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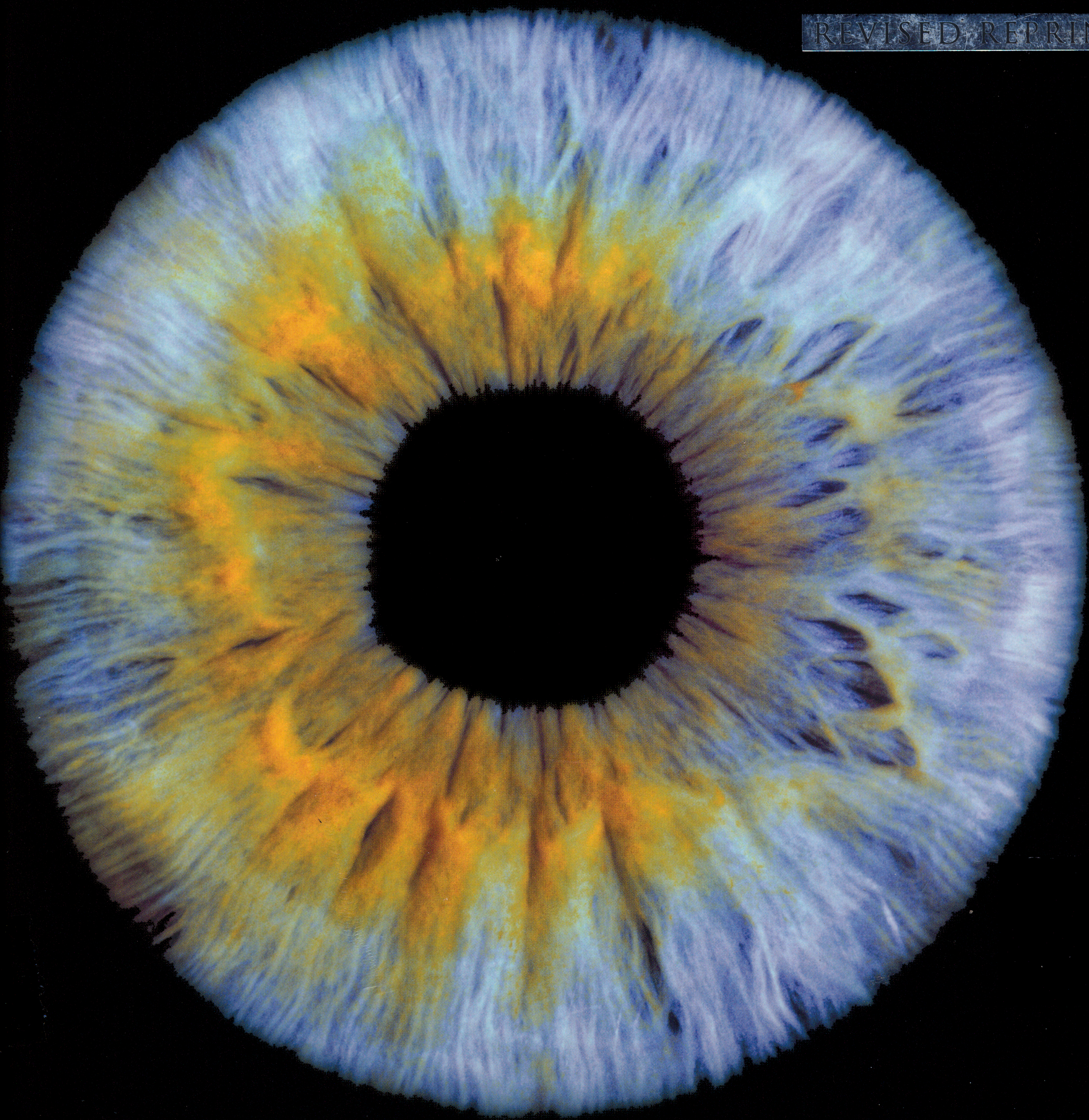

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PSYCHOPHYSICAL TESTS OF VISUAL FUNCTION

Vision arises from the detection and subsequent processing of light stimuli from the external environment and the integration of several different sets of information. Visual acuity, colour vision and visual fields are routinely assessed in clinical practice. The visual system also detects other modalities such as luminance or motion but these are not normally investigated in routine clinical examination. Clinicians need to understand exactly what such tests measure, how they should be used and their limitations.

