

Measurement of acuity variations within the central visual field caused by neurological lesions

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SYNOPSIS We describe a method capable of quantitatively measuring the visual acuity of small, eccentrically-located areas of the visual field, even within the macular area. Fixation errors are minimized by presenting stimuli briefly and in random order. The method is more sensitive than Bjerrum screen campimetry in detecting hemianopic and quadrantic losses.

Visual acuity—that is, the ability to see fine detail—is a term that covers several different types of visual performance each of which is measured by a different type of test. For this reason, visual acuity tests have been divided into five classes. These are tests for detection, recognition, resolution, modulation transfer function, and location (Kling and Riggs, 1972).

In both conventional perimetry and Bjerrum screen campimetry the patient's task—namely, to detect a bright disc—can be regarded as a special form of intensity discrimination. Resolution can be tested by asking a subject to distinguish a patterned from an unpatterned area of similar mean brightness. Recognition tests such as, for example, Jaeger and Snellen tests involve both resolution and intensity discrimination (Kling and Riggs, 1972).

For clinical purposes it is of the first importance to know how visual acuity varies over the visual field. Conventional perimetry or campimetry describes this variation over the visual field, but is limited to a detection task and does not measure resolution: Jaeger and Snellen tests provide some indication of resolution, but do not describe how resolution varies over the visual field. In this article we suggest that these are serious limitations, on the basis of our evidence that resolution measures are in some cases more sensitive indicators of functional loss than Bjerrum screen campimetry.

We describe here a method for measuring the visual acuity of small eccentrically-located areas within the visual field, even when the test area is close to the fixation point (Regan, 1972a). A feature of this method is that local visual acuity can be reliably measured in the diagnostically-important region close to the fixation point, since systematic errors caused by the tendency of a patient's gaze to wander towards a test object are reduced by a special procedure.

METHODS

RELATIONS BETWEEN DIFFERENT QUANTITATIVE MEASURES OF VISUAL ACUITY We measured visual acuity as the angular subtense of the smallest checks that could just be seen as a checkerboard pattern.

Among other patterns that have been used to test visual acuity are letters of the alphabet, single lines, squarewave gratings (black/white bars), sinewave gratings, and checkerboard patterns. These different spatial patterns do not give the same numerical values of angular acuity, nor do they necessarily measure the identical visual function. A further reason for differences is that some tests require the subject merely to detect a target, while others require him to recognize its shape. As yet, these different measures of acuity cannot be related on theoretical grounds. Therefore we have compared all our data with results of conventional Jaeger tests taken at the same time.

REDUCING THE EFFECT OF FIXATION CHANGES Test stimuli were presented briefly, so that the eye did not have sufficient time to move any appreciable distance

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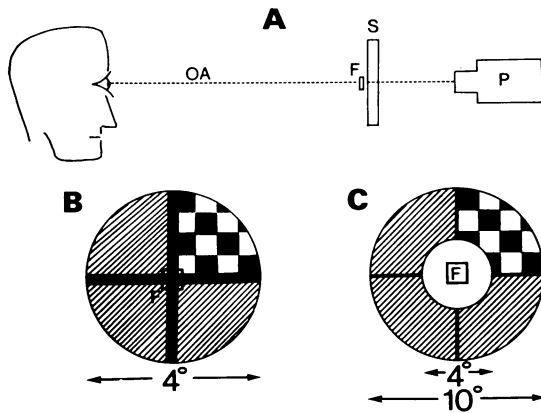


FIG. 1 A. Subject shown gazing at the fixation light F. Projector P briefly throws an image of the test pattern onto the rear of the translucent screen S. B. Subject's view of screen S when acuity of macular quadrants is being tested. Check pattern can occupy any of the four quadrants. C. Subject's view of screen S when acuity of extra-foveal annular region is being tested. Check pattern can occupy any of the four quadrants.

during the stimulus presentation. The aim of this procedure was to increase the precision and reproducibility of visual field mapping by minimizing the disturbing effects of eye movements systematically directed either towards or away from the test target.

