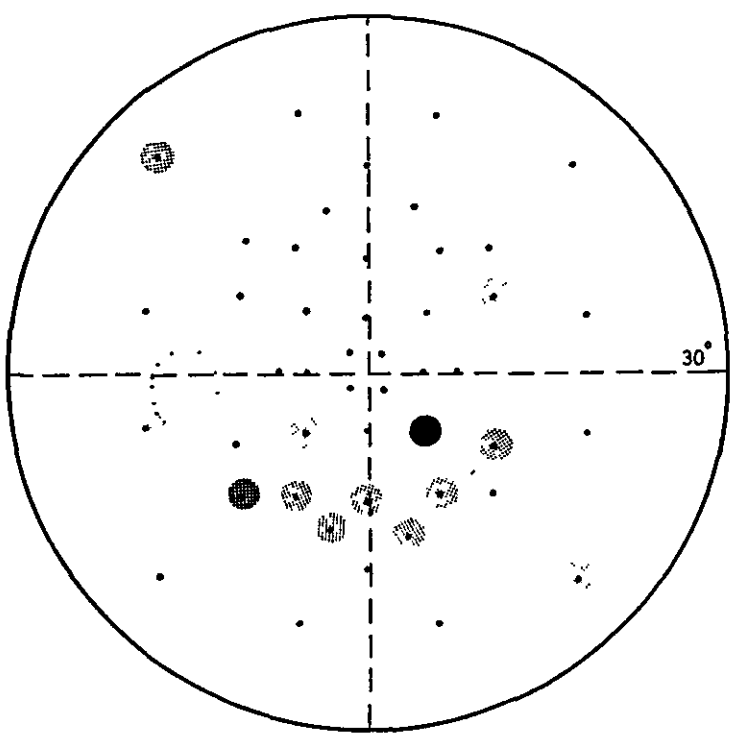

FIG. 6. Typical case history of early relative visual loss in glaucoma (Mr D., left eye, age 42; V.A 6/7 5. C H B.) Stimuli not marked seen at 1 8 N D F.

than the normal can be used, though it is still relatively safe clinically to screen at the recommended age/N.D.F. setting.

To determine the significance of reduction of minimum discernible luminance difference in terms of possible pathological visual loss, large numbers of patients have been investigated over a period of several years, initially by Mr Friedmann at the Royal Eye Hospital, on prototype instruments under normal clinical conditions. In the earlier stages patients were examined by classical techniques, in addition to the Visual Field Analyser, to obtain comparative data. Latterly a considerable number of instruments have been in use in different parts of the world, and results in general appear to indicate that this method can be more sensitive than classical methods of visual field investigation.

Where stimuli cannot be seen within 0·4 log units of the age/filter setting, the response can be regarded as abnormal. If there is a patho-

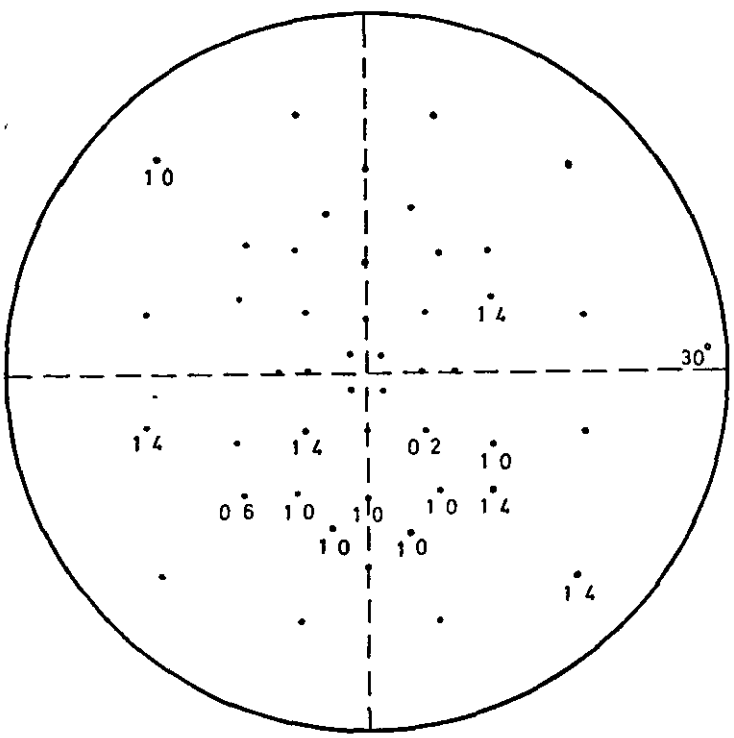

FIG. 7. Visual response in Fig 6 in terms of neutral density filter log units at which the stimuli can just be seen. The response is normal for age at the unmarked points (Mr D, left eye, age 42; V.A 6/7 5 C H B) Stimuli not marked seen at 1 8 N D F.

logical condition producing the visual loss, it is usual to find that vision will be depressed over a number of stimulus positions, and that the shape of the loss will tend to be indicative of a certain type of field defect. If stimuli cannot be seen at the brightest setting on the Visual Field Analyser, a dense visual loss is indicated.

Use of the Visual Field Analyser makes routine visual field examination a possibility; it can also provide a quantitative record of any visual loss, which is available for comparison at any times and to different investigators.

ACKNOWLEDGEMENTS

The author would like to acknowledge the helpful cooperation of Mr A. Friedmann (The Royal Eye Hospital, London) in the joint development of the Visual Field Analyser from his original design, of Clement Clark Ltd, in the construction of prototypes, and of the staff of the Department of Ophthalmic Optics of the City University for assistance in the preparation of this paper.

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Factors affecting the detection of early visual loss

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ABSTRACT

Results are discussed of original research on the effect of the main variables involved in the detection of early visual loss in the central field, with particular reference to the use of flashed stimuli of short duration of exposure (approximately 200 microseconds)

The importance of retinal adaptation, stimulus size, luminance, and retinal location is discussed, together with the effect of age Variations in visibility, that can be regarded as within physiological limits, are indicated.

Charles Bedwell is at present writing a book on Visual field investigation to be published by Butterworth & Co (Publishers) Ltd, London.

The importance of detecting early visual loss is generally realised, particularly in relation to such conditions as glaucoma and cerebral lesions, where the damage may be considerable and irreparable if the condition is unnoticed. There is, therefore, a considerable clinical need for incorporation in a routine eye or medical examination of a rapid yet sensitive method of visual field investigation It should detect these early changes, and yet avoid too many unnecessary referrals

Classical methods of visual field investigation require skill on the part of the investigator, and are laborious and time-consuming. In consequence, various attempts have been made to design instruments which could be used to screen the visual fields, eg Harrington and Flocks[1] and Fincham and Sutcliffe[2]. Unfortunately these attempts have only been of limited value, because there was inadequate control during the examination There was no quantitative assessment of visual loss, and no data available as to what changes could be regarded as being within physiological limits, and what would be regarded as abnormal In addition, if any defect was found, it was necessary to resort to the ordinary classical methods of visual field investigation afterwards

To fulfil the need for improved instrumentation the Visual Field Analyzer was developed, Friedmann[3], Bedwell[4] In this instrument, figure 1, a multiple-pattern stimuli technique of static perimetry is employed, the stimuli being illuminated by a xenon discharge light source, using a short duration of stimuli exposure (approximately 200 microseconds). The adaptation level is controlled, the stimuli varied according to the requirements of retinal physiology, and the visual loss assessed quantitatively in logarithmic units.

Though experimental work has been undertaken on the visibility of flashed light stimuli, eg Davy[5], this appears to be the first time that such a light source has been used for clinical visual field investigation. It was therefore felt desirable to produce a separate paper giving details of basic research on the visibility of such stimuli, as well as on various aspects of visual field examination in general.

Adaptation of the eye

During the visual field investigation, the general adaptation of the eye is controlled by the light reflected from the background screen, the examination normally being carried out in a dark room.

Even when considering the central fields of vision, up to say 30° eccentric, it is largely the response of rod-type receptors which is being examined. Various workers[3, 4, 6, 7, 8, 9] have found that, at least in the case of glaucoma, visual field defects are more likely to be exhibited in their early stages, if the examination can be conducted using levels of adaptation near to the mesopic state In the investigations with which I was concerned, a level of adaptation of approximately 0 1 millilamberts (0 3 candelas m^2) was chosen as being a clinical compromise near to the mesopic level, without allowing an undue period for dark adaptation. Figure 2 shows an average relation between adaptation and stimuli luminance for these flashed stimuli.

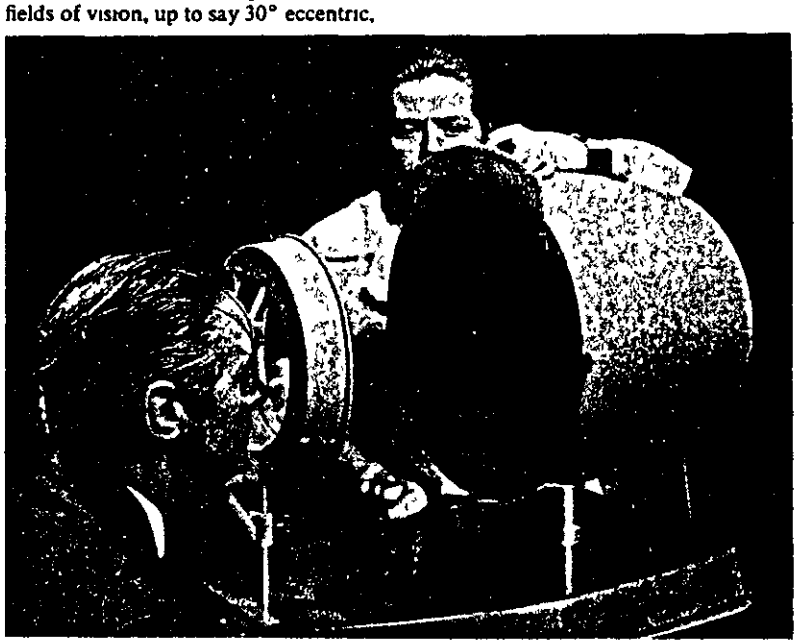


Fig 1 The visual field analyzer in clinical use

Detection of early visual loss

Stimuli size and luminance

In visual field investigation, one is actually examining rather minimum discernible luminance difference than visual acuity The eye appears to respond approximately linearly to logarithmic changes of stimulus area and stimulus illumination, figure 3* Thus equal logarithmic changes of stimulus area give approximately equal isopter intervals over most meridians. However, a change in the level of background luminance may result in a higher rod and/or cone activity, which can upset this regular spacing of isopters, figures 4(a) and 4(b) particularly when the effect of adaptation on summation tends to be critical, Obstfeld[10], and Bedwell and Obstfeld[11]

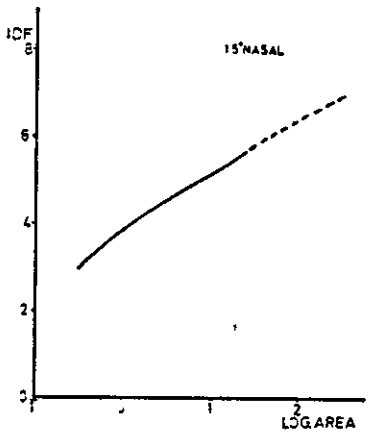
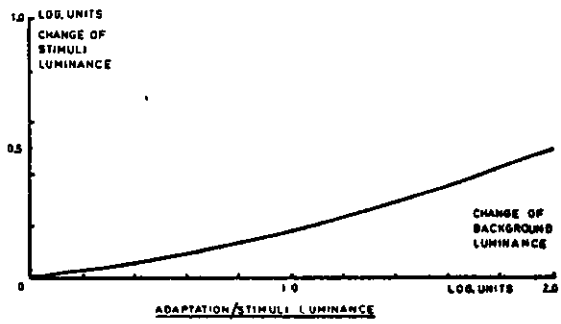


Fig 3 Log stimuli area (2 mm). Relative stimuli luminance (NDF) for an average young observer

* *In this and subsequent diagrams NDF* represents the neutral density filter (in log units) for threshold visibility of the stimulus for the adaptation used.

