NEUROLOGICAL INVESTIGATIONS

Vision

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Before the era of scientific medicine the eye was the window to the soul, and after the invention of the ophthalmoscope, the eye became the window to the brain. Now, in the 1990s, the "decade of the brain", it is no exaggeration to say that it is the neurobiology of the visual sensory apparatus as a whole and not just the eye which offers a window to the brain. As visual function is now increasingly understood in terms of the parallel processing of streams of data concerning form, colour, and motion in parvocellular and magnocellular systems so is modern clinical practice increasingly based on these concepts. This article offers a guide based on current practice to the clinician faced with a patient with an apparently normal eye but who has poor vision and who therefore starts to cross the threshold from ophthalmology into neurology.¹

Visual acuity testing

Although acuity testing only measures the central 1 to 2 degrees of field at 100% contrast, this measurement of visual health is almost universally understood and changing levels of performance measured in this way sometimes assume great medicolegal significance. The physiological basis and shortcomings in clinical practice may be less widely appreciated. The minimal resolvable or ordinary acuity is most applicable to everyday practice, involving the correct identification of a target characteristic. In health, there is a remarkable concordance between the observed minimal angle of resolution and the expected resolving capacity of the eye's optics. In disease, the observed minimal angle of resolution will drop not only as a result of defects in optical imagery, but also where abnormalities arise in foveal fixation, photoreceptor structure and function, photopic luminance levels, and full integrity of the neural pathways.^{2,3}

The purest visual acuity test uses a square

wave grating comprising black and white stripes of equal width. An acuity of 6/6 equates to a grating made up of stripes each subtending 1 minute of arc at the testing distance, so that the separation between two black and two white stripes is 1 minute; pairs of stripes must therefore be repeated 30 times to subtend a visual angle of 1°. This is termed the spatial frequency and is measured in cycles/degree; the narrower the stripes the higher the spatial frequency. The highest frequency grating which elicits a response is the measure of the visual acuity. Table 1 shows the correlation between Snellen values, stripe width, and spatial frequency.

Grating acuities have been shown to be superior to visual acuity based on optotypes especially when there is foveal pathology or dense amblyopia. The stripes can be presented on a TV screen and form the basis for the objective measurement of acuity using optokinetic nystagmus (rotating striped drum to elicit eye movements), visually evoked cortical potentials, and preferential looking techniques. Grating acuity techniques are in standard use in visual science and in the clinical assessment of visual function in infants (fig 1).

For the remainder of clinical practice, acuity is measured by presenting a selection of ordinary, recognisable targets or optotypes for the subject to choose between so that guessing is eliminated. A variety of optotype patterns can be used for the determination of the minimal resolvable acuity. The most familiar is the Snellen chart in which the standard pattern is enlarged so that resolution is achieved (fig 2). For a normal observer in best focus the resolution limit is 30 to 60 seconds of arc. The E optotype for 6/6 vision (which uses a sans serif or Gothic typeface) subtends 5 minutes of arc vertically and horizontally, and 1 minute between each stroke when viewed at 6 m (or 20 feet). If the subject can only see at a distance of 6 m an optotype which would subtend 1 minute of arc at 9 m, then the acuity is said to be 6/9 and so on through to 6/60. Sometimes it is convenient to express acuity in terms of visual efficiency scores (for example, in medicolegal work) or as Snellen ratios (for example, when entering acuity data into automated perimetry equipment) (table 2).

Because some optotypes are easier to see than others, single letter charts have some advantages particularly when assessing

Table 1 Visual acuity and grating acuity equivalents

Acuity (m)	Acuity (feet)	Spatial frequency (cycles/degree)	Stripe width (mm)
6/6	20/20	30	1
6/12	20/40	15	2
6/30	20/100	6	5
6/60	20/200	3	10

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Figure 1 Contrast gratings used to obtain grating acuities. (A) $0.29 \text{ cycles/}^\circ$ at 38 cm roughly equivalent to a Snellen acuity of $6/620$. (B) $7.7 \text{ cycles/}^\circ$ at 38 cm roughly equivalent to a Snellen acuity of $6/24$.

