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CONTRAST SENSITIVITY OF THE HUMAN RETINA*

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ABSTRACT

Contrast thresholds ($\Delta L/L$) were measured from the fovea to the far periphery at 2 degree intervals, along 12 meridians for a total of 1350 data points. The test spot, 10 minutes of arc in diameter, was presented against a 0.85 mL background in the Harms perimeter. Contrast senstivity decreases (i.e. thresholds increase) in all directions from the fovea out to a distance of 10 degrees. A broad region of equal sensitivity was found to extend from 10 degrees to 20 degrees in the superior, inferior and nasal visual fields and to 35 degrees in the temporal field. We call this region of equal sensitivity the "plateau." Beyond the edge of this plateau, contrast sensitivity decreases at a uniform rate to the edge of the visual field. The size of the plateau remains constant in photopic, mesopic and scotopic vision (at background luminances from 8.5×10^{-1} to 8.5×10^{-5} mL).

The clinical method of kinetic perimetry is often used to define the sensitivity in the visual field along different meridians. A circular target of given size and contrast is moved from the periphery toward the fovea, and the position in the visual field where detection occurs is noted[1,2]. This method suffers from several defects which make it unsuitable for precise specification of sensitivity at different visual field loci: 1) exposure duration is not constant; 2) the target is moving (usually not at a uniform rate) and 3) the reaction time of the subject influences the results. Thus target detection depends at least on a complex interaction among target contrast, target size, speed of movement and subject's reaction time.

A more rigorous and scientifically more satisfactory way to measure sensitivity of the visual field is that of static perimetry. With this technique the test target remains stationary. The difference between the luminance of the target and that of the background (ΔL) divided by the background luminance (L) is defined as the target contrast ($\Delta L/L$)[3]. One of the goals of static perimetry is to measure threshold contrast at different retinal locations. The several studies which have measured static contrast thresholds have concentrated on measurements along the horizontal meridian, e.g. Sloan[4], Aulhorn[5] and Aulhorn, Harms and Raabe[6]. The recent careful measurement of contrast threshold by Kishto[7] and Kishto and Saunders[8] were restricted to the area of the visual field within 10 degrees of the fovea and along the horizontal meridian. We have been interested in defining the basic contrast sensitivity of the visual field from the fovea

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to the far periphery along many meridians. The purpose of this paper is to present such data.

METHODS

All measurements were made with the Harms perimeter. This device presents an evenly illuminated, hemispherical field of view to the subject at a viewing distance of 33 cm. The luminance of the projected test can be varied in 0.1 log unit steps and is under the control of the experimenter. For a detailed description of this apparatus see Sloan[9].

Two series of measurements will be presented here. In the first series, contrast thresholds were measured in the fovea and at 2° intervals into the far periphery of each eye. A 10′ test field was presented with a 200 msec exposure duration against a background luminance of 0.85 mL. The ascending method of limits was employed, using luminance steps of 0.1 log units. In this fashion, contrast thresholds were measured along 12 meridians spaced 15 degrees apart. One author served as observer (E. P.); the other served as experimenter (L. O. H.). The results were confirmed by measuring contrast thresholds along the horizontal meridian and several other meridians under the same conditions with 9 additional subjects. In the second series of measurements contrast thresholds were measured at 2° intervals along the horizontal meridian with a 10′ test target presented for 200 msec against background luminances of 0.85, 0.085, 0.0085, 0.00085 and 0.000085 mL.

The natural pupil was used in all conditions. Although it is desirable to control the pupil size, this goal cannot be attained in a perimetric apparatus without restricting the peripheral view. The pupil size could have been controlled by using a Maxwellian view system, but the consequent disadvantage of severely limiting the size of the background field. In the present experiment the fluctuating size of the natural pupil may have contributed an increase in the variability of the results. A second consequence of using the natural pupil is the change in effective pupillary area which occurs at increasing perimetric angles[10-12]. The measurements of Jay[12] indicate a reduction of retinal illuminance of 0.1 log units at 50°, 0.2 log units of 65° and 0.3 log units at 75°. Since this reduction of retinal illuminance affects both the background and test target to the same degree, the contrast threshold values should not be affected.

The subject fixated a red spot 30 minutes of arc in diameter projected onto the center of the hemisphere. When foveal thresholds were measured, this single spot was replaced with four small spots forming a diamond pattern 1° on each side. The luminance of the fixation spot was 0.5 mL above the background. Eye fixation was not monitored continuously, but was checked periodically by means of the telescope built into the Harms perimeter. The target exposure duration of 200 msec prevented eye movements while the target was presented. If the subject felt that his fixation had shifted just prior to target presentation, that particular trial was discarded.

RESULTS

The basic data are threshold contrasts. Contrast is defined as:

$$C = \frac{L_t - L_b}{L_b}$$

where L_t = luminance of the target and L_b = luminance of the background.