Fig 2 Adaptation and relative stimuli luminance (Approximate average relationship over the central field)



Duration of exposure of stimuli

Within certain limits, for a short duration of exposure, and for a given level of adaptation, and over a given retinal area, the visibility of a stimulus depends on its total luminous energy content (ie size, intensity, and duration of exposure). In the case of static perimetry, it is possible to control all these variables, and therefore more readily obtain a quantitative assessment of any reduction of vision.

If the stimulus exposure is sufficiently short, the pupil size will be dependent on the adaptation level, and will be unaffected by the stimulus exposure In addition, a flashed stimulus allows better control of fixation during the visual field examination, makes examination of cases with lenticular changes easier, eg figure 5. It is also possible to use shorter working distances, and more compact instrumentation, compared to classical methods involving constant stimulus exposure

In the present research, a xenon electronic discharge light source was employed. This has a relatively short duration of exposure—in this case approximately 200 microseconds This lamp was chosen for the Visual Field

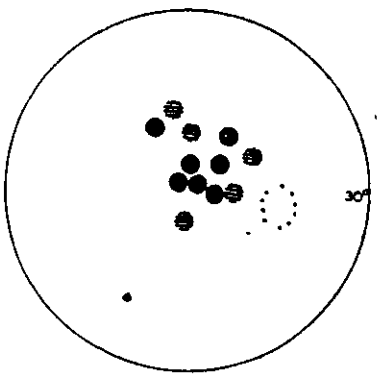


Fig 5 Visual field analysis showing relative visual loss in a case of lenticular change where the fundus was obscured Mrs B., age 80, right eye, VA 1/60, CHB. Solid black circles represent a dense visual loss and cross-hatched circles represent a relative loss of 0.8 log units. Otherwise, stimuli seen at 0.8 log units NDF

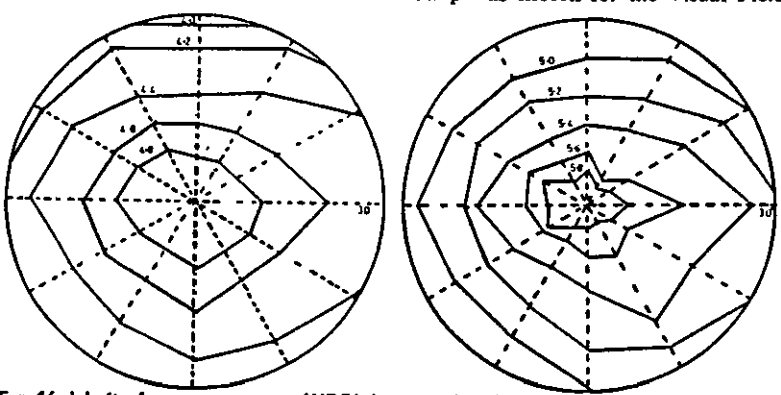


Fig 4(a) Left. Average isopters (NDF) for stimuli subtending 24' at the eye and for a background luminance of 15 millilamberts showing approximately equal spacing Fig 4(b) Right Average isopters (NDF) for stimuli subtending 24' at the eye and for a background luminance of 0.1 millilamberts showing unequal spacing

Analyzer, as the spectral emission approximated that of daylight, the light output could be kept fairly constant, there was less variation of light output with voltage change compared with tungsten light sources, and a very long lamp life was possible, especially if the tube was under-run

The total light output from the flash tube will depend on the integrated area, under the emission curve, that relates period of flash to intensity at a given instant. As the light output of the tube is a function of the electrical energy input, the latter will be a function of the capacity of storage condenser used, and the square of the applied voltage It is, therefore, possible to approximate similar light output with condensers of different capacitance, using the appropriate voltage. There are, however, limits imposed in the choice of these quantities in the design of any given instrument Though the total light energy output may be the same, however, the shape of the output curve will be different

Detection of early visual loss

Retinal physiology and stimulus luminance and size

In general, if stimuli presented over different areas of the visual field are to be adequately sensitive in detecting early reduction of vision, it is important that the stimuli are only just discernible over the areas being examined To achieve these results, therefore, allowance must be made for differences in visibility over different parts of the retina, because of variations in retinal physiology

Isopters have been obtained, for minimum discernible difference, for stimuli of different sizes, and for different levels of adaptation, for short periods of stimulus duration, in this case using a xenon flash tube as the source, Obstfeld[10], Bedwell and Obstfeld[11]. The shape of the isopters is in general oval, with an extension on the temporal side of the field (figure 6)

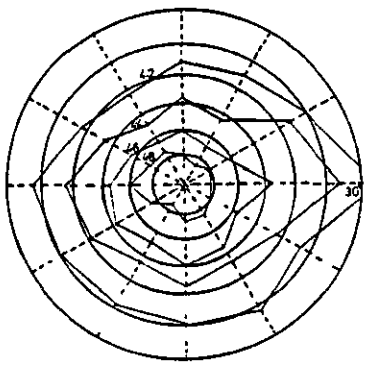
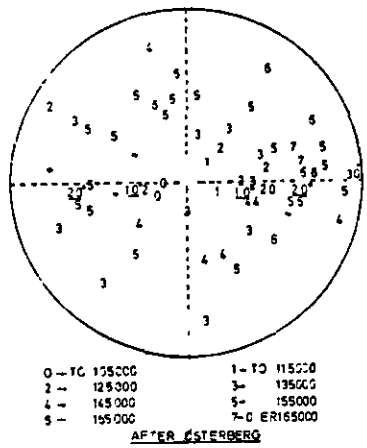
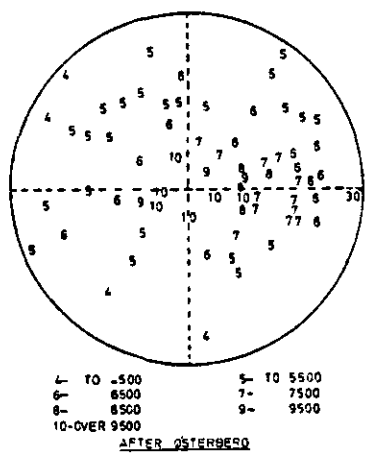


Fig 6 Isopters NDF showing variation in visibility over the central retinal area for a stimulus subtending 12' at the eye using an adaptation level of 0 1 millilamberts

Because of technical difficulties, only a few studies of the receptor and ganglion cell distribution over the retina have been made Population data, however, provided by Osterberg[12], on rods (figure 7) and cones (figure 8) and by Van Buren[13], and by Oppel[14] on ganglion cells (figure 9) will be found to give isopters resembling very much the general shape of the visual field isopters (figure 10) As the adaptation level for the visual field investigation is reduced, the separation between the isopters tends to increase in certain areas These areas tend to be those with the highest population of rod-type receptors and ganglion cells, indicating that summation is playing an increasing role in visibility, within certain limits of stimulus size It so happens that rod population densities are highest in the mid-





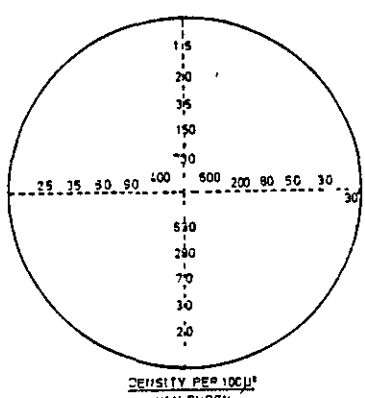


Fig 7 (top) Retinal distribution of rod receptors
Fig 8 (middle) Retinal distribution of cone receptors
Fig 9 (bottom) Retinal distribution of ganglion cells

central field 10-20 degrees eccentric above and below the central fixation point, representing the distribution of the arcuate retinal nerve fibre bundles

Clinical research by a number of workers, eg Aulhorn and Harms[15], has shown that, in about half the cases of glaucoma investigated, visual field defects occur in this arcuate area, either isolated, or connected to the blind spot Therefore, when looking for early glaucomatous field defects in this area, an area of high visual sensitivity is being examined, and any reduction is more likely to be missed in classical kinetic methods of visual field investigation. Though the target may be quite sensitive, for use, say, at 30 degrees eccentric, as it is moved towards fixation, travelling over these more sensitive areas, the test becomes less sensitive for detection of reduction of vision If, therefore, the investigation is to be adequately sensitive, the stimulus must be adjusted in size, or luminance, according to the retinal location being examined (figure 11).

A study of these visual field isopters will also reveal that there tends to be greater variations in the data obtained, between different individuals, in certain areas of the visual field, compared to other areas—in particular the temporal field, and also with generally increasing degrees of eccentricity from the fovea When, therefore, considering the position of stimuli to be employed in, for example, a multiple-pattern instrument, not only must the most likely position of early visual field defects for the more common pathological conditions be borne in mind, but also, the individual variations in minimum discernible luminance difference over the retinal area. Fortunately these two aspects are not irreconcilable clinically, and, therefore, for the central field at least, it is possible to design a series of multiple apertures over most of the visual field that will present approximately the same luminance difference for the average observer.

In general, when deciding on stimulus size, too small a stimulus causes greater problems, (a) due to aberrations from refractive errors, (b) with patients with below normal visual acuity, and (c) because of the presence of small angioscotomata produced by the retinal vessels On the other hand, too large a stimulus does not allow assessment of a deterioration of summation effect, which appears to be an important factor in pathological visual loss

Deterioration of vision with age

It is generally realised that with increase of age, particularly beyond middle age, increasing illumination is required to achieve the same visual performance as a younger person (figure

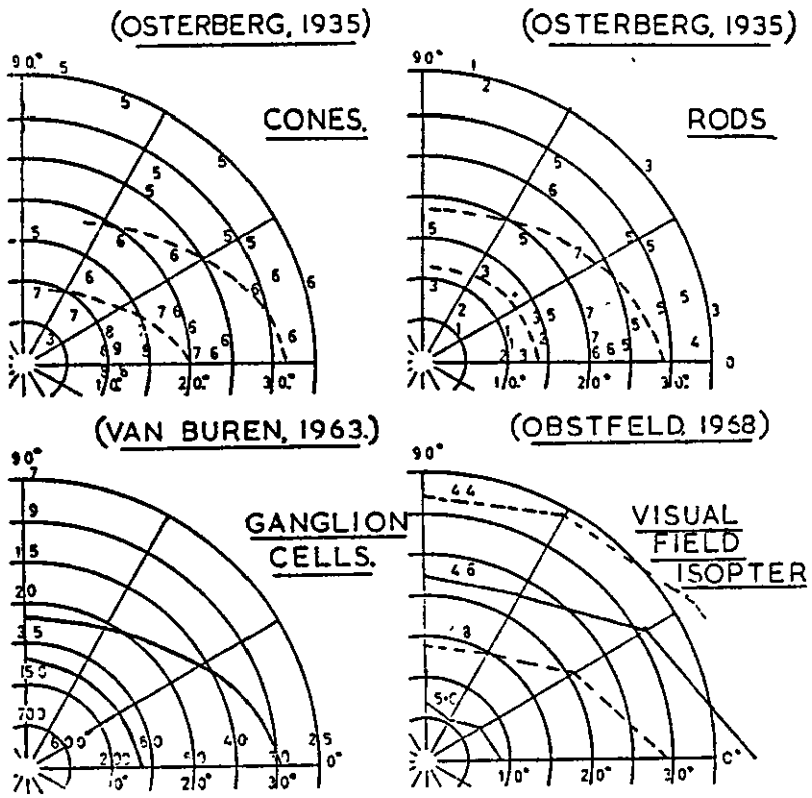


Fig 10 A comparison of receptor and ganglion cell population isopters and visual field isopters of minimum discernible luminance difference Cones x 1,000, rods x 100,000, stimulus size 12', background luminance 1 5 millilamberts, isopters for 4 4, 5 6, 4 8, 5.0 NDF

12). Various workers, eg Friedmann[3], Bedwell[4], Drance[16], and Bedwell and Obstfeld[11], have demonstrated that the visual field isopters decrease in size with increase of age The author has found, for example figure 13, that between the ages of 40 years and 60 years, an average increase of illumination of stimuli of 0 6 log units is required to achieve the same minimum discernible luminance difference.