patients with cognitive or reading difficulties. In the Landolt C test, the subject must identify the orientation of the C by finding the side of the gap in the curve and in the E for illiterate patients test the direction of the bars must be recognised. If the minimal resolvable optotype size is 1 minute of arc then the

acuity is said to be 6/6. These tasks may be easier to perform than the task of reading a standard Snellen line alone and are not strictly equivalent. Although the Snellen chart is well understood, the patient's performance may vary simply because of poor illumination and variable optotype complexity. As a general rule the smallest line that the patient can read is used to quantify visual acuity—one or two mistakes per line are often allowed. Changes in visual acuity over time are reported in units of "number of lines lost or gained". This method is subject to a number of limitations: as each line becomes smaller the number of letters becomes greater and therefore harder to read; a two line loss from $6/20$ to $6/60$ is a tripling of the visual angle but a two line loss from $6/5$ to $6/9$ is less than double the visual angle and therefore is not comparable. In terms of visual pathophysiology, there may only be a weak correlation between the level of underperformance on a Snellen chart and the level of dysfunction of the visual apparatus and it is not correct to say that an eye with a Snellen fraction of 0.25 ($6/24$) has a disease process twice as severe as one with a fraction of 0.5 ($6/12$).

For these reasons the "Logmar" chart is preferable. The working distance is 4 m . Each letter on a line has uniform difficulty, there are the same number of letters on each line, and the size increase from one line to the next is governed by a simple geometrical progression of the log of the minimal angle of resolution (LOGMAR). In conjunction with standardised illumination systems Logmar charts were first introduced into ophthalmology in 1982 for the Early Treatment of Diabetic Retinopathy Trial and other multicentre prospective trials and are now widely used in clinical practice where accurate follow up data are required (fig 3).^{4 5}

NEAR VISION TESTING

It is often extremely useful to determine acuity for near as well as for distance as some patients experience difficulty in reading out of proportion to their Snellen acuity as a result of parafoveal scotomata (for example, macular degeneration) or to poor foveal fixation in certain eye movement disorders (for example, jerk nystagmus), which prevent the whole word being seen at the same time. The post-fixational blindness of a dense bitemporal hemianopia may also be detected by this method, as may cerebral dyslexia. In the United Kingdom, the current standard notation used is the N system where text printed in the Times Roman font is expressed in font sizes as points (multiples of $1/72\text{nd}$ of an inch) and the reading acuity is denoted as the minimum size comfortably seen at a normal reading distance (33 cm) with presbyopic correction when appropriate. This is likely to be replaced by reading versions of the Snellen and Logmar charts in the near future.

FACTORS INFLUENCING VISUAL ACUITY

To achieve peak performance, referred to as normal visual acuity, all optical, anatomical,

Figure 2 Snellen charts. (A) Standard format; (B) single letter format.

and physiological elements must themselves perform normally. For example, acuity is readily degraded by refractive error so that 1 dioptre of defocus will reduce the Snellen fraction to about 0.3. Young hypermetropes (hyperopes) can accommodate to overcome their own refractive error, but myopes and presbyopes cannot. A pinhole is a very helpful method of determining whether acuity is due to refractive error rather than ocular pathology or neurological disease. It is important to remember that a pinhole, however, will only correct to 6/6 up to a maximum of 4 dioptres of spherical and cylindrical error and that an

up to date refraction is essential in all cases of unexplained visual loss. Optical quality also depends on pupil size: visual acuity remains roughly constant in the range of 2.5 to 6 mm after which the minimal angle of resolution falls off. In elderly people, as pupil size diminishes and lenticular opacities increase the spatial resolution of the eye may fall even in the absence of specific pathological conditions.

Pupillary light reflexes

The assessment of afferent pupil defects is an important part of the neuro-ophthalmic