Nevertheless, even this stratagem of brief presentation might be inadequate if the patient anticipated the position of the test pattern. Therefore the different positions of the test pattern were briefly presented one after the other in pseudo-random order so that the patient was not able systematically to anticipate the position of the next checkerboard pattern.

Visual sensitivity to a briefly-presented pattern is roughly proportional to the presentation time, so long as this does not exceed a critical duration (Graham and Cook, 1937; Keese, 1960). Consequently, estimates of visual acuity will depend on the presentation time of a patterned test target if the presentation time is not sufficiently greater than the critical duration.

APPARATUS Test patterns were back-projected onto screen S by means of an automatic projector P (Fig. 1A). The brightness of the white checks was 2.3 log ft lamberts. The subject sat comfortably in a dentist's chair with the head supported so that the eyes were in the optic axis OA (Fig. 1A) at a distance of 3.4 m from the screen for 4° diameter field. A small white

lamp at the centre of the screen acted as a fixation spot (F in Fig. 1A).

Test patterns were 35 mm transparencies. The two types of pattern used in these experiments are shown in Figs 1B and C. The quadrantic pattern of Fig. 1B was used to test the acuity of retinal quadrants close to the fixation point. The annular pattern of Fig. 1C was used to test the acuity of annular quadrantic areas at various eccentricities. Annular patterns were obtained from quadrant patterns by masking.

Test patterns were available in 14 different check sizes (1.6, 1.9, 2.1, 2.6, 3.1, 3.7, 4.6, 5.4, 6.6, 8.6, 12, 15, 20, 30 minutes for a 4° diameter stimulus field). There were four transparencies for each check size, one for each test quadrant. Transparencies were loaded into the projector's magazine in an order that was pseudo-randomized both for different quadrants and for different check sizes. The projector was operated by two foot switches. The first switch briefly projected the slide, and the second switch changed the slide.

Subjects were told that they would sometimes, but not always, see a checkerboard pattern in part of the screen. They were told to look steadily at the fixation light (F in Fig. 1) and to say after each projection both whether they saw checks and which quadrant was checked.

RESULTS

In preliminary experiments the effectiveness of a brief (185 ms) presentation time in reducing the effect of eye movements was tested by deliberately moving the eye immediately the test pattern was presented. Eye movement during the stimulus presentation would cause the after-image of the test pattern to be blurred and displaced from the fovea. We found that, unless the eye movement anticipated the presentation, the after-image was not appreciably displaced from the fovea for the presentation time of 185 ms used in the present experiments.

The following examples illustrate some features of this method by comparing acuity measures with Bjerrum screen campimetry.

CONTROL EXPERIMENTS Control data were obtained from the unaffected eyes of 17 patients with pre-chiasmal lesions and from five control subjects. Ages ranged between 20 and 35 years. For the 4° stimulus all control subjects could see checks down to a check size of either 1.6 minutes

or at the worst 2.6 minutes in every quadrant. For any given eye the acuity of different quadrants did not differ by more than 30%. In eight control eyes examined with the annular stimulus, acuity was better than 4.9 minutes in every quadrant.

CASE 1

RETINAL ARTERY OCCLUSION FROM A CHOLESTEROL EMBOLUS A 60 year old male patient presented with sudden onset of visual failure in the right upper field of vision. This progressed over two days to involve the whole of the right field. The patient had suffered a myocardial infarction 10 years previously with subsequent angina of effort. General examination was normal except for the signs of aortic stenosis. Examination of the central nervous system showed

for the right eye the large upper/lower asymmetry evident on campimetry was also marked within the macular area. Even so, the resolution of the two lower macular quadrants was within normal limits. The left eye showed some upper/lower asymmetry in the same sense as the right eye's though much less marked. This asymmetry was not evident in the campimetric plot.

CASE 2

RETINAL CHOLESTEROL EMBOLI AND HYPERTENSION A 57 year old male patient was admitted with a history that six weeks previously he suddenly lost the sight in his right eye for four minutes and then vision recovered. He experienced four further similar attacks before admission and in the final attack he noted a persisting visual field defect.