It is, therefore, very important that during a visual field examination allowance be made for age. If this is not done, the test may not be adequately sensitive for the younger age group—where it is especially important to detect visual loss early—and yet too sensitive for the older patients, with the result that here the number of referrals for further investigation is unnecessarily high

If adequate allowance is made for these factors of physiology and age, it is possible to considerably reduce the number of unnecessary referrals, when a visual field investigation is conducted under controlled conditions, as part of a normal routine eye or medical examination. If, for example, it is found that approximately 2 per cent of all patients screened appear to have a visual field anomaly, when an instrument such as the Visual Field Analyzer is used, approximately 1½ minutes need only be spent examining each of the 98 per cent, with 15 to 20 minutes on the remaining 2 per cent, where a quantitative record must be made of any visual loss present.

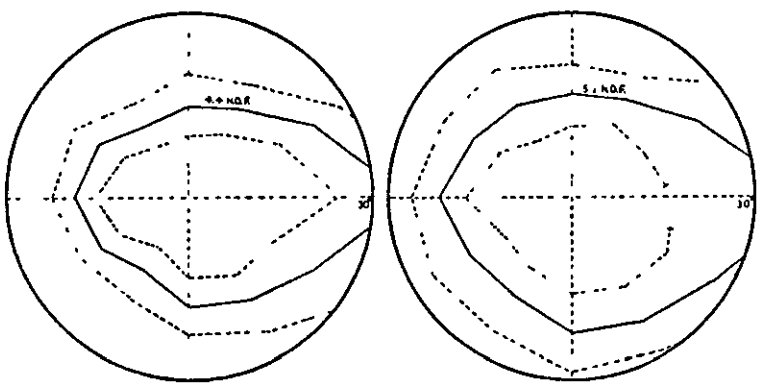


Fig 11 Average isopter (NDF) and standard deviation for minimum discernible luminance difference for an adaptation level of 0 1 millilamberts (a) for a stimulus subtending 12' at the eye (right), (b) for a stimulus subtending 24' at the eye (right)

The assessment of abnormal visual loss

If a technique of visual investigation is to be undertaken as part of a general routine, it is important to know, both from the point of view of efficiency and safety, what reduction in vision, for a given age setting, can be regarded as being abnormal. To obtain this data large numbers of patients have been examined with prototypes of the Visual Field Analyzer, initially comparing any doubtful cases with existing methods of visual field investigation.

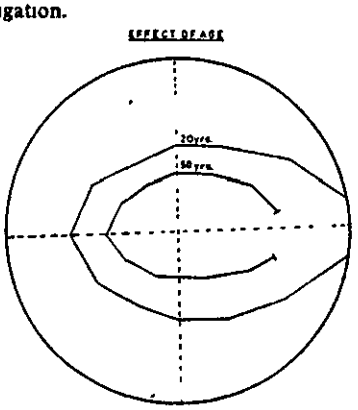


Fig 12 Typical effect of age on isopters (NDF) for minimum discernible luminance difference for a stimulus subtending 12' at the eye and for an adaptation level of 0 1 millilamberts (a) for a subject of 20 years and (b) of 50 years

In general, if the visual field is examined by a large number of stimuli set near the threshold of visibility, in a normal person, the pattern of those that are not seen will tend to take a random appearance. If, however, there is any tendency for early pathological visual loss, usually vision over an area represented by a number of stimuli will be slightly depressed, and the appearance of the loss will tend to represent that of a typical visual field defect. In initial and subsequent clinical work, it has been found that, when using the Visual Field Analyzer at the correct age setting, if some stimuli cannot be seen at a setting of 0 4 log units or

Detection of early visual loss

more brighter than this age setting, the visual loss can be regarded as abnormal In the case of some good observers, a setting of 0 2 log units dimmer can be used than the age level setting, but in this case sometimes it is necessary to differentiate random misses, because the examination may now be undertaken very near threshold If any stimuli are not seen at a setting of 0 4 log units brighter than the age level setting, then the neutral density filter is reduced again by a further 0 4 log units, and these points re-examined This process is repeated at 0 4 log unit steps until either all the stimuli can be seen, or some are still missed at a zero setting, which indicates a severe visual loss (figure 14)

By the technique described it is possible to obtain a quantitative assessment of visual loss, which is independent of the operator, and which can be compared after further intervals of time If immediate treatment is instituted, then the effect of this treatment on visual loss can be recorded. In other cases, if the visual loss appears to be at a very early stage, and no immediate action is deemed necessary, the investigation can be repeated at intervals of time to determine if the loss progresses

It is hoped that a better understanding of the phenomena involved in visual field investigation, and the control of the variables concerned, will enable many cases of unnecessary visual loss, and often resultant blindness, to be avoided.

ACKNOWLEDGMENT

The author acknowledges the co-operation of H Obstfeld in research on the isopters for flashed stimuli, and to the staff of the Department of Ophthalmic Optics and Visual Science, in the preparation of material for this paper

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Fig 14 (right) Case history demonstrating relative visual loss in case of meningeoma detected by routine visual field screening using the visual field analyser Miss T, age 46, right eye, VA 6/9, −4 0D sph, CHB

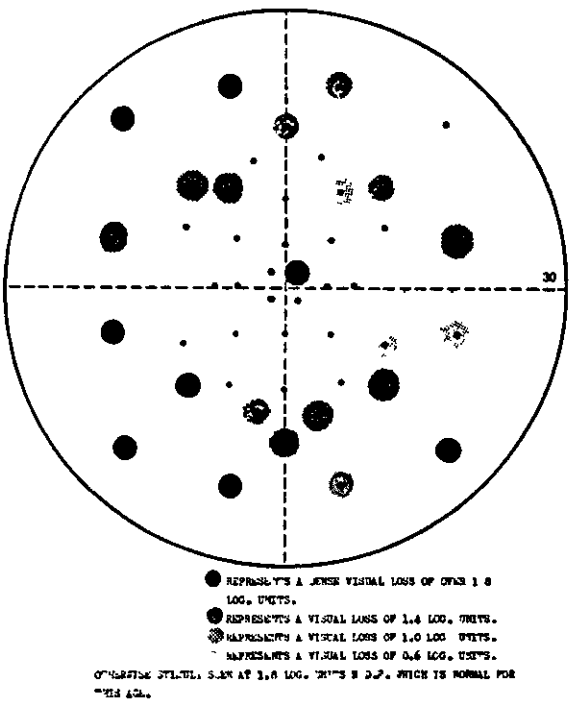
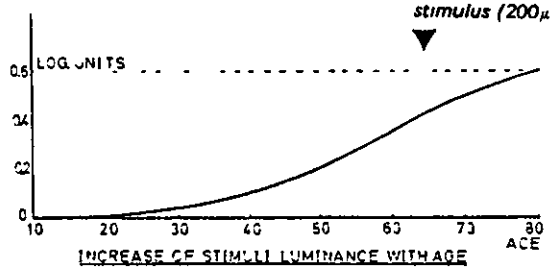


Fig 13 (below) Average increase of stimulus luminance with age for short duration of exposure of stimulus (200μ secs)



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THE RELATION BETWEEN DIFFERENTIAL THRESHOLD CONTRAST, LIGHT ADAPTATION AND STIMULI EXPOSURE

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ABSTRACT

Using a static quantitative technique of perimetry, the differential threshold contrast was determined for different stimuli sizes, using short duration of exposure, for different levels of light adaptation From the data obtained spatial summation coefficients were derived

The application of this research to the efficient yet sensitive investigation of the visual fields in clinical practice is then discussed

SUMMARY

Factors affecting the early detection of visual loss are discussed. In particular, the effect of adaptation and stimuli size in static quantitative perimetry is considered, where short duration of exposure (approximately 200 micro-seconds) of stimuli is employed The importance of retinal physiology is also considered Spatial summation coefficients for short duration stimuli have been derived The effect of age on minimum discernible luminance difference is investigated, a comparison between static and kinetic methods of investigation is made, and case histories given

NTRODUCTION

The importance of detection of early visual loss is generally realized in such conditions as glaucoma and cerebral lesions, where permanent visual impairment may