Table 2 Visual acuity equivalents in different notations

Minutes of arc (minimal angle of resolution—MAR)	Log MAR	Snellen acuity at 4 m	Snellen acuity at 20 feet	Snellen acuity at 6 m	Visual efficiency (%)	Snellen fraction
0.75	− 0.1	4/32	20/15	6/4.5	104	1.33
1.0	0.0	4/4	20/16	6/5		
1.25	+ 0.1	4/5	20/20	6/6	100	1.0
1.5			20/25	6/7.5	96	0.8
			20/30	6/9	91	0.67
	+ 0.2	4/6.3	20/32	6/10		
2.0	+ 0.3	4/8	20/40	6/12	84	0.5
2.5	+ 0.4	4/10	20/50	6/15	76	0.4
3.0			20/60	6/18	70	0.33
	+ 0.5	4/126	20/63	6/20		
4.0	+ 0.6	4/16	20/80	6/24	58	0.25
5.0	+ 0.7	4/20	20/100	6/30	49	0.2
6.0			20/120	6/36	41	0.17
	+ 0.8	4/25	20/125	6/38		
7.5			20/150	6/45	31	0.133
	+ 0.9	4/32	20/160	6/48		
10.0	+ 1.0	4/40	20/200	6/60	20	0.10
20.0			20/400	6/120 (3/60)	3	0.05

examination and subtle abnormalities may often be clinically significant. A discussion of unequal pupils and efferent pupil defects is beyond the scope of this paper.

The pupil of an eye that is blind from retinal or optic nerve disease will fail to react directly to light but will constrict consensually when the other healthy eye is stimulated. The blind eye shows an afferent pupil defect. Much more commonly, however, a disease process will leave one eye with a degree of visual impairment and direct stimulation will still result in pupillary constriction. In these circumstances it is important to perform a

swinging light test to look for a relative afferent pupillary defect (Marcus Gunn pupil). Relative afferent pupillary defects are best seen by moving a hand held light from one eye to the other, holding the light to each eye for about one second in a regular symmetric way. As the light shifts from the eye with normal vision to the eye with reduced vision, the direct light stimulus is no longer sufficient to keep both pupils small; thus they both dilate. The test is very quick and easy to perform and is sufficiently sensitive to detect residual optic nerve dysfunction after an episode of retrobulbar neuritis and recovery of acuity to

Figure 3 Logmar chart.

6/6. Only one working iris sphincter is necessary to perform this test. For example, a third nerve palsy or anterior ocular segment disruption as a result of trauma, inflammation, or surgery will not stop the examiner from observing the direct and consensual responses of the intact pupil as each is alternately stimulated. A dim side light is invaluable, especially in patients with dark irides, to observe the pupillary movements. The afferent pupil defect may also be quantified by using a series of neutral density filters over the good eye to reduce the stimulus to the point at which a balance is reached.

Afferent pupil defects are absent in functional visual loss and in lesions of the retinal macula, and are either absent or subtle when central visual loss is due to amblyopia. Optic nerve lesions, however, typically produce significant afferent defects and hence the test is of great value in cases of unexplained visual loss. When optic neuritis has been diagnosed and there is no relative afferent pupillary defect, the diagnosis is either wrong or else there is bilateral disease. The acronym PERLA standing for "pupils equal and reacting to light (and accommodation)" is often used in clinical notes but does not indicate whether the consensual reflex has been tested, or whether a relative afferent defect is present.

Colour vision

It is a characteristic of certain disorders of the anterior visual pathways that sensitivity to hue discrimination (colour vision) may be impaired whereas luminance and contrast based functions (acuity) are preserved.^{6,7} At the level of retinal photoreceptors, colour vision is a function of three classes of cones of overlapping spectral sensitivities for red, green, and blue so that colours are represented by differential matching of the output of each group. At a neural level, colour vision is processed according to a colour opponent code whereby certain colour pairs appear as mutually exclusive opposites such as red-green and blue-yellow. The physiological substrate for colour opponent encoding lies within the neural elements of the retina. In clinical terms, these concepts are reflected in

the classification of congenital defects of colour vision according to whether one or more classes of photoreceptor are missing (dichromats and monochromats) or have anomalous sensitivity to specific wavelengths of light (anomalous trichromats):

The inherited dyschromatopsias are binocular and symmetric and do not change over time. Monochromats have major cone defects and also have poor acuity. Dichromats and anomalous trichromats have normal acuity.

Acquired dyschromatopsias are different from congenital defects in several respects. Firstly, they are noticeable to the observer. Secondly they may be monocular or even restricted to one part of the visual field. Thirdly, although colour defects may be much more pronounced than acuity defects, acuity is generally reduced to some degree. It is helpful to classify acquired defects of colour vision as follows:

According to Kollner's rule patients with neural disorders have a preponderance of damage to red-green discrimination with preservation of blue-yellow discrimination (type I and II defects), whereas those with retinal and choroidal disease may show selective loss of blue-yellow discrimination (type III defects).