VISUAL ACUITY

The measurement of visual acuity is the first essential part of any ocular examination and, although the examination technique is simple, the process being assessed is complex and requires the interaction of many factors, both physiological and psychological. Assessment of visual acuity requires the eye to detect the object and resolve it into its component parts. This information is then transmitted to the cerebral cortex where it is matched against existing memory shapes. The patient must then be able to communicate recognition of the object to the examiner. Physiologically, visual acuity measures the capability of the visual system to resolve a target; this is dependent on three main factors: the background illumination, the contrast of the target to the background and the angle that the target subtends at the nodal point of the eye.

In theory the eye has a maximal resolution of 1 minute of arc at the nodal point. In practice, young people normally have a better acuity than this at 20/15 (6/5) which corresponds to the spacing of individual cones in the foveola. Although visual acuity is primarily a function of cones the degree of visual processing in the retina must be considered and, in particular, the receptive fields of the retinal ganglion cells. In the foveola there is a 1 : 1 relationship of cones to ganglion cells but this increases rapidly more peripherally. There is an increasing loss of visual acuity with age so that in old age 20/30 (6/9) or even 20/40 (6/12) may be considered normal.

Although distance acuity is normally measured clinically near vision is in some ways more important in the daily life of the patient. Near vision is tested by reading test print of standardized sizes with the appropriate spectacle correction and good illumination. Factors of accommodation and magnification are important in the assessment of near vision and the correlation between distance acuity and near acuity is not always good. Patients with 20/60 (6/18) distance vision can often manage to read print of J3(N5) size, provided their macular function is normal. There appears to be a large redundancy of nerve fibres in the visual pathways: probably only approximately 15 per cent of the optic nerve fibres are actually required to be able to read 20/30 (6/9).

Table 1.1 shows the pathological and physiological factors that can limit visual acuity. This process can be influenced by physiological and pathological factors anywhere along this pathway.

Background illumination alters the level of retinal adaptation. Low levels of light stimulate the rod system; the receptor density and level of retinal integration of this system are less than that of the cones and consequently acuity is also low. At high levels of illumination the cone system is stimulated and acuity is maximal. To obtain the best visual acuity illumination should be in the optimal photopic range. Because of the effect of reduced retinal illumination from lens opacities in patients with cataract may be seeing in the mesopic to low photopic range where the acuity is proportional to background illumination. In these patients, an increase in the ambient lighting will give them better vision provided that light scattering by the cataract does not counter this.

Table 1.1 Factors that limit visual acuity

Steps in visual perception	Physiological factors	Pathological factors	Physiological limitations
Image formation on the retina	Refractive error	Media opacities	Optical aberrations
Image detection by photoreceptors	Cone receptor function (retinal adaptation)	Cone receptor loss or dysfunction	Cone receptor spacing and integration
Initial data processing and transmission	Optic nerve axonal content	Damaged to anterior visual pathway	
Higher visual processing		Dysfunction of visual cortex, secondary cortical areas	