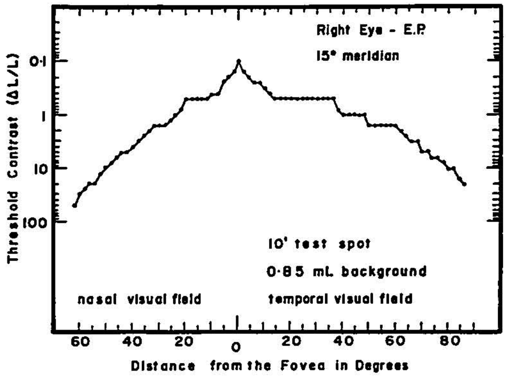

Fig. 1. Contrast threshold (ΔL/L) as a function of retinal locus along the 15°-195° meridian in the visual field of E.P.'s right eye. Test target 10 min arc presented on a 0.85 mL background with an exposure duration of 200 msec.

This definition is identical with:

$$C = \frac{\Delta L_t}{L_b}$$

where ΔL_t is the luminance which must be added to the background in the area of the test target in order to reach threshold detection.

EXPERIMENT 1

Fig. 1 presents contrast threshold as a function of retinal locus for a typical

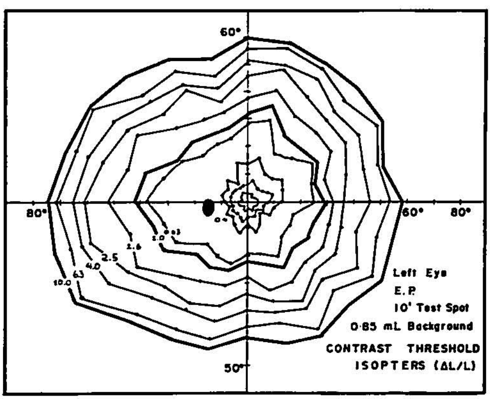

Fig. 2. Left eye: Contrast threshold (ΔL/L) isopters for 10 min arc test spot on a 0.85 mL background. Visual field is represented in polar coordinates with the fovea at the origin. The vertical and horizontal meridians are marked in 10 degree intervals. Outer isopter (heavy line) represents threshold contrast = 10.0. Each isopter represents an interval of 0.2 log contrast. Inner heavy line represents contrast = 1.0. Threshold at the fovea is 0.1.

meridian, in this case 15°-195°. Note that the ordinate scale is logarithmic and inverted, so that values higher up the scale indicate a higher contrast sensitivity (i.e., a lower contrast threshold). Three features are important in Fig. 1: 1) Contrast sensitivity is highest in the fovea, decreasing with distance from the fovea; 2) this decrease stops at about 10° and contrast sensitivity remains constant out to about 35° in the temporal visual field and about 20° in the nasal field. We suggest that this region of relatively constant sensitivity be called the "plateau"; 3) at the edge of the plateau sensitivity falls without interruption to the edge of the visual field. From the maximum sensitivity in the foveal ($\Delta L/L = 0.1$) to the minimum measured at the edge of the field ($\Delta L/L = 32$) covers a range of over two log units.

Figs. 2 and 3 are polar coordinate plots of contrast threshold isopters (i.e., contours of equal contrast sensitvity) for the left and the right eye. They were constructed by connecting points of equal contrast threshold along the 12 separate meridians of the type shown in Fig. 1. Each contour represents an interval of 0.2 log contrast. The outer heavy line represents $\Delta L/L = 10$, the next heavy line $\Delta L/L = 1.0$, and the center of the fovea $\Delta L/L = 0.1$. These figures emphasize the features seen in Fig. 1. There is a central cone of sensitivity whose vertex is in the fovea and whose base spreads out to 10 degrees in all directions. The base of this central cone is resting on a broad plateau whose edges extend to about 20° in the superior, inferior and nasal visual fields and to about 35° in the temporal visual field. Beyond the edge of the plateau contrast sensitivity decreases smoothly at a rate of approximately 0.05 log units of contrast per degree. The plateau is not concentric with the fovea, but with a point located about 6° in the temporal visual field. The center of the plateau thus falls quite close to the optical axis of the eye, estimated by Bennett and Francis[18] to lie 4-5° from the fovea.