Some optic neuropathies, however—especially those associated with preserved acuity—may show type III defects. Cones sensitive to blue are not found in the central 0.5 degrees of the field, so that disease processes that selectively damage the extrafoveal visual field will leave the patient with normal acuity and normal red-green discrimination. Examples include glaucoma, dominant optic atrophy, chronic papilloedema, and early chloroquine retinal toxicity. More typically, optic neuropathies that involve the fibres of the papillo-macular bundle such as retrobulbar neuritis, Leber's disease, and extrinsic compression will damage neural elements serving foveal function and green-red discrimination will be damaged, often out of proportion to acuity loss. Table 3 summarises the classifications of colour deficiency.

Formal colour vision testing with spectral light sources graded for luminance changes is very demanding and time consuming, and not very practical in the clinical setting.

Table 3 Classification of congenital and acquired colour deficiency

Name	Red deficient	Green deficient	Blue deficient
<i>Congenital colour deficiency</i>			
Anomalous trichomats	Protanomal	Deuteranomal	Tritanomal
Dichromats	Protanope	Deuteranope	Tritanope
Monochromats	Blue cone monochromats/ rod monochromats		
<i>Acquired colour deficiency</i>			
	Alternative name	Hue discrimination defect	Visual acuity loss
Type I	Red/green "protan like"	red/green discrimination loss: preserved blue/yellow discrimination	moderate to severe
Type II	Red/green "deutan like"	red/green discrimination loss plus mild blue/yellow impairment	moderate to severe
Type III	Blue/yellow "tritan like"	blue/yellow confusion	mild to moderate

Figure 4 Humphrey automated perimetry showing increased retinal thresholds to static testing in the central (24°) temporal hemifields of each eye representing a bitemporal hemianopia.

Pseudoisochromatic plates are very widely used because of their portable nature, low cost, and ease of use. The plates consist of a series of dots of various colours and sizes that are clustered together into carefully arranged patterns of various hues. These hues can readily be distinguished by normal trichromats but not by those with defective colour vision. The patterns form highly legible figures that are visible even to those with poor acuity. An initial test plate excludes subjects whose acuity or reading skills do not allow them to perform the test. Commercially available pseudoisochromatic plates (Ishihara and Hardy, Ritter, Read (HRR) plates) are designed to detect those with congenital dyschromatopsias, but do not allow protan-deutan distinctions or the separation of anomalous trichromats from dichromats. They may be used in the qualitative assessment of acquired colour defects. A greater quantitative element is supplied by the Farnsworth-Munsell 100 hue test in which the subject is required to arrange a series of coloured discs in sequence between pairs of reference discs.⁶ The order of discs is then plotted in a circular diagram so that the degree of error is represented by points far away from the centre of the diagram. Characteristic patterns for errors along the red-green and blue-yellow axis will emerge allowing full characterisation of the dyschromatopsia. Even with automated, computer assisted versions, this test remains inconvenient and time consuming and is not greatly used. The Farnsworth D-15 (dichotomous) panel test simplifies matters by recording confusions in the allocation of non-adjacent hues into their correct colour grouping.

Other techniques include the Pickford-Nicholson anomaloscope in which the subject views a translucent panel through a monocular objective and has to match pairs of coloured lights. A more modern alternative is provided by computer assisted colour contrast sensitivity systems in which standard optotypes are presented in colour against a coloured background and the contrast thresholds measured in each of the colour confusion axes. It is likely that in many clinics a psychophysical central vision assessment package can be used where thresholds for acuity tasks, contrast sensitivity, and colour contrast sensitivity can all be presented in a sequence of quick user friendly formats with a micro-processor and standard computer monitor.

Visual field testing

The analysis of the visual fields retains central importance in the localisation of defects in the visual system, and for monitoring the natural history of a condition and responses to treatment.⁸ Simple confrontation testing (qualitative) remains useful in clinic based and bedside topical diagnosis, but semiquantitative and quantitative methods are essential for accurate documentation, detection of more subtle defects, and for assessing progress.