At examination he was overweight and hyper-

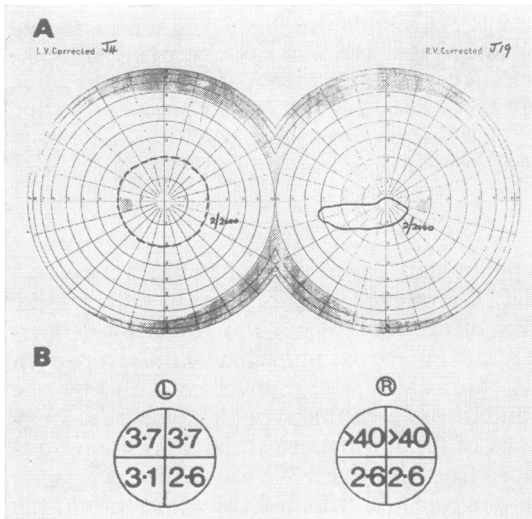


FIG. 2 Case 1. A. Bjerrum screen campimetry showing 2/2 000 isopter. B. Acuity measurements for individual quadrants of the left and right eyes' central 4°. The numbers are the side lengths (in mins arc) of the smallest checks that could just be seen.

reduced visual acuity in the right eye (J19). Visual acuity was J4 in the left eye. Retinal examination showed an intraluminal refractile cholesterol embolus in a descending branch of the retinal artery at the lower disc margin.

The resolution measurements of Fig. 2 show that

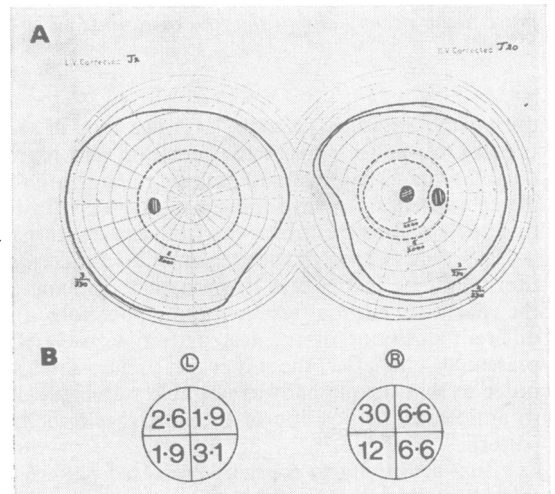


FIG. 3 Case 2. A. Bjerrum screen campimetry showing 3/2 000, 6/2 000, 3/330, and 11/330 isopters. B. Acuity measurements for the individual quadrants of the left and right eyes' central 4°.

tensive (blood pressure 230/120 mmHg). The right optic fundus showed an oval area of pallor in the upper temporal retinal quadrant with distal flame-shaped haemorrhage, and cholesterol crystals were seen at several arterial bifurcations. Visual acuity was J2 R, J2 L.

No further abnormal signs were elicited at

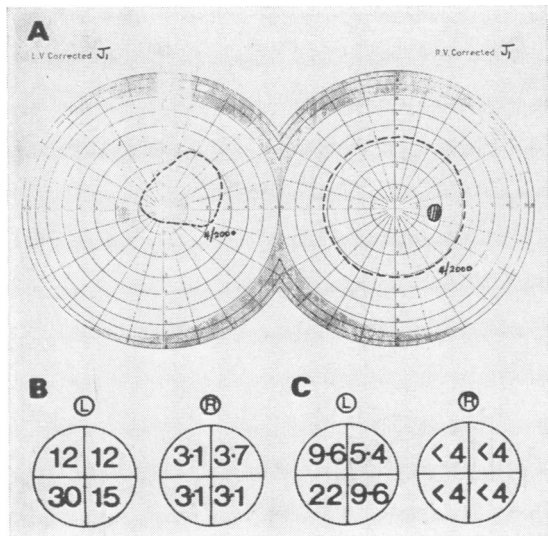


FIG. 4 Case 3. A. Bjerrum screen campimetry showing 4/2 000 isopter. B. Acuity measurements for the individual quadrants of the left and right eyes' central 4°. C. Acuity measurements for individual quadrants of an annular region surrounding the macula of inner diameter 4° and outer diameter 10°. The annulus was centred on the fovea.

examination. Investigations were normal apart from cardiac enlargement on a chest radiograph and an electrocardiogram indicated previous myocardial infarction.