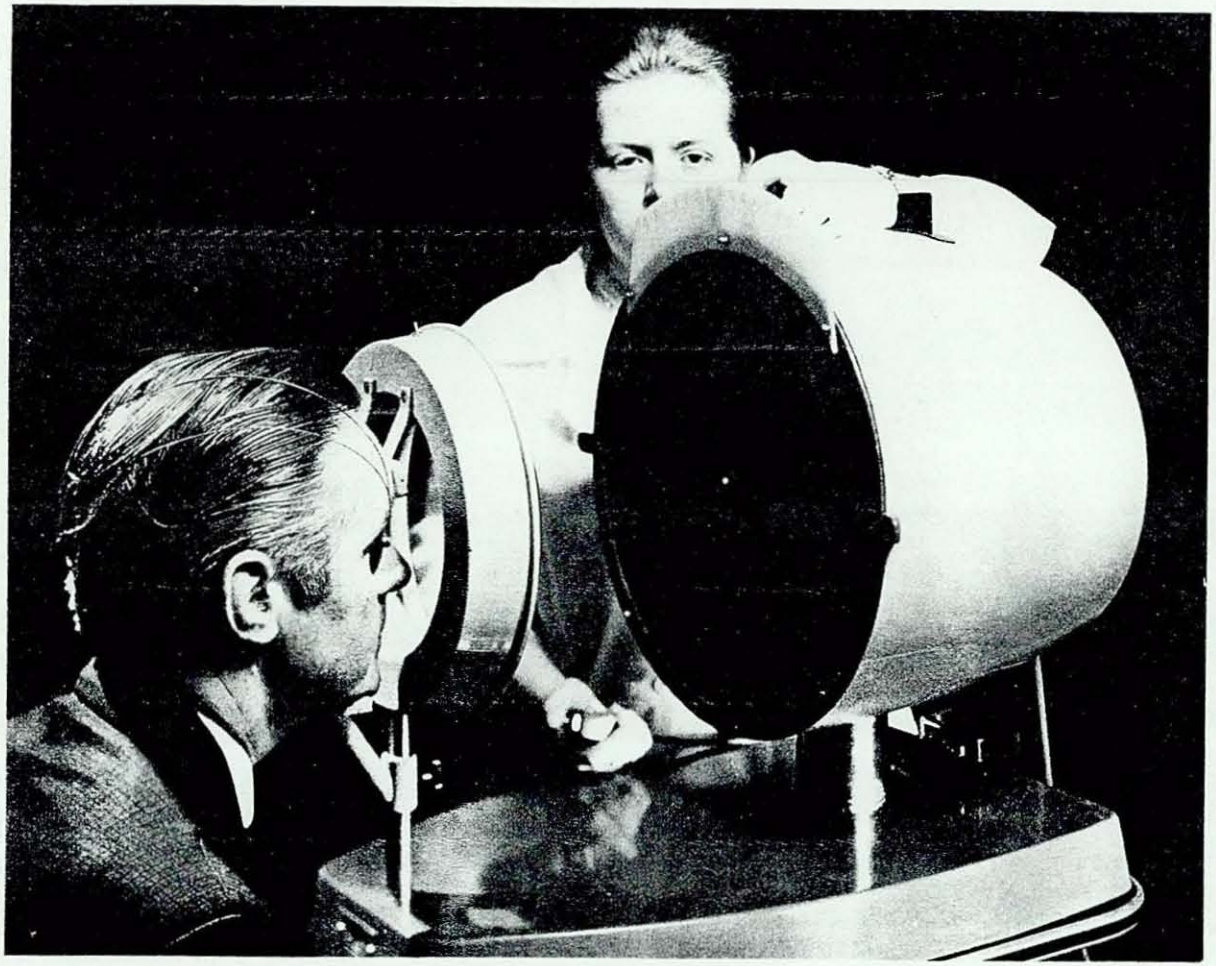


FIG. 1. *The Visual Field Analyser in clinical use.*

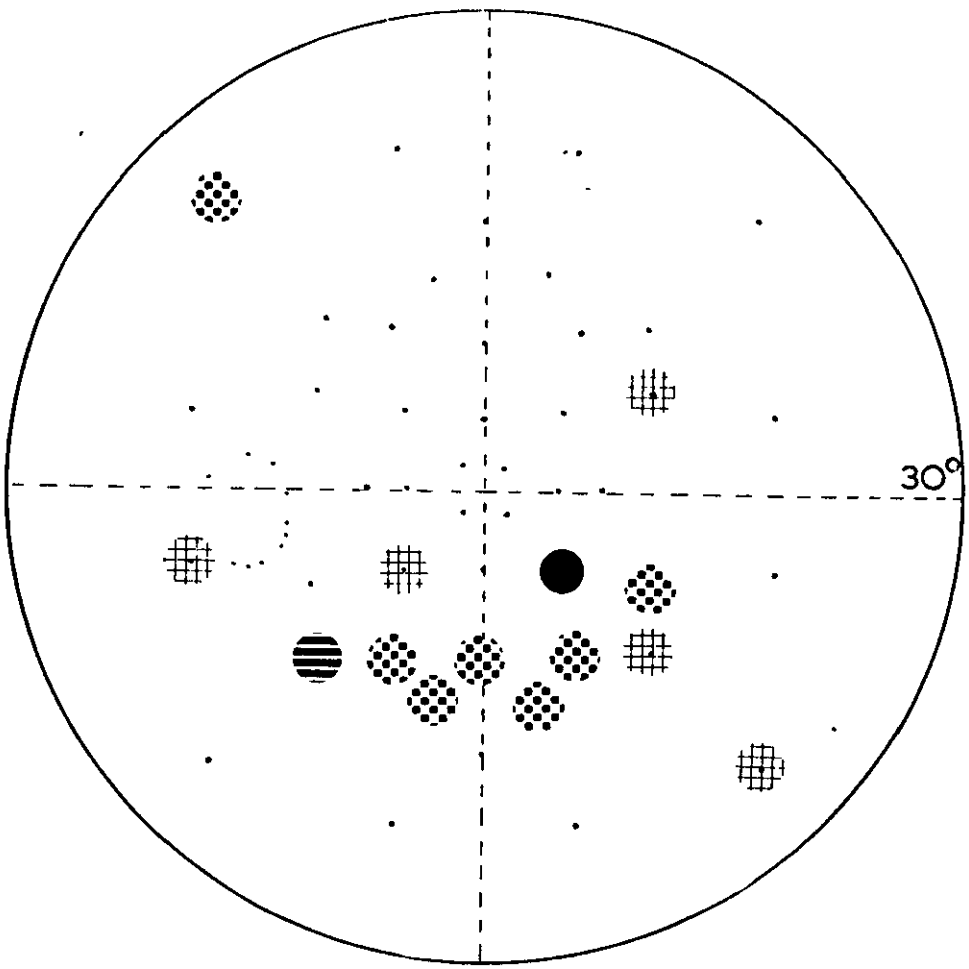


FIG. 2. *Typical case history of early relative visual loss in glaucoma.*
Mr. D. *Left Eye* *Age* 42
V.A 6/7·5 *C.H.B.*
Stimuli not marked seen at 1 8 *N.D.F.*

result unless the condition is treated in time. Therefore, there is a great clinical need for speedy techniques for routine visual field investigation that will allow adequate sensitivity, yet avoid too many referrals for further investigation

If these aims are to be achieved, visual field investigation must be made under maximum control of the variables involved The assessment of visual loss should be quantitative, and data should be available as to which changes might be within physiological limits, and which might be abnormal. It should also be possible to obtain reasonable repeatability of data at subsequent times, and by different examiners

Increasing use is now being made clinically of static methods of perimetry, where vision at individual retinal areas is examined, rather than of kinetic perimetry, where

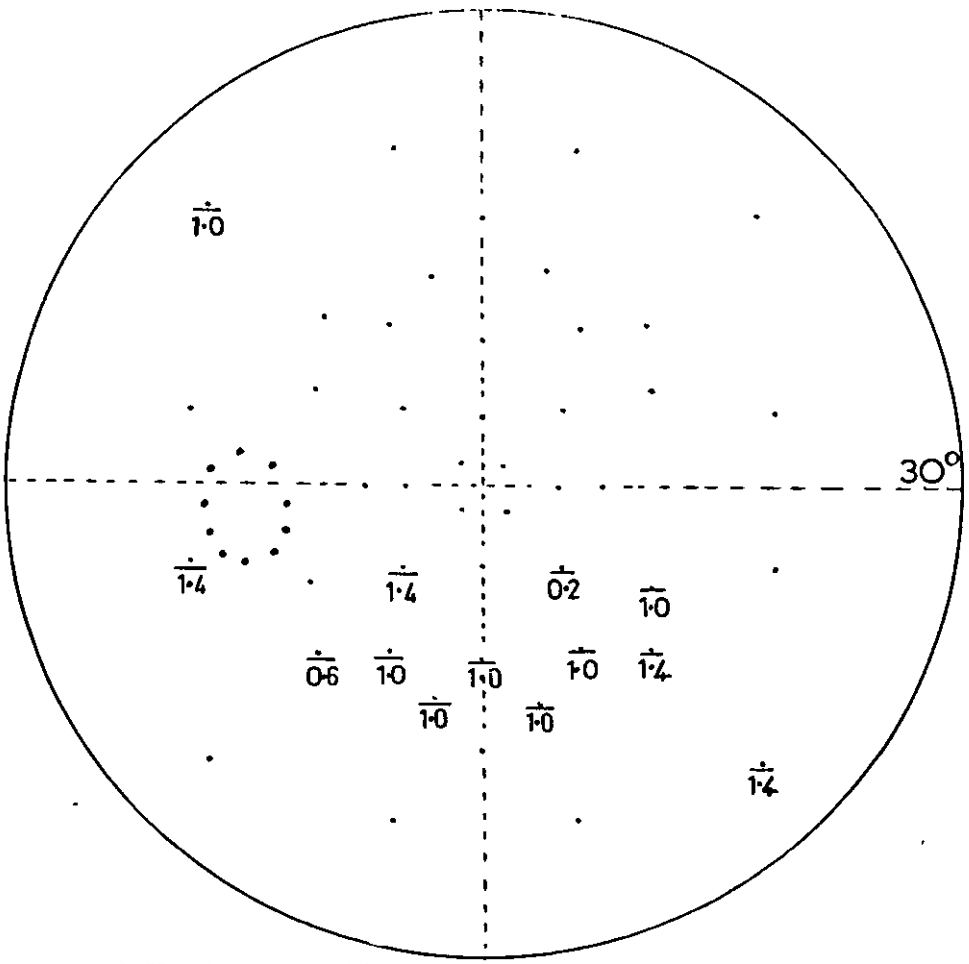


FIG. 3. *Visual response in* (2) *in terms of neutral density filter log units at which the stimuli can just be seen. The response is normal for age at the unmarked points*

Mr D. *Left Eye* *Age* 42
V A 6/7 5 *C.H B*

the stimulus is moved continuously over the visual field In kinetic perimetry it is much more difficult to control the variables involved, and the data obtained depend very much on the expertise of the investigator

Static visual field investigation under controlled conditions, combined with the use of multiple patterns of stimuli, are used in the Visual Field Analyser, – (Friedmann 1966) and (Bedwell 1967) – an instrument developed for rapid and sensitive routine investigation of the central visual fields In this instrument visual loss is recorded quantitatively in logarithmic units, allowance is made for age and physiological variations, and data are available on which changes can be regarded as abnormal

THE EFFECT OF ADAPTATION OF THE EYE

The adaptation of the eye during the visual field investigation is controlled by the light reflected into the eye from the screen, and by any ambient illumination present Therefore, the screen reflection factor is important, a black surface reflecting approximately 10 per cent of the incident light, light grey approximately 30 per cent and white approximately 80 per cent

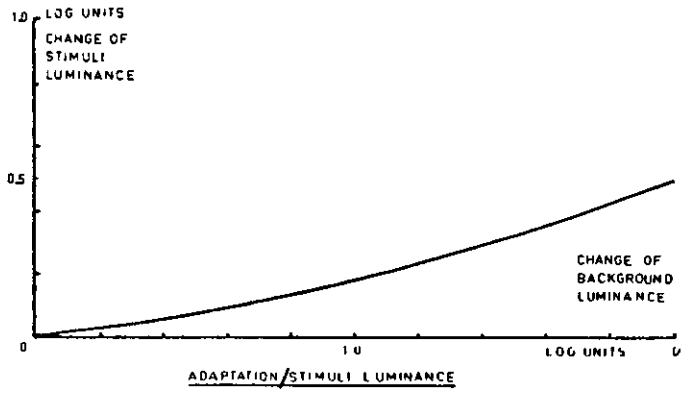


FIG 4. *Adaptation and stimuli luminance (approx. relationship over the central field)*

Various other workers, (Marlow 1957), (Jayle *et al* 1965), (Endo 1967), have found that there appears to be an advantage in using lower levels of adaptation in the early detection of visual loss, particularly in the case of glaucoma * When examining even the central fields of vision, rod-type receptors are mainly being examined, and the employment of a low photopic to mesopic adaptation level appears a reasonable clinical solution to reduce the time required for adaptation of the retina, and yet allow a reasonably equal sensitivity of investigation of receptor types

Adaptation of the eye will also influence retinal summation, and in addition summation will vary with stimulus size and retinal location Therefore, the relationship, (Obstfeld 1968), between stimulus size and luminance has to be determined for each adaptation level, if reliable clinical data are to be obtained

Adaptation of the eye will also influence pupil diameter, and therefore retinal illumination, a constant level ensuring better control Pupil variations during the investigation can also be minimized by employing short duration of stimuli exposure

STIMULI LUMINANCE AND SIZE

In visual field investigation one is really examining minimum discernible luminance difference rather than visual acuity The eye responds very approximately linearly to logarithmic changes of stimuli area, and stimuli luminance over a given retinal area (Stimuli of diameter 1 0, 1·7, 3 55, and 9 50 mm diameter give approximately 0 5 log area changes) If, therefore, for a given stimuli luminance, stimuli area is changed logarithmically, then there will be approximately equal isopter intervals

* An adaptation level of approx 0 1 millilamberts is used in the Visual Field Analyser

AVERAGE CO-EFFICIENTS OF SUMMATION FOR SHORT EXPOSURE STIMULI (200 μsecs.) AT FOUR LEVELS OF BACKGROUND LUMINANCE

BACKGROUND LUMINANCE	ECCENTRICITY		
mL	10°	20°	30°
0 1	(1.3)	1.5	(1.4)
0.5	(0.6)	0.95	(1.3)
1.0	(0 8)	1.1	(1.4)
1.5	(0.7)	0.9	1 0

Figures between brackets include estimated values

FIG 5. *Average coefficients of summation for short duration exposure stimuli*

over most of the visual field meridians However, the level of background luminance may result in a locally higher rod and/or cone activity which can alter this regular spacing of isopters.