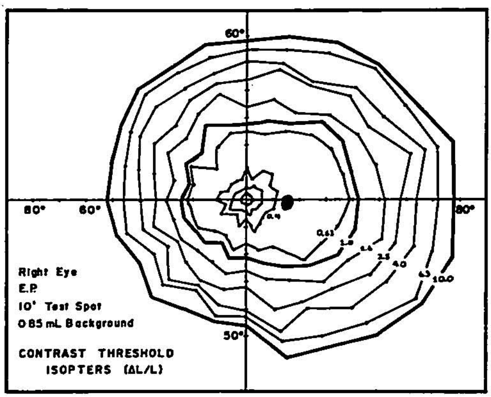

Fig. 3. Right eye: Contrast threshold ($\Delta L/L$) isopters for 10 min arc test spot on a 0.85 mL background. Visual field is represented in polar coordinates with the fovea at the origin. The vertical and horizontal meridians are marked at 10 degree intervals. Outer isopter (heavy line) represents threshold contrast = 10.0. Each isopter represents an interval of 0.2 log contrast. Inner heavy line represents contrast = 1.0. Threshold at the fovea is 0.1.

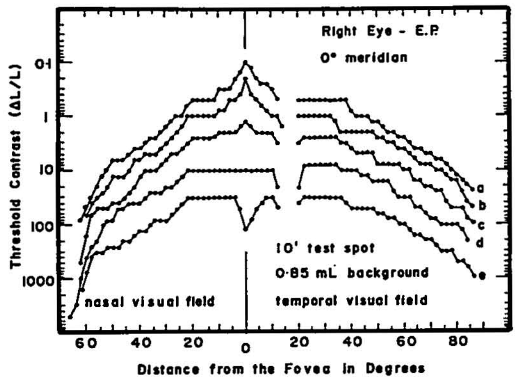

Fig. 4. Contrast threshold ($\Delta L/L$) as a function of background luminance and retinal locus along the horizontal meridian (0°-180°) in the visual field of E.P.'s right eye. Background luminances: $a=8.5 \times 10^{-1}$; $b=8.5 \times 10^{-2}$; $c=8.5 \times 10^{-3}$; $d=8.5 \times 10^{-4}$; $e=8.5 \times 10^{-5}$.

EXPERIMENT 2

Fig. 4 presents threshold contrast at 2° intervals along the horizontal meridian for five background luminances. As in Fig. 1, the ordinate scale is logarithmic and inverted, so that values higher up the scale indicate a higher contrast sensitivity (lower contrast threshold). The background luminances include the photopic, mesopic and scotopic range of vision. It is important to note that the size of the plateau remains unchanged over the range of luminances used here. The sensitivity of the fovea relative to the plateau, however, changes widely. At the highest background luminance (8.5×10^{-1} ml) the fovea is about five times (0.7 log units) more sensitive than the plateau. As background luminance decreases the foveal peak also decreases until at 8.5×10^{-4} ml, the foveal sensitivity is equal to that of the plateau. At scotopic luminance levels (8.5×10^{-5} ml) the plateau has a higher contrast sensitivity than does the fovea.

DISCUSSION

The most important feature of the present data is the plateau, the broad area of equal contrast sensitivity which surrounds the central 10° of vision and which extends out to 20° in the superior, inferior and nasal visual field and to 35° in the temporal visual field. The scotopic sensitivity data of Zigler and Wolf[14] and Crozier and Holway[15] both show this plateau but neither investigators measured farther than 30° from the fovea and thus did not define its limits. Using the Goldman perimeter at photopic levels, Sloan[16] measured contrast sensitivity along the horizontal meridian out to 60° in the nasal visual field and to 80° in the temporal visual field. Her data (see figure 10 of Sloan[9]) clearly show the plateau extending to 20° nasally and about 40 degrees temporally. The measurements of Aulhorn[5,6] along the horizontal meridian, made under conditions similar to our present experiment, do not clearly show the limits of the plateau. This difference may be because her data are the mean of 10 subjects (some of these data are reproduced by Newman[17], Fig. 19-16).

Figs. 2 and 3 bear a superficial resemblance to clinical isopters which are based on different size test objects. Indeed the fanciful paintings in Harrington[1] representing the normal visual field also show a plateau. A close examination will reveal that the isopters of clinical use are not equal size (or acuity) increments, a condition which is necessarily for topographic representation of the sensitivity of the visual field. Further, the limits of the plateau shown by Harrington do not correspond to those reported here and seen in the other experimental data discussed above. The existence of this plateau in the sensitivity of the visual field presents the danger of misleading results when using kinetic perimetry. We would like to quote a warning given by Sloan[16].

> Gradients that are almost flat in certain regions . . . are however not as desirable for kinetic perimetry as is a gradient with a moderate regular increase in threshold from center to periphery. With a very flat gradient, slight changes in luminance either of the test object or its background, or minor fluctuations in retinal sensitivity of no clinical significance may result in marked variations in the limits of the field for a given test object.

We are presented with intriguing questions about the functions of this plateau. What role does it play in brightness perception in the periphery of the visual field? Does the plateau correspond to the "functional visual field" defined by Sanders[18,19]? Does it play any role in saccadic eye movements? We are in the process of investigating these questions experimentally.

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