His hypertension was treated and anticoagulant therapy with Warfarin was started.

The resolution measurements of Fig. 3B show a marked upper quadrant loss in the right eye that is not evident in Fig. 3A. Also for the left eye the resolution measurements of Fig. 3B are sufficiently sensitive to show differences between quadrants that are not suggested by the symmetrical 3/3 000 isopter.

CASE 3

LEFT RETROBULBAR NEURITIS IN MULTIPLE SCLEROSIS

A 25 year old female patient attended with a classical history of left retrobulbar neuritis. The attack occurred six weeks before presentation. Visual loss was complete in the left eye for two weeks and then gradually improved. A week before presentation she developed other symptoms and signs of demyelination consisting of numbness in the left arm and in both lower limbs and in the trunk. General examination was normal. Examination of the central nervous

system showed left optic atrophy and a spastic paraparesis with sensory impairment to pinprick to a level of the 4th dorsal segment. Visual acuity was J1 in the left eye and J1 in the right eye.

By comparing acuities within the macula and the 4°-10° annulus it is possible to detect a depression of macular activity with respect to the adjacent periphery or *vice versa*. This point is illustrated when Figs 4B and 4C are compared for the left eye, showing a depression of macular acuity relative to the adjacent peripheral field. The acuity measurements also show relatively greater loss in the lower half-field especially in the lower left quadrant, in accord with campimetry (Fig. 4A).

CASE 4

RIGHT RETROBULBAR NEURITIS IN MULTIPLE SCLEROSIS

A 25 year old male patient presented with a classical attack of retrobulbar neuritis. Vision was lost in the right eye for several days and slowly recovered over the subsequent four months. Three months after the attack of retrobulbar neuritis he developed symptoms and signs of spinal demyelination consisting of paraesthesiae in both lower limbs and clumsiness of the left hand. General examination was normal. Neurological examination showed that visual acuity in the right eye was reduced to finger-counting. There was peripheral constriction of the right visual field and right optic atrophy. Visual acuity was J1. The left optic disc was normal. He had increased reflexes in both lower limbs, a right extensor plantar response, and contact dysaesthesiae in both lower limbs to the level of the second lumbar segment. Vibration sensibility was impaired to the anterior superior iliac crests. Visual fields (Bjerrum screen) showed a central scotoma in the right field. Figure 5 shows isopters recorded during the acute phase of the attack. The large central field loss in the right eye extended well into the temporal half-field.

Figure 6A shows isopters recorded some two months after those of Fig. 5. The right eye's 3/2 000 isopter was slightly constricted, but showed no evidence of greater loss in the temporal half field. In contrast, the acuity measurements of Fig. 6B were sufficiently sensitive to show a clear left:right asymmetry in the right eye with depression of acuity in the temporal half-field.

CASE 5

PITUITARY TUMOUR COMPRESSING OPTIC CHIASM AND OPTIC NERVES

A 54 year old male accountant was admitted for investigation of impaired vision in his left eye which had been present for six months. At examination the only clinical finding was a temporal

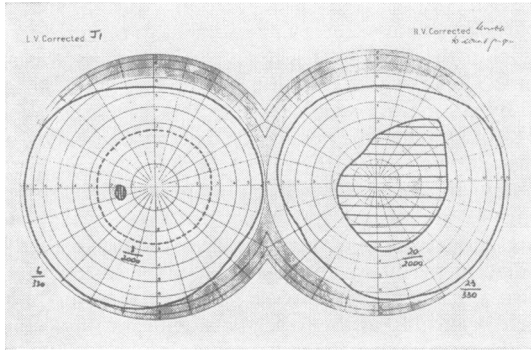


FIG. 5 Case 4. Bjerrum screen isopters recorded during the acute phase of retrobulbar neuritis. The 3/2 000 and 6/330 isopters are shown in the unaffected eye and the 20/2 000 and 23/330 in the affected eye.

paracentral scotoma in the right eye and a smaller paracentral scotoma in the left eye.