It is interesting to consider that Traquair's 'hill of vision' has steeply sloping edges to its plateau, largely because arithmetic changes of stimuli size were employed in these classical investigations.

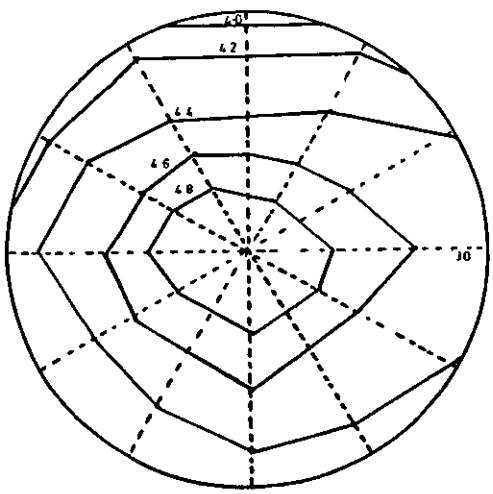


FIG 6. *Isopters showing approximately equal spacing for stimuli subtending 24' at the eye and for a background luminance of 1 5 millilamberts*

STIMULI DURATION

In static quantitative perimetry it is possible to control stimuli duration as well as the other variables involved. For short duration of exposures, visibility of the stimuli varies approximately as the total luminous energy (i e., size, intensity, and duration of exposure of stimuli) and also the summation effect.

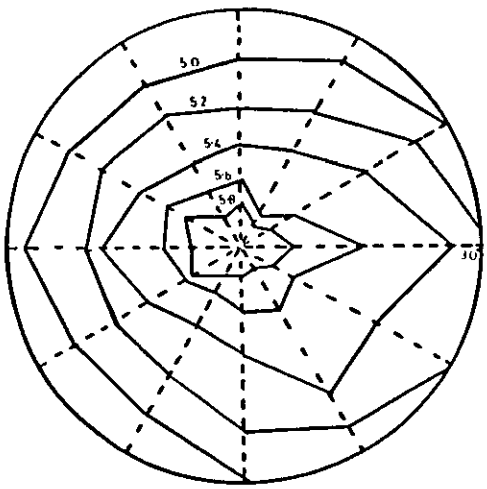


FIG 7 *Isopters showing unequal spacing for stimuli subtending* 24′ *at the eye and for a background luminance of* 0·1 *millilamberts*

Controlled duration of exposure of stimuli not only makes a more satisfactory assessment of visual loss, but it also reduces the problem of wandering of fixation during the visual field examination With this technique investigation of cases with lenticular change is much easier than with a constantly exposed stimulus. Also, as the total luminous energy of the stimuli is now controlled, it is possible to use a shorter investigation distance of the eye from the stimuli than would be possible for constantly exposed stimuli

STIMULI SIZE AND COLOUR

With very small stimuli there are increasing problems due to aberrations from refractive errors, and localized reduction of vision because of small angioscotomata On the other hand, if the stimulus is too large, it does not allow assessment of a deterioration of summation effect, which can be reduced in pathological visual loss

In general, it appears more satisfactory to employ stimuli of spectral characteristics similar to daylight, but for certain clinical investigations, coloured stimuli may be an advantage. For example, red stimuli can be used to investigate the functioning of cone-type receptors, as in assessing the visual effect of certain drug treatments In other cases, blue stimuli may be used where the selective investigation of rod-type receptors is desired, for example in early retinitis pigmentosa.

STIMULUS SIZE AND ECCENTRICITY FROM THE FOVEA

Due to the technical problems involved, very few studies of the distribution of rods, cones, and ganglion cells over the retina have been made. If, however, work by Østerberg (1935) on rods and cones, and by Van Buren (1963), and Oppel (1967), on ganglion cells are studied, it is possible to plot these data on a visual field diagram in the form of population isopters

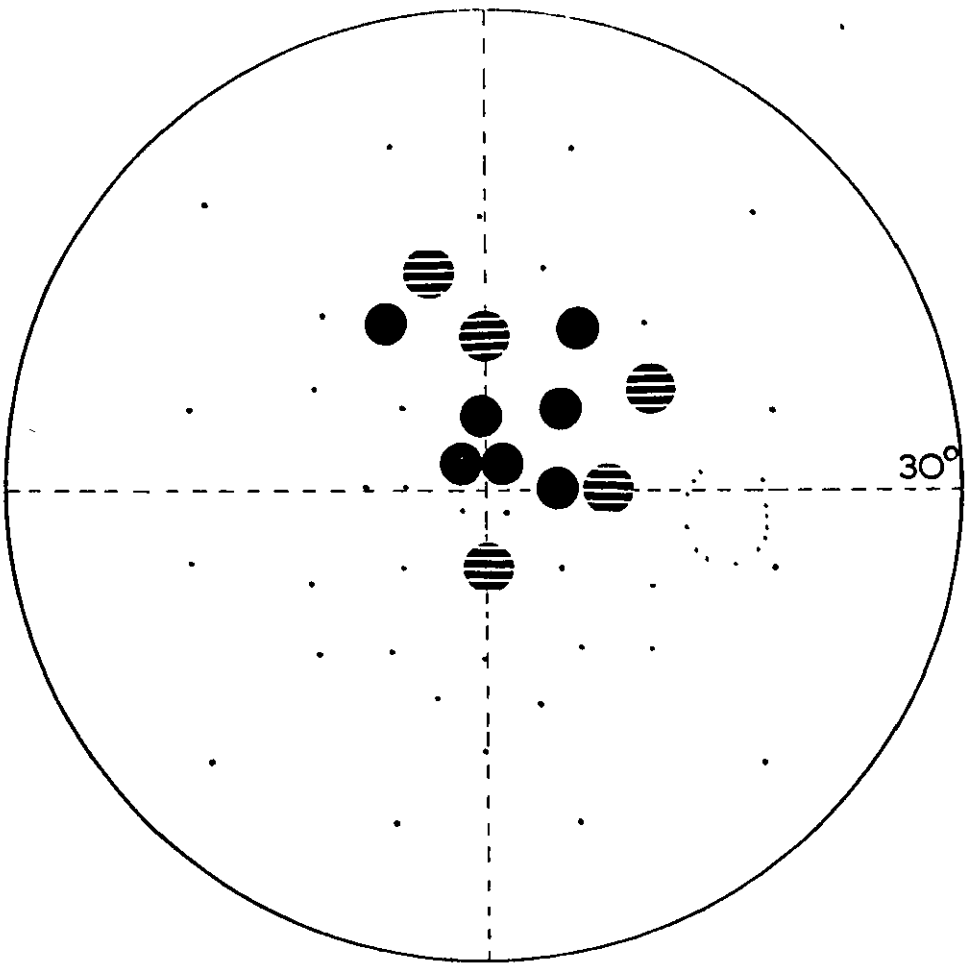


FIG 8. *Visual field analysis showing relative visual loss in a case of lenticular change where the fundus was obscured*
Mrs. B *Right Eye* *Age* 80
V A. 1/60 *C H B.*
Stimuli not marked seen at 0 8 *N D F*

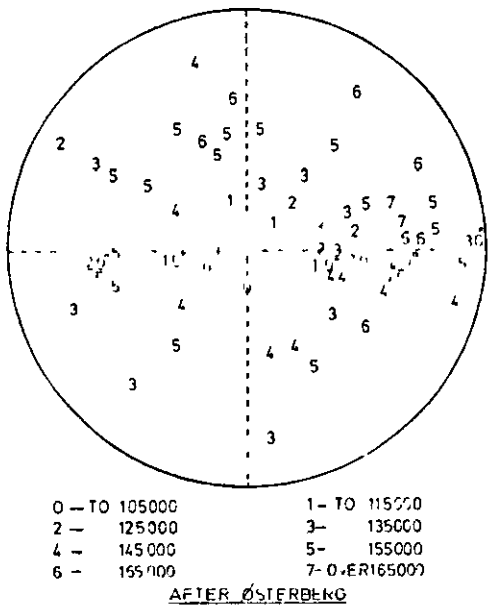


FIG. 9. *Retinal distribution of rod receptors*

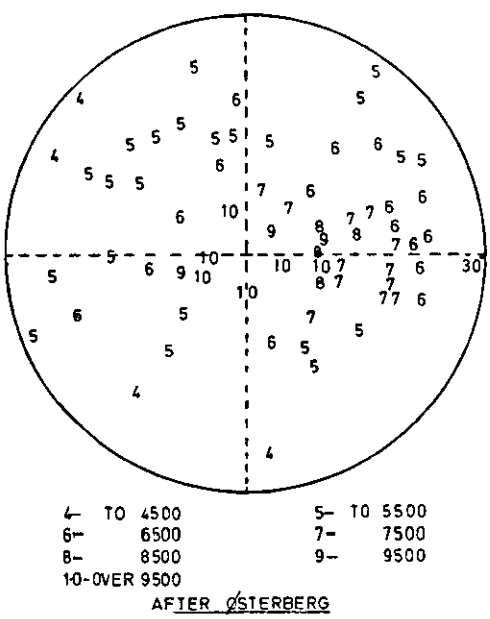


FIG 10. *Retinal distribution of cone receptors*

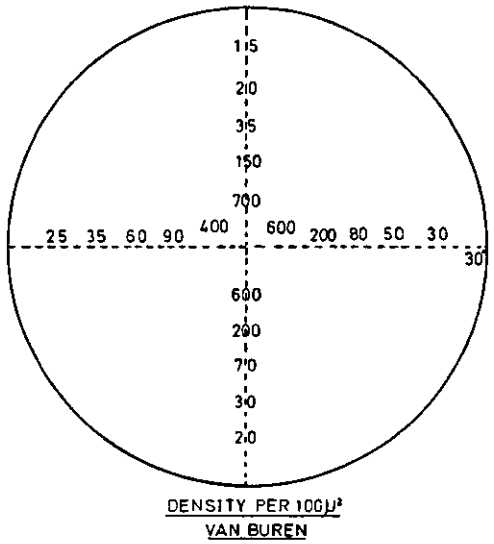


FIG 11. *Retinal distribution of ganglion cells.*

If these isopters are compared, it will be seen that they resemble the general shape of the visual field isopter, being of the same oval pattern in the central portion, and more egg-shaped in the periphery. This suggests that the population density of rod, cone, and ganglion cells is closely related to the distribution of visual field isopters, and to the effect on the latter of retinal adaptation Therefore, the size and location of stimuli are of considerable importance, especially at the retinal adaptation levels where rod activity plays an important part

DETERIORATION OF MINIMUM DISCERNIBLE LUMINANCE DIFFERENCE WITH AGE

It is generally realized that with increased age, higher levels of illumination are required to obtain the same visual performance With short duration stimuli, such as is used in the Visual Field Analyser, it has been found, (Friedmann 1966), and (Bedwell 1967), that an increase of 0 6 log units of illumination was needed to achieve minimum visibility for age increases from 40 to 60 years.