In quantitative perimetry the task is always

hampered by the need for highly trained and experienced perimetrists who can reliably distinguish between pathology and artefact. Enormous efforts have been devoted to the task of replacing perimetrists with computers and now automated perimetry machines are widely available (fig 4).⁹⁻¹¹ These can now generate numerical indices of point by point deviations in retinal thresholds supported by reliability scores and by statistical analysis packages to help to determine the significance of any departure from age matched controls. Ease of data storage and standardisation of presentation are advantages. With increasing sensitivity, however, specificity is lost. Although it is now possible to explore the visual field at the limits of complex physiological measurement—even to the extent of measuring differential function in ganglion cell subpopulations according to their motion detection and luminance functions—it is important to deploy strategies that support practical management decisions. Automated systems measuring static or motion detection thresholds are primarily designed for the detection of subclinical disease states not detectable by confrontation, in particular early glaucomatous optic neuropathy, and are not necessarily suitable for characterising patterns of field defect, which are so important in neuro-ophthalmic diagnosis.¹² Other problems include patient learning effects, physiological variation in field performance over time,¹³⁻¹⁶ and fatigue.¹⁷ Also, test strategies emphasise threshold changes across the horizontal meridian, but in neuro-ophthalmic assessment, the vertical meridian is of crucial diagnostic importance, and fixation testing strategies rely on repeated blind spot checking; this is of course lost in bitemporal defects with chiasmal disease.^{18,19} Table 4 summarises these techniques for assessing the visual field.

COLOUR PERIMETRY

As described in the section on colour vision testing, acquired lesions of the optic nerve characteristically show chromatic defects that may precede luminance defects. It follows that in some circumstances colour visual field testing is more sensitive than using white test targets of differing sizes and light intensities. From Kollner's rule, optic neuropathies often manifest red-green discrimination defects that are readily picked up with a red target and confrontation methods ("in which hemifield is the colour brighter?"), especially with the tangent screen.

Funduscopy: direct and indirect ophthalmoscopy, special techniques

The direct ophthalmoscope incorporates a light source focused directly on to the retina through a small angled mirror that fills either half or the whole of the aperture. The mirror centre is unsilvered so that the illuminated fundus can be seen through it. Between the returning light rays and the examiner's eye there is a revolving magazine of lenses that usually range from -30 to $+30$ diptres to

Table 4 Techniques for assessing the visual field

Method	Variants	Comments
Qualitative	Confrontation with fingers or neurological pin heads Visually elicited eye movements Finger mimicking Hand and colour comparison Blinking to menace and flashing lights	Infants and obtunded adults Preverbal children and dysphasic adults Children and adults Children and obtunded adults
Semiquantitative	Target screen perimetry (Bjerrum)	Very rapid. Suitable for all patients with steady fixation. Good for topical diagnosis of neuro-ophthalmic disease
Quantitative	Goldmann kinetic and static perimetry Automated perimetry	Standard reference method: very operator dependent Excellent for detecting early bitemporal defects. Unsuitable for ill patients or those with poor concentration, poor acuity, or functional visual loss

correct any inherent refractive error in either the patient or the examiner. In practice, it may be easier to view the fundus of a patient with a larger refractive error by leaving the glasses on and turning the ophthalmoscope lens to zero. Changing the ophthalmoscope lens power will also change the depth of focus within the eye and allow examination of media opacities, especially in the lens. The field of view with the direct ophthalmoscope is small, about 6° with a magnification $\times 15$; the image is erect and real. A green or "red free" filter is useful for examining nerve fibre detail, retinal vessels, haemorrhages, and microaneurysms. The examiner views the patient's right eye with his right eye and changes eyes to view the left. Pupillary dilatation with 1% tropicamide drops is essential for the best retinal view. The risk of precipitating an attack of acute angle closure glaucoma by using dilating drops is very low and is usually outweighed by the benefits of achieving an adequate view.

The direct ophthalmoscope, by virtue of its small field and high magnification, is very suitable for viewing the optic nerve head. When a wider field and an appreciation of stereoscopic depth detail is required, indirect ophthalmoscopy is used. In this technique a light source is directed into the eye and the reflected light is gathered by a hand held condensing lens to form a virtual inverted image of the retina. The size of the image varies according to the power of the condensing

lens: the greater the power the smaller the image. A +13D lens magnifies the retina about four times and a +30D lens by two. Indirect ophthalmoscopy has the advantage of providing high intensity illumination, stereopsis, and a wide field of view as well as allowing dynamic assessment of vitreoretinal pathology. Disadvantages include the inverted image, the requirement for wide pupillary dilatation, and the considerable practice needed to master the technique.