A skull radiograph showed an enlarged pituitary fossa. Carotid angiography showed elevation of the left anterior cerebral artery. Lumbar pneumo-encephalography confirmed a suprasellar extension of a pituitary tumour.

Endocrine investigations confirmed mild hypopituitarism.

At operation (Mr J. W. McIntosh) through a right frontal trephine the optic chiasm and both optic nerves were elevated by a tumour arising from the pituitary gland. The tumour was removed. Histology confirmed a chromophobe adenoma. Treatment was completed with Cobalt 60 teletherapy to the pituitary. He was discharged on maintenance therapy of cortisone and thyroxine.

The resolution measurements of Fig. 7B show a marked temporal half-field loss in the left eye. Though resolution was comparatively unaffected in the central 4° of the right eye, the major loss again fell in the temporal half-field.

CASE 6

LEFT HOMONYMOUS HEMIANOPIA AFTER HEAD INJURY

A 44 year old male patient was admitted with a history of having been struck on the head with a piece of metal two days previously. He did not lose consciousness.

He complained of vertigo and that he was unable to see objects in the left half of his vision.

On examination the only abnormal finding was a left homonymous hemianopia. Investigations including skull radiography, electroencephalography, and right carotid arteriography were normal. A clinical diagnosis of right posterior cerebral artery

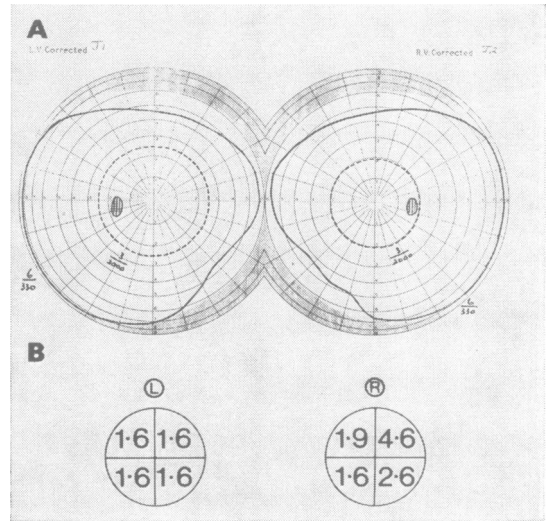


FIG. 6 Case 4. Same patient as in Fig. 5 tested 2 months later. A. Bjerrum screen campimetry showing 3/2 000 and 6/330 isopters. B. Acuity measurements for individual quadrants of the left and right eyes' central 4°.

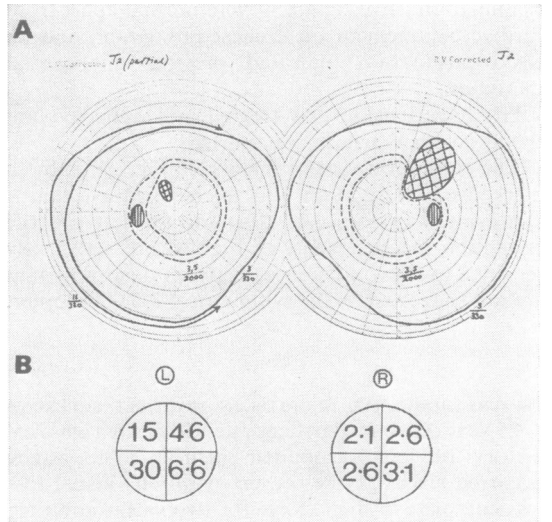


FIG. 7 Case 5. A. Bjerrum screen campimetry showing 3/2 000, 5/2 000, 3/330, and 11/330 isopters. B. Acuity measurements for individual quadrants of the left and right eyes' central 4°.