When using the Autoplot projection Bjerrum Screen with constantly exposed stimuli, the writers found that the isopters decreased in size with increase of age under the same adaptation and stimuli conditions

COMPARISON OF METHODS OF VISUAL FIELD INVESTIGATION

Where static quantitative techniques of perimetry can be employed, with control of adaptation, stimuli luminance, size, and duration of exposure, it is much easier to make allowances for physiological variations in threshold contrast over the retinal area. For example, stimuli can be so adjusted that they are adequately sensitive to

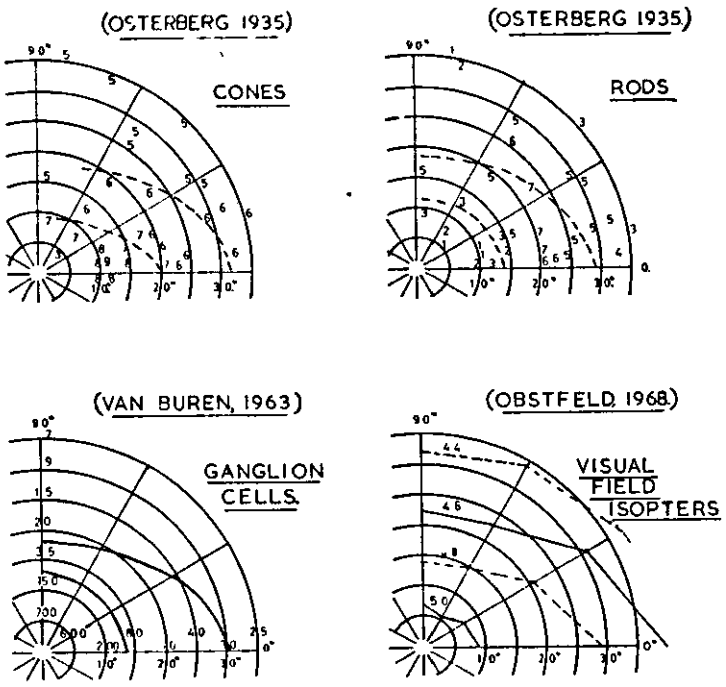


FIG 12. *A comparison of receptor and ganglion cell population isopters and visual field isopters of minimum discernible luminance difference*
Cones x 1000
Rods *Refer to Fig 9*
Ganglion cells per $100\mu^2$
Isopter stimulus size 12'
Background luminance 1 5 *millilamberts*
Isopters for 4 4/4 6/4 8/5·0 *N D.F.*

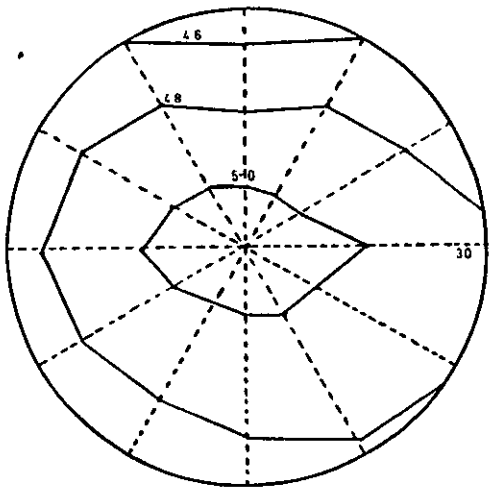


FIG. 13 *Isopters showing spacing for a stimuli subtending* 24′ *at the eye for a background luminance of* 0·1 *millilamberts* (*Compare with illustrations* 6 *and* 7)

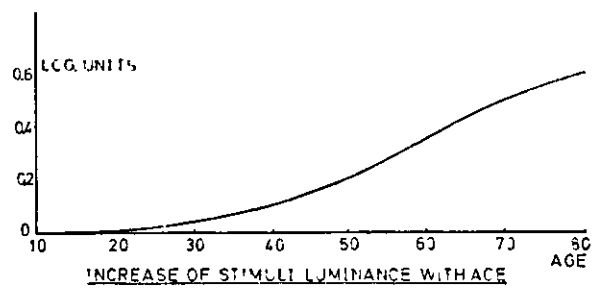
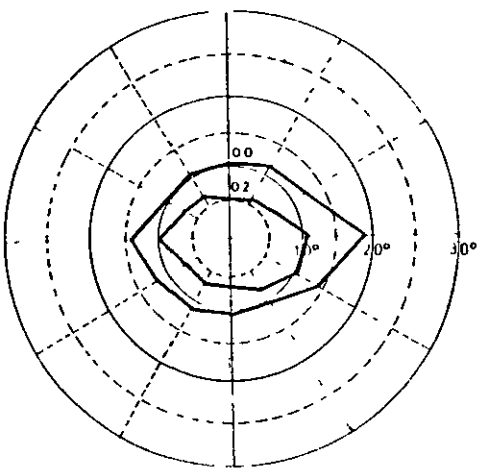


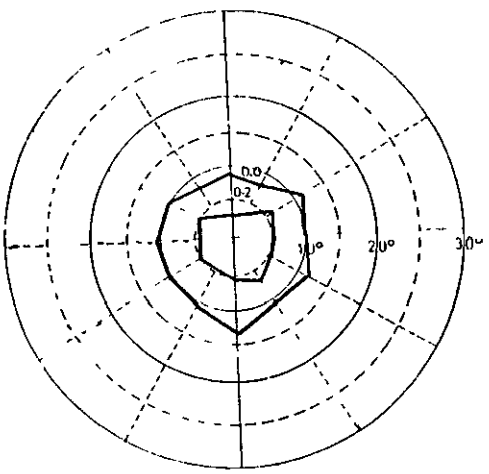
FIG. 14 *Increase of stimuli luminance with age for short duration of exposure of stimuli* (200 μ *s.*)

investigate the arcuate nerve fibre bundle areas of the visual field, where there is a high concentration of rod type receptors and ganglion cells. This is far more difficult in kinetic perimetry, where it is harder to vary the stimuli to allow for these factors, and where constant movement of the stimulus makes quantitative assessment more difficult. In consequence, with kinetic techniques it is easier to miss certain types of field defects, or if any defect is found, for it to be much smaller than it is with a more sensitive static method.

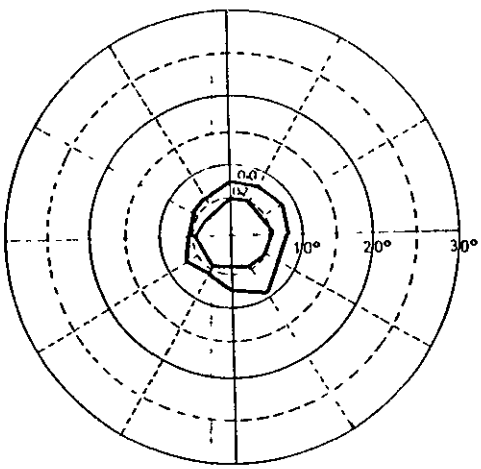
In conclusion it is hoped that this paper will have made some contribution to the use of visual field investigation as a routine preventative technique.



(i) *Average age* 20 *yrs.*



(ii) *Average age* 46 *yrs.*



(iii) *Average age* 57 *yrs.*

FIG 15 *The effect of age on visual field isopters using the Autoplot Bjerrum screen and constantly exposed (projected) stimuli of the same size* (9·4 *mm.*^{2}) *with and without a* 0·2 *N.D F. filter in front of the stimuli projector*

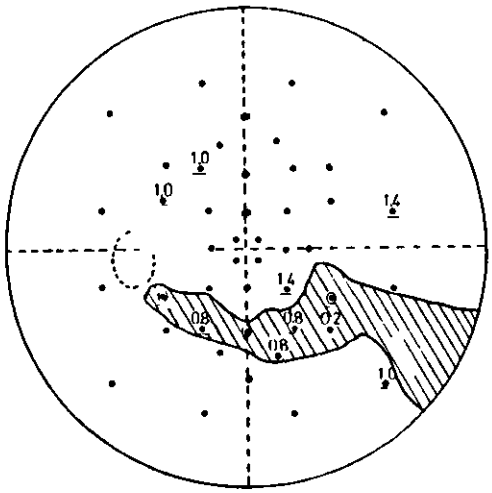


FIG. 16. *Comparison of early visual loss using the multiple stimuli static technique of the Visual Field Analyser and the Bjerrum screen with a 2 mm white hand-held target at the same low adaptation level of 0·1 millilamberts*
Mr. L.T. *Left eye* *Age 50*
V.A. 6/6 *G G L*

Representation of visual loss

SLIGHT LOSS	MEDIUM LOSS	APPRECIABLE LOSS	DENSE LOSS
(0.4)	(0.8)	(1.2)	(1.6 or more) Log. units

A solid black circle represents a dense loss, where the stimuli cannot be seen at zero, or the brightest stimuli setting At unmarked stimuli positions the visual response can be regarded as normal

ACKNOWLEDGMENTS

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THE APPLICATION OF SHORT-DURATION FLASHED STIMULI TO VISUAL FIELD EXAMINATION

C H Bidwell (London)

INTRODUCTION

Flashed light stimuli of approximately 300 μ secs. duration produced from an electronic flash tube have latterly found application in visual field investigation in the Visual Field Analyser, described by Friedmann (1966) and Bidwell (1967), and subsequent papers.

This light source has the advantage of consistancy of output, long life, and a spectral emission near daylight. The duration of exposure is within the critical limits to allow integration of the light flash by the eye, and short enough not to affect retinal light adaptation, or to alter pupil size during the examination. A flashed light stimulus is particularly applicable to static quantitative perimetry, employing either single or multiple stimuli.

In general, the threshold of visibility of a stimulus will depend on its luminance in relation to that of the surround, — hence retinal adaptation — its angular subtense at the eye, duration of exposure, the area and region of the retina — hence receptor type and population — stimulated, and coefficient of summation. The purpose of this paper, then, is to discuss some of the research with which the author has been concerned regarding these various aspects of visibility applied to flashed stimuli of approximately 300 μ sec. duration.