Other methods for viewing the fundus require a slit lamp and are especially helpful in the assessment of stereo detail in macular pathology. These include fundus contact lenses and the non-contact Hruby and Volk lenses.

FLUORESCCEIN ANGIOGRAPHY

Fluorescein angiography provides an important adjunct to the ophthalmoscopy of diseases of the retina and the optic nerve head by showing evidence of disease activity and by providing a permanent record. After an intravenous injection, a dilute solution of fluorescein in the blood will absorb blue light at a peak of 480 nm and emit it as green-yellow at a peak frequency of 530 nm. With appropriate filters on flash fundus photography the exciting blue light can be separated from the emitted light and the retinal and choroidal circulations studied. Dynamic studies of the passage of dye from the arterial to venous sides of the circulation in the two vascular

Table 5 Common indications for fluorescent angiography in neuro-ophthalmology

Clinical problem	Comment
Optic disc swelling	Distinction between true acquired pathological disc swelling of raised intracranial pressure or local disease and pseudopapilloedema of hypermetropic eyes, buried disc drusen, and other anomalies.
Multifocal white matter lesions or unexplained optic neuropathy	Subtle or subclinical retinal vasculitis indicates an inflammatory cause (multiple sclerosis, sarcoidosis, or Behçet's disease).
Unexplained visual acuity loss with a central scotoma	Subtle macular pathology (age related macular degeneration, branch retinal vein occlusion, retinal dystrophies) well demonstrated.
Unexplained neuromuscular disease	Mild or severe forms of retinal pigment epithelial degeneration well shown in the mitochondrial myopathies (Kearns-Sayre syndrome).
Unexplained (aseptic) meningitis	Demonstration of choroidal abnormalities in the uveomeningeal syndromes (Vogt-Koyanagi-Harada syndrome, Behçet's disease sarcoidosis, non-Hodgkin's lymphoma, metastatic carcinoma).

Figure 5 Fundus fluorescein angiogram showing abnormal microvascular perfusion at the macula in a patient with central visual loss due to a branch retinal vein occlusion.

beds are obtained. In the evaluation of optic disc swelling, true disc oedema can be distinguished from the pseudopapilloedema of buried optic disc drusen or elevated discs in hypermetropic eyes by demonstrating the presence of dilated capillaries on the disc surface during the arterial phase of the angiogram, and hyperfluorescence in the late venous phase. Also, buried disc drusen may fluoresce without any injection of dye—a phenomenon known as autofluorescence. This avoids unnecessary imaging and CSF studies, and even shunting procedures. Table 5 gives further examples.

It is important to remember that fluorescein angiography is an invasive study. Patients often experience nausea and occasionally vomit shortly after injection. They should be warned that the skin (but not the sclera) appears icteric for a few hours and that urine passed during this time will fluoresce. Rarely, hypersensitivity reactions occur—probably due to the presence of macromolecular impurities because fluorescein itself has a low molecular weight and does not provoke an antigen-antibody reaction. This usually takes the form of urticaria and transient bronchospasm but may occasionally give rise to anaphylactic shock. Full resuscitation equipment is mandatory and the investigation is contraindicated in patients with a history of asthma or adverse reactions to radiological contrast media.

Contrast sensitivity

In visual science contrast sensitivity forms the basis of one of the most important psychophysical methods for measuring visual function—for example, allowing the demonstration that neurons of the visual system are

sensitive to limited ranges of spatial frequency and orientation. In clinical practice these methods allow the detection of otherwise sub-clinical pathology and offer a sensitive way of following up patients with chronic disease such as optic nerve function after an episode of optic neuritis.

The patient who complains of “faded” vision but who has a normal (high contrast) Snellen acuity may have defects in contrast sensitivity.²⁰ The level of contrast at which a light and dark pattern is first discriminated is the contrast threshold. No consistent discrimination occurs for contrast below the subject’s threshold for a particular spatial frequency. High and very low spatial frequencies require higher contrast for resolution. Contrast sensitivity is the reciprocal of the contrast threshold and is measured with sine wave (sinusoidal) gratings that show gradual change from light to dark. Measurement aims to record the patient’s contrast threshold over a range of spatial frequencies with gratings of different contrast levels. Because two variables are involved (spatial frequency and contrast threshold) a graph is constructed that sets out the contrast threshold for each spatial frequency, and results in a contrast sensitivity curve. Pathological reduction in contrast sensitivity occurs in developmental and acquired visual defects when the contrast threshold can be raised for low, high, or all spatial frequencies depending on the underlying cause.

In formal systems, spatial vision is represented by sinusoidal or square wave gratings presented on a TV monitor with frequencies ranging between 0.1 and 25 cycles/degree, with standardised visual angles of 5° height and 32° width and with additional counter-phasing at a frequency of 0.6/s to prevent afterimages. User friendly book mounted and

Figure 6 Pelli-Robson format for qualitative contrast sensitivity testing.

wall mounted charts are available—for example, the Vis Tech and Pelli-Robson systems.^{21–24} In a Vis Tech chart photographs of sinusoidal gratings are presented and thresholds for different spatial frequencies are determined by the subject recognising the correct orientation of the stripes whereas in the simpler Pelli-Robson chart (fig 6) standard sized optotypes of uniform spatial frequency are presented with decreasing contrast as the patient reads along a line allowing threshold detection. Computer generated presentations have the advantage of a capability to assess temporal effects (loss of contrast sensitivity with time), and colour contrast sensitivity.^{25–29}

Macular pathology and amblyopia

In all instances of deficient vision the clinician must ask whether the observed pathology matches the degree of visual loss. Normally this question lies within the province of the general ophthalmologist, but it is not unusual for a patient to have an apparently normal eye and yet still have poor vision raising the question of a retrobulbar optic neuropathy. Localisation to the optic nerve is supported by the presence of dyschromatopsia, a central scotoma or altitudinal field loss, and a relative afferent pupil defect. A central scotoma (but **not** a relative afferent pupil defect) may also be due to retinal pathology at the macula and subtle pathology may be overlooked. Sometimes the scotoma is too small to be detected by confrontation or perimetry. The Amsler grid is a coarse high contrast grid against which the small paracentral scotomas and central distortions (metamorphopsia, micropsia, macropsia) of macular disease can

readily be seen. In the photostress test the subject fixates on a bright light for a defined period of time (about 30 seconds) and the time to recovery of acuity to the pretest level after eventual disappearance of the induced positive scotoma is measured. In lesions of the choroid, pigment epithelium, or photoreceptors, recovery from this bleaching is greatly prolonged, whereas in optic nerve disease recovery is normal as function is not dependent on the rapid functioning of the visual cycle.

AMBLYOPIA

An additional common difficulty arises in the discrimination between poor uniocular vision due to amblyopia (“lazy eye”), which the adult patient may suddenly become aware of, and an acquired cause of visual loss without evident intraocular pathology. Amblyopia arises from a failure to establish normal cortical representation of the visual input from one eye during the critical period for visual maturation in childhood (six months to nine years) as a result of strabismus, stimulus deprivation, or uncorrected refractive error. Amblyopic eyes may have a small relative afferent pupil defect. When illumination is reduced (for example, by using a standard neutral density filter), acuity is preserved in eyes with amblyopia, but is profoundly degraded in an acquired optic neuropathy. Another characteristic of the amblyopic eye is that acuity improves on testing with a single letter per line format on the Snellen chart compared with a chart with four to five letters per line: this phenomenon is known as crowding. Because amblyopia is often associated with some degree of concomitant squint, the demonstration of reduced motor and sensory fusion by an orthoptist can be invaluable. A squint can be shown by the cover-uncover test where an occluder is placed over one eye and the patient fixates with other eye. Then the occluder is placed in front of the eye initially fixating—in a patient with manifest squint the uncovered eye will move to take up fixation.

Electrophysiological assessment of visual function

Psychophysical methods of acuity measurement, contrast function, motion detection, perimetry, and colour vision all depend on a stimulus-response paradigm that is mediated by the subject’s conscious understanding of the test, and certain assumptions must be made about the correlation of these stimulus-response properties to physiological events. The clinical electrophysiology of vision bypasses this area of theoretical and practical complexity and allows closer correlation with physiological functions. There is the added advantage of being suitable for the assessment of vision in preverbal children, and in cognitively impaired patients.