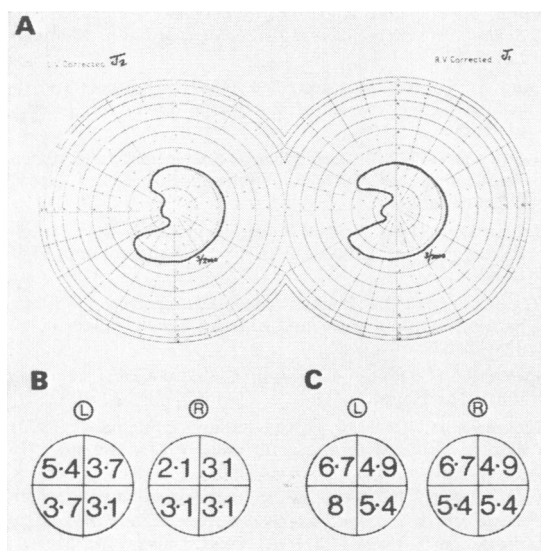


FIG. 8 Case 6. A. Bjerrum screen campimetry showing 3/2 000 isopters. B. Acuity measurements for the individual quadrants of the left and right eyes' central 4°. C. Acuity measurements for individual quadrants of an annular region surrounding the macula of inner diameter 4° and outer diameter 10°. The annulus was centred on the fovea.

occlusion was made. The hemianopia has not improved when examined 12 months after the event.

The isopters at 3/2 000 were asymmetrical in each eye. Although the visual fields in the two eyes were congruent (Fig. 8A), the macular acuities were not congruent. While the right eye had normal acuities for the central fovea and for the extrafoveal annulus, the left eye had diminished foveal acuity (Figs 8B and C).

DISCUSSION

The six patients illustrate features of the method described in this article which may offer additional information and advantages over Bjerrum screen campimetry. These features are: (1) greater sensitivity to visual pathology; (2) reliable measurements of quadrantic or hemianopic losses within the macula; (3) measurements of differential losses between the macula and adjacent periphery; (4) an objective quantitative expression of acuity; (5) the test can be completed quickly (three minutes) and is straight-

forward enough to be carried out by a non-medical assistant. The method has since been extended to test octant and quadrant sectors of the central field and out to 25° in order to assist early detection of glaucoma (Regan, 1972a).

The test will provide additional information in lesions of the visual pathway. We have described its application to retinal lesions, lesions of the optic nerves, and lesions of the optic chiasma produced by a pituitary tumour. It may also have application to other lesions such as cranio-pharyngioma, suprasellar meningioma, in the bizarre field defects that occur in chiasmatic arachnoiditis and in central and caecocentral scotomas that occasionally occur with chiasmatic disease and may be misinterpreted as optic neuritis or toxic amblyopia. Its sensitivity might indicate early visual acuity loss by inward radial extension of an acuity defect where measurement of visual acuity in the macula could be compared with measurements in a more peripheral annulus (as, for example, in Fig. 4B, C).

Finally, there is reason to suppose that measurements of the way in which resolution varies within the visual field might not only be more sensitive but might also provide information complementary to that provided by Bjerrum screen perimetry. This possibility is suggested by the body of sensory and electrophysiological evidence that different neurophysiological mechanisms are responsible for the visual resolution of fine detail and visual sensitivity to the illumination level of a localized region within the visual field (for example, see Spekrijse, 1966; Green, 1968; Cornsweet, 1970; Land and McCann, 1971; Regan, 1972b, 1973; Spekrijse *et al.*, 1973). In both monkey and man, the result of visual injury may be to degrade visual sensitivity to fine detail separately from visual sensitivity to either illumination level or total light flux; furthermore, these two visual functions may recover with different time courses (Humphrey and Weiskrantz, 1967; Teuber *et al.*, 1960; Brindley *et al.*, 1969). All this suggests that, on the one hand, degraded visual resolution and, on the other hand, impaired ability to detect an illuminated disc might reflect different types of damage to the visual system.

We thank Dr R. Hully who carried out Bjerrum screen campimetry and Dr E. C. Hutchinson who referred case

1 and case 6 for investigation. The instrument used in the experiments reported here is a prototype acuity campimeter constructed and supplied by Wilkinson Sword (Research) Ltd.

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