BACKGROUND LUMINANCE, STIMULI LUMINANCE, AND STIMULI ANGULAR SIZE

Threshold contrast visibility was examined for stimuli subtending 12' and 24' at the eye for background luminances of 1, 5,

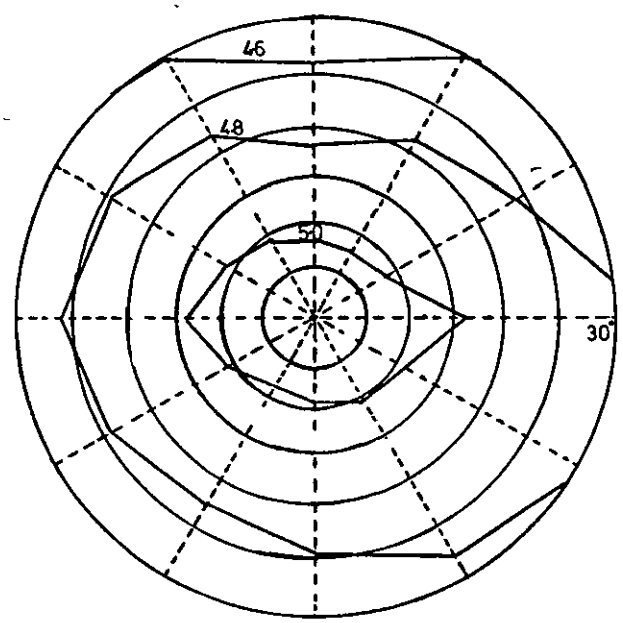

Fig. 1 (left)

FIG. 1. — Typical average isopters showing variations in threshold contrast for a background luminance of 5 asb. For stimuli subtending 12' and 24' respectively at the eye

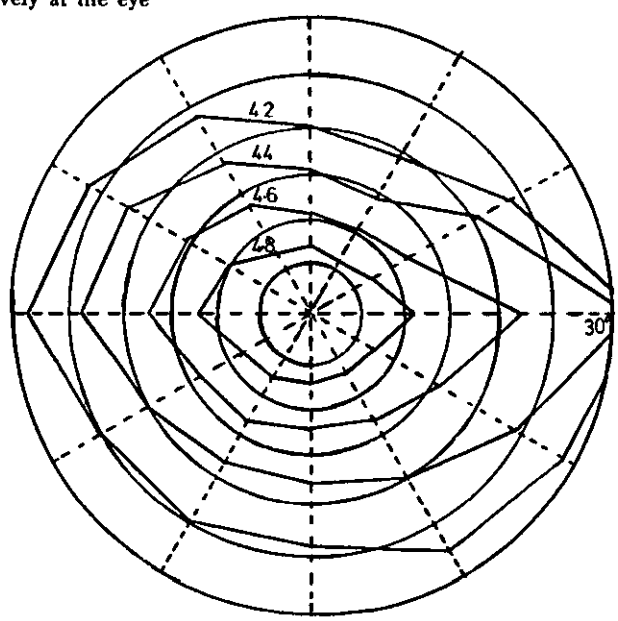

Fig. 1 (right)

10, and 15 asb. (0.1, 0.5, 1.0, and 1.5, ft lamberts) for the central field of the right eye up to 30° eccentric from the fovea, Bedwell and Obstfeld (1970), and Bedwell (1972).

The intervals between isopters tend to decrease with increase in background luminance, and with increased stimuli size, fig. 1. There appears to be an approximately linear relation between the spacing of these intervals and logarithmic changes in stimuli luminance. These results appear to be in general agreement with those of other workers using comparable sizes of stimuli and background luminances, but longer duration of exposure, e g. Jayle, e.t.c. (1965), examining the nasal meridian. The isopter shape and spacing will

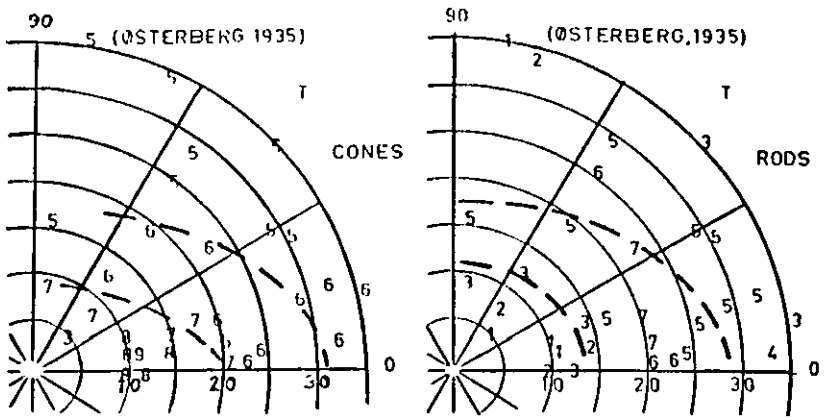

Fig. 2 (left)

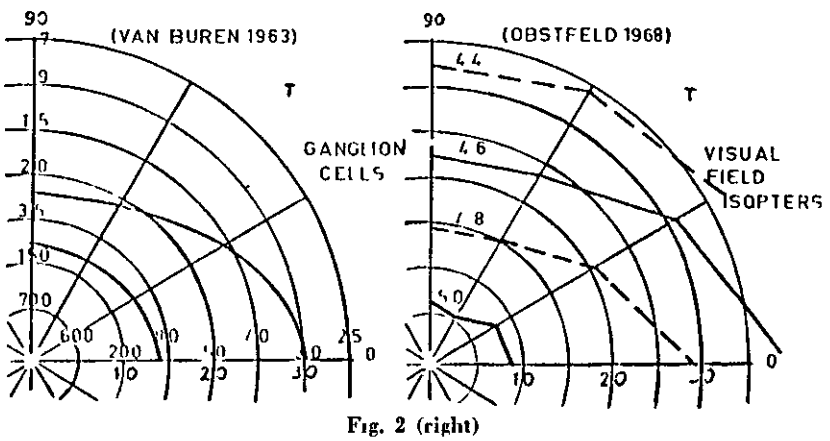

Fig. 2 (right)

Fig. 2 — Comparison of receptor and ganglion cell population isopters and visual field isopters at threshold contrast, for a background luminance of 15 asb, and a stimulus subtending 12' at the eye. (Cones × 1 000, rods × 100 000 per mm², and ganglion cells 100 per μ²).

be influenced by the receptor type stimulated and population density of the area involved, fig. 2.

BLACKGROUND LUMINANCE		ECCENTRICITY	
ASB	10	20	30
1	(1 3)	1 5	(1.4)
5	(0 6)	0 95	(1.3)
10	(0 8)	1 1	(1 4)
15	(0 7)	0 9	1 0

Average coefficients of summation for short-exposures stimuli at four levels of background luminance (figures between brackets include estimated values).

FIG. 3.

COEFFICIENTS OF SUMMATION

The coefficients of summation increase with eccentricity, decrease with background luminance, fig. 3, and tend to vary along different meridians, OBSTFELD. These results appear to be in keeping with those obtained by others under similar circumstances but much longer duration of exposure, e.g. FANKHAUSER and SCHMIDT (1958, 1960).

INDIVIDUAL VARIATIONS IN VISIBILITY

As with other stimuli, individual variations in threshold contrast visibility depend on the meridian examined and eccentricity, fig. 4 & 5, apart from external aspects. Approximately the variations are of the order of 0.3 to 0.4 log units, for a young age group, and are comparable with threshold data obtained with the Goldmann bowl perimeter using static stimuli, VERRIEST and ISRAEL (1965).

VISIBILITY AND AGE

In general threshold contrast visibility tends to decrease with age, the deviation in the older age group depending on the visual state of the sample used. In a survey of 100 subjects with normal vision, the thresholds were assessed on the Visual Field Analyser at a setting where all the patterns could just be seen Fig. 6.

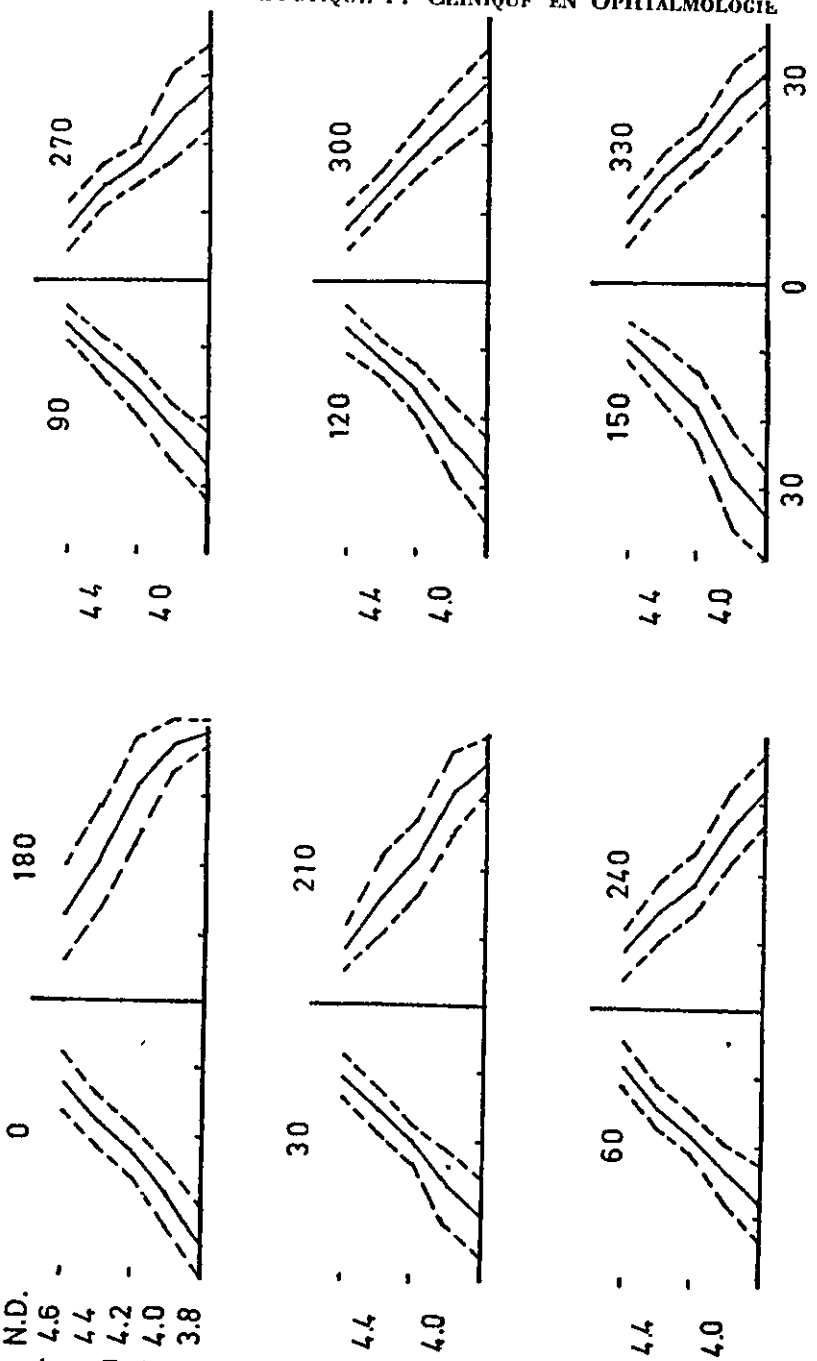

Fig. 4 — Typical average threshold gradients and standard deviations for a background luminance of 15 ASB, and stimulus size subtending 24' at the eye

ROUTINE VISUAL FIELD SCREENING

To obtain an appraisal of the application of multiple patterns of these stimuli using static quantitative perimetry, the central fields of nearly 2 000 subjects — the majority over 40 years of age — were screened on the Visual Field Analyser. A filter setting

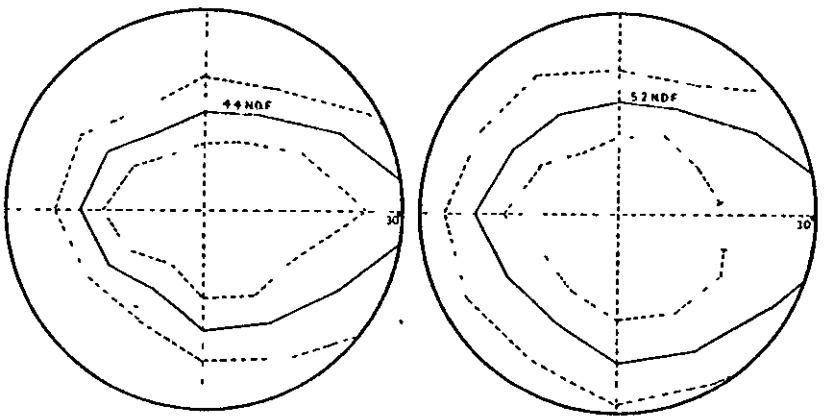

FIG. 5. — Average isopters with standard deviations in terms of isopters of threshold contrast for a background luminance of 1 0 ASB for a stimulus subtending 12' at the eye, and B 24' at the eye respectively.