VISUALLY EVOKED POTENTIALS

After repetitive visual stimulation using

flashes of light or sudden changes in a grid pattern, a cortical potential is detectable that may be summated and averaged using micro-processors after repeated testing to yield the visually evoked cortical potential or visually evoked response (VER).^{30,31} The VER reflects the integrity of the central visual field throughout the entire afferent visual system but is non-specific in localising a lesion to the retina, optic nerve, or cortex. A flash generated VER is stimulated by luminance change whereas a pattern VER is stimulated by contrast change. The complex wave form is described in terms of amplitude and latency according to characteristics of the P₁ wave which is a large positive deflection occurring at around 100 ms. Amplitude varies widely among normal subjects but latency is constant. Pathological conditions of the anterior visual pathways yield relatively non-specific abnormalities of the VER, but the test is none the less useful, especially when carried out in conjunction with flash and pattern generated electroretinograms (see later). Latency delay with relative amplitude preservation is found in demyelination, even long after the acute episode and after visual recovery, and also in optic nerve compression. Amplitude reduction is a feature of ischaemic optic neuropathy and other conditions where axonal loss is prominent compared with conduction block. By careful choice of stimulus variables (check size and reversal speed in the pattern generated VER), the effects of optical blurring can be minimised and the test made sufficiently sensitive to be useful in moderate or minimal acuity loss. For example, the persistent latency changes of optic neuritis are best demonstrated and the effects of optical defocus minimised by using high contrast squares. Additional specificity can be achieved by half field testing whereby differences in amplitude and latency recorded from each hemisphere after uniocular stimulation can be used to assess abnormalities of the optic chiasm. Further refinements in VER techniques, which are currently undergoing clinical evaluation, include differential testing of the parvo and magnocellular systems by the use of test targets that selectively stimulate chromatic, temporal, and spatial functions, and also the discrimination between striate, extrastriate, and subcortical responses. These are likely to be of value in the early detection of subclinical abnormalities such as glaucomatous optic neuropathy and in the assessment of residual vision in those with cortical visual impairment, especially children.³²

ELECTRORETINOGRAPHY

Stimulation of the eye with either a flash or a pattern reversal system results in a recordable potential from the retina that has two principal components^{33,34}: the "a" wave, which depends on the activity of the photoreceptors, and the "b" wave, which arises from the inner nuclear layer and the Müller cells. Disorders predominantly involving cones can be distinguished from those involving rods by performing the test in light (photopic) and dark

(scotopic) conditions. In primary retinal diseases, such as diabetic retinopathy, pigmentary retinopathies and dystrophies, and in toxic degenerations, both the a wave and the b wave are abnormal. Exceptions to this are seen in central retinal artery occlusion where in the acute phase the photoreceptors that derive their blood supply from the choroidal circulation are preserved and therefore the a wave persists whereas the b wave is extinguished. Superimposed on the b wave in a normal retina are a series of rhythmic oscillations referred to as oscillatory potentials. These may be of diagnostic importance when lost in the early stages of both diabetic retinopathy and in pigmentary retinopathies. In advanced disease, the flash ERG will be abnormal whereas in a primary optic neuropathy it will be unaffected unless secondary trans-synaptic degeneration of outer retinal cells has taken place. The flash ERG, however, is a mass retinal response to luminance change, and just as the use of pattern reversal stimuli offers greater sensitivity in the VER, so it does in the ERG. Although origins of the pattern ERG are not entirely clear, it is accepted that the response does arise from retinal structures proximal to the photoreceptors, and it is this anatomical localisation which, together with the fact that pattern reversal stimuli test the central retina only, gives the test its potential power. Unlike the flash ERG, the late components of the pattern ERG are abnormal in disorders of the optic nerve and retinal ganglion cell. Therefore, the pattern PERG may be of value in discriminating subtle cases of central visual loss of central retinal origin, when early and late components will be abnormal, from visual loss of optic nerve origin when the late component alone is abnormal. With the increasing recognition that subclinical abnormalities of retinal function may be of diagnostic importance in, for example, the tapetoretinal degenerations and in the mitochondrial cytopathies, the use of electroretinography is likely to gain in importance in clinical neuro-ophthalmology.³⁵⁻⁴⁰

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