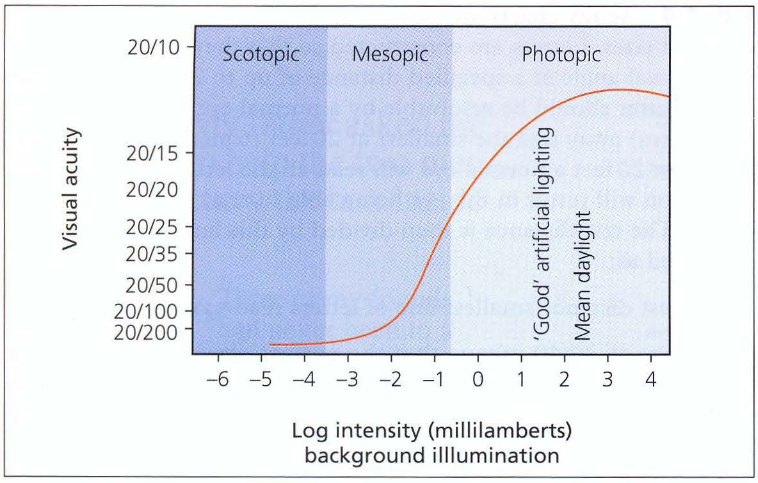

Fig. 1.1 As high-resolution central vision depends on cone receptors any reduction in cone function will greatly compromise acuity. This graph shows visual acuity plotted against background illumination. The best acuity in the scotopic (rod-sensitive) region of the curve is 20/200 (6/60), whereas under photopic (cone-sensitive) conditions acuity can increase to approximately 20/15 (6/5). The curve flattens once optimal conditions are reached and then reduces owing to the effect of dazzle.

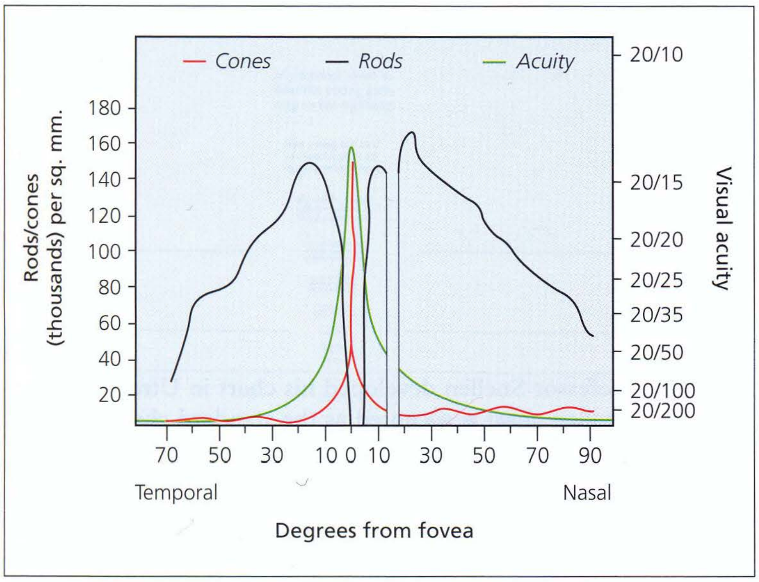

Fig. 1.2 Visual acuity and cone and rod density plotted against degrees from the foveal centre. There are no blue cones at the fovea.

MEASUREMENT OF VISUAL ACUITY

Visual acuity is usually measured at a distance of 6 metres (20 feet) to eliminate the contribution from accommodation. It should be performed on each eye in turn without and with full refractive correction. Acuity is usually measured at high contrast. The visual angle refers to the angle subtended by an object at the nodal point of the eye; it depends on the size and distance of the object from the eye. The normal limit of resolution is 1 minute of arc but some individuals see better than this possibly due to a finer cone mosaic, better image processing in the retina or cortex, or fewer optical aberrations.

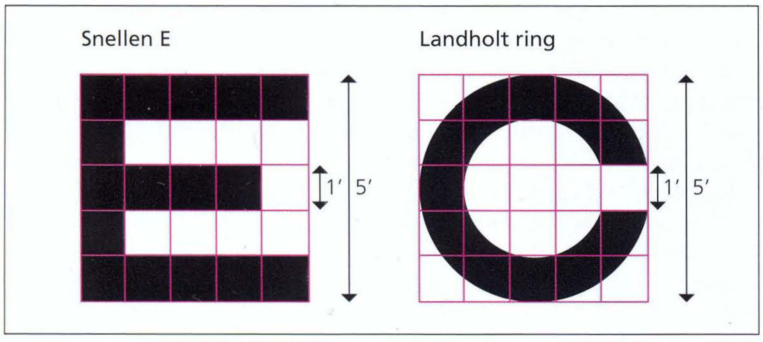

Fig. 1.3 Each individual component of a letter or shape must be resolved to be identified. A letter 'E' viewed at the limit of resolution (20/20, 6/6) subtends 5 min of arc, each individual component subtending 1 min. The same principle is used in the construction of the Landholt rings.

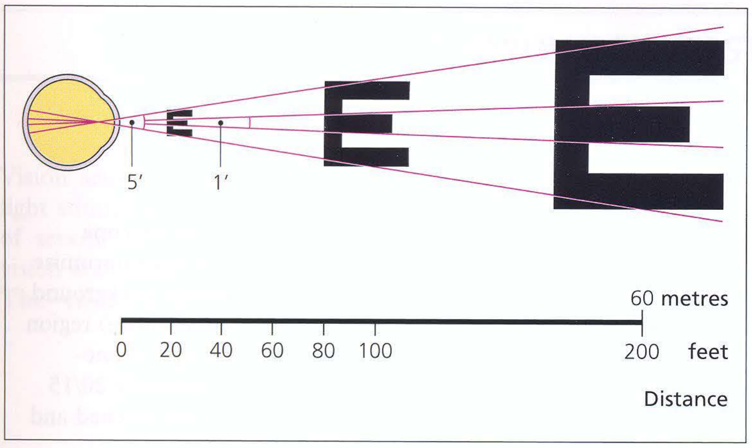

Fig. 1.4 Acuity charts are constructed with rows of letters of different sizes. Letters are constructed so that they subtend the same visual angle at a specified distance of up to 200 feet. Thus the largest letter should be resolvable by a normal eye from 200 feet (60 metres) away and the smallest at 20 feet (6 metres). If the chart is read at 20 feet a normal eye will read all the letters. Any loss of resolution will result in the eye being able to read only larger letters. The test distance is then divided by this line and is expressed as:

test distance/smallest line of letters read = visual acuity

An acuity of 20/40 means that the patient sees at 20 feet what a normal eye would see at 40 feet. It can also be measured in metres (6/12), as a decimal (0.5), or as the angle subtended by the smallest gap of the letter (2 min of arc).

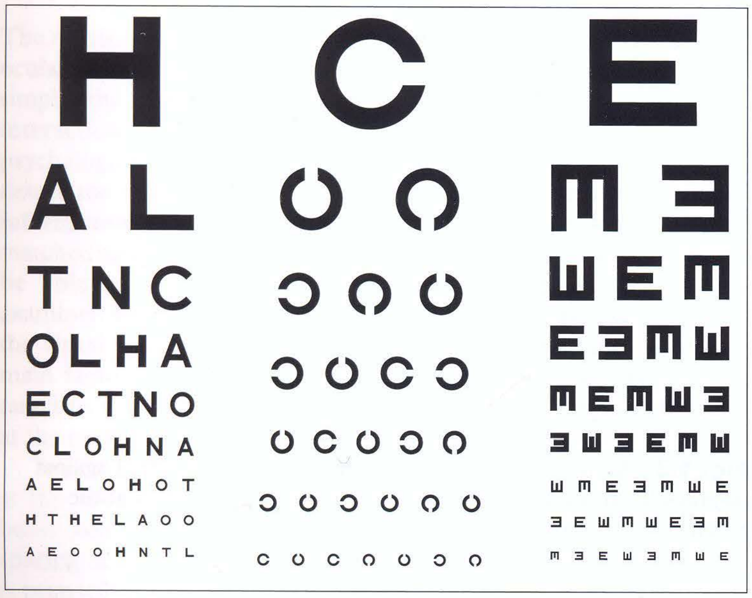

Fig. 1.5 Professor Snellen developed his chart in Utrecht in 1863. The Snellen chart is accepted as the standard chart for clinical practice but it has some problems. Some letters are more legible than others; for example, 'L' is easier to read than 'E'. Patients must also be literate. Modifications to avoid this include Landholt rings where the patient must identify the orientation of a gap or illiterate charts where a cutout letter 'E' is matched with the same letter in different orientations.