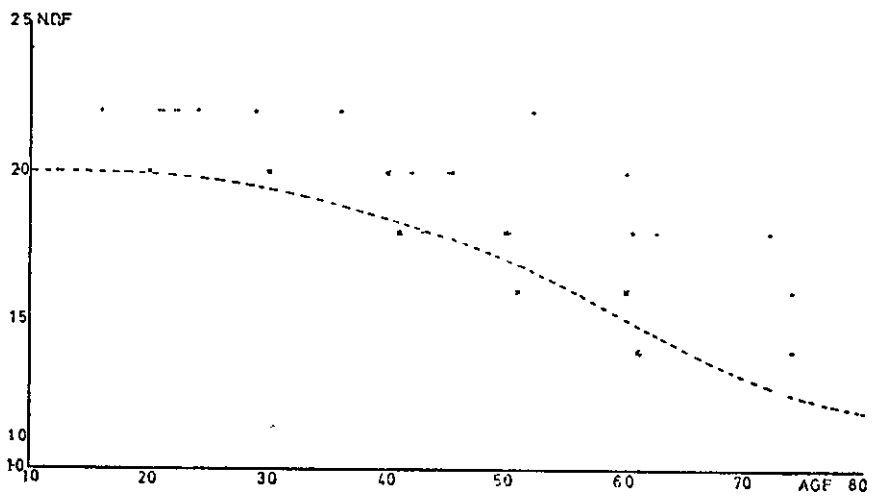

FIG. 6. — Scattergram of threshold contrast in terms of N D F. filter setting and age for 100 normal subjects.

of just below the threshold — usually 0.2 log units above, or at, recommended age level setting — was needed. To enable a more useful assessment of routine screening to be made a number of situations involving readily observable fundus changes were omitted, in particular myopic degeneration, senile macular degeneration, choroidal changes, active and passive evidence of retinal haemorrhage, and amblyopia. Under miscellaneous retinal conditions were two cases of retinitis pigmentosa — one new and partly sine-pigmentosa, and one unusual case of bilateral senile pigmentary degeneration were however included.

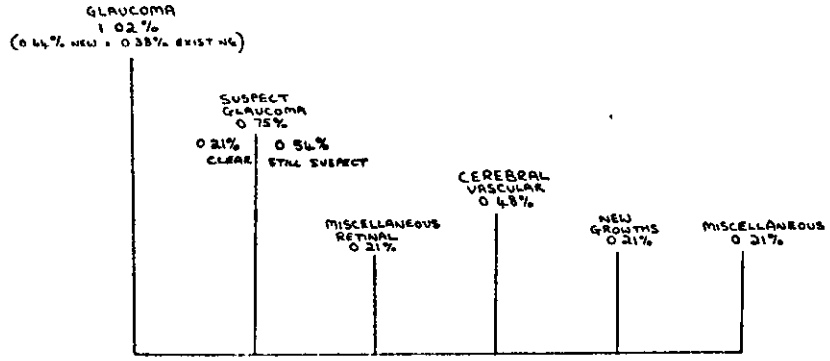

Fig. 7. — Types and proportions of field defects out of 1860 cases screened - total defects 2 86 %.

The 2.86 % of visual field defects detected appears significant, and the 1 02 % of glaucoma cases compatable with the likely incidence of the condition. Fig. 7.

Further aspects of multiple stimuli static perimetry in glaucoma are discussed in Greve.

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THE EFFECT OF PUPIL SIZE ON MULTIPLE STATIC QUANTITATIVE VISUAL FIELD THRESHOLD

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INTRODUCTION

The relationship between pupil size and visual perceptual threshold in the human eye is more complex than that of an optical instrument, such as the camera Though reduction in pupil size decreases retinal illumination, the effect on vision is partly compensated by retinal summation changes adjusting to retinal light adaptation In addition there are also other physiological aspects that can affect these thresholds.

With aging, there is a gradual reduction of light sensitivity, Drance et al (1967) and Lyne & Phillips (1969), associated with a decrease in pupil size, reduction of transparency of the optical media, some degeneration of the retina and associated structures, Fisher (1967) and possibly also a reduction in nerve conduction efficiency. With increasing obliquity of viewing stimuli are imaged on more eccentric areas of the retina, with differing receptor density, type, and interconnections, affecting summation. Also increasing with obliquity is the optical effect of the thickness of the pigmented inner edge of the iris, this thickness increasing with increasing pupil size, and the Styles-Crawford effect on oblique incidence to the retina, Weale (1956, 1974), Jay (1962), and Ronchi (1973).

In general, the effects of obliquity of viewing on visual field thresholds are much more significant for the peripheral fields beyond 30 degrees eccentricity, than that for the central field within this range with which we are concerned. For example, in the case of The Visual Field Analyser. Greve (1973) found that a change in pupil size between 2mm and 6mm had an insignificant effect on central visual field thresholds

The present study was undertaken to determine possible interactions between pupil size, sex, and stimuli eccentricity, and hence their functional and clinical value, in addition to assessing the possible value of dynamically monitoring pupil size during visual field investigation

THE EXPERIMENT

Because of its wide-spread clinical use, and the considerable research data that had been obtained, Bedwell (1971, 1972), and Bedwell & Obstfeld (1970), Greve (1971, 1973), multiple static quantitative perimetry in the form of the Visual Field Analyser, Friedmann (1966) and Bedwell (1967) was used for the visual field investigation. Infra-red photography was used

to determine pupil size of the subject, while viewing The Visual Field Analyser screen, so that retinal light adaptation was not affected.

So that the effect on accommodation would be negligible 5% ephedrine was used to dilate the pupil, and 0 2% thymoxamine to constrict.

Twelve male and female subjects between the ages of 18 and 23 years were studied, all of whose eyes had no ocular abnormalities, and a visual acuity of 6/6 or better.

Because of the random distribution of the visual field stimuli locations, only the eight meridians containing four observations were used Thus an experimental factorial design of pupil x eccentricity x sex was set up, (3 x 8 x 2).

RESULTS

The effects of pupil size x sex summed over eccentricity on threshold are shown for sex in diagram 1, and pupil diameter x eccentricity summed over sex on threshold in diagram 2, for the small, the normal, and the large pupil The dilated pupil was found to lower the threshold and the constricted pupil had a negligible effect ($P < 0.005$). Threshold was lowest for males with a dilated pupil and highest for females with a normal pupil, with a maximum difference of 0 14 log units With increasing eccentricity from 12 5° to 20 0° there is a consistent trend for threshold values to be raised ($P < 0\ 001$) by up to about 0 1 log units

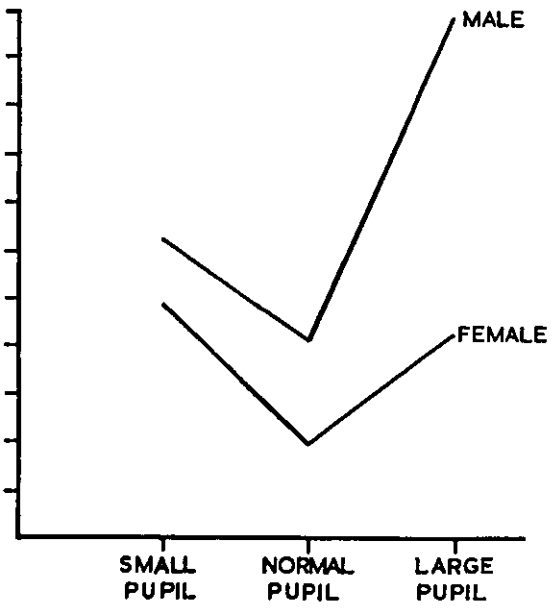

Fig 1 Pupil Dia X sex summed over eccentricity

The effect of sex was that the threshold for males was lower than that for females ($P < 0.005$)

DISCUSSION

The finding that males have a lower threshold than females was interesting A possible explanation may be that in visual perception tests males tend to have a better performance, whereas on aural tests the position is reversed.

Variations of threshold of within 0 2 log units are usually accepted clinically as within normal physiological limits, in this technique of visual field investigation. As the variation in threshold was an approximate maximum of 0 14 log units for variations in pupil size of between approximately 3 5 to 9 5 mm diameter, one could say that the variation was within physiological limits However, as the effect of other variables on visual field threshold have also to be considered, it is possible that under certain circumstances, especially where the pupil may be dilated in young males, and the very earliest indications of visual field reduction are being sought, it may be pertinent to take the effects of pupil size into consideration. In more every day clinical situations, where the pupil variations are less, and less strict tolerances need be observed, then the variations in pupil size likely to be encountered normally, do not appear likely to have a significant clinical effect

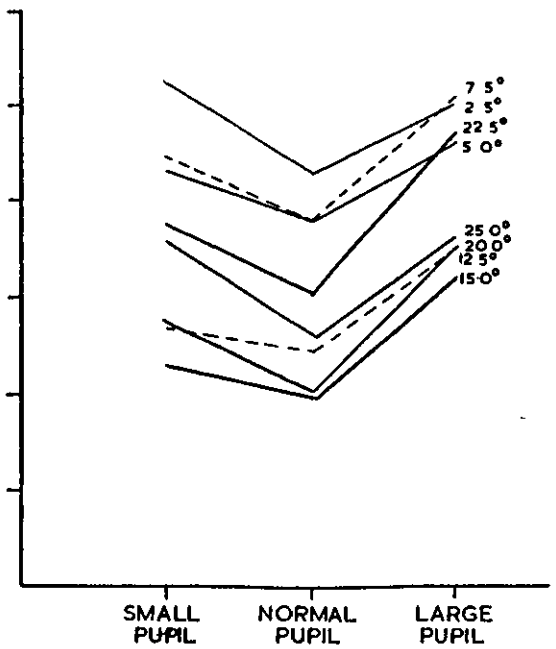

Fig 2 Pupil dia X eccentricity summed over sex

SUMMARY

Using infra-red photography, the effect of variations in pupil size on visual field threshold were determined, employing the techniques of multiple static quantitative perimetry over the central field with The Visual Field Analyser To minimise any effect on accommodation ephedrine and thymoxamine were used to produce mydriasis and miosis. The maximum effects of pupil size, eccentricity, and sex were 0.14 log units. Males were found to have a significantly lower threshold than females, the dilated pupil lowered the threshold, and increasing eccentricity raised it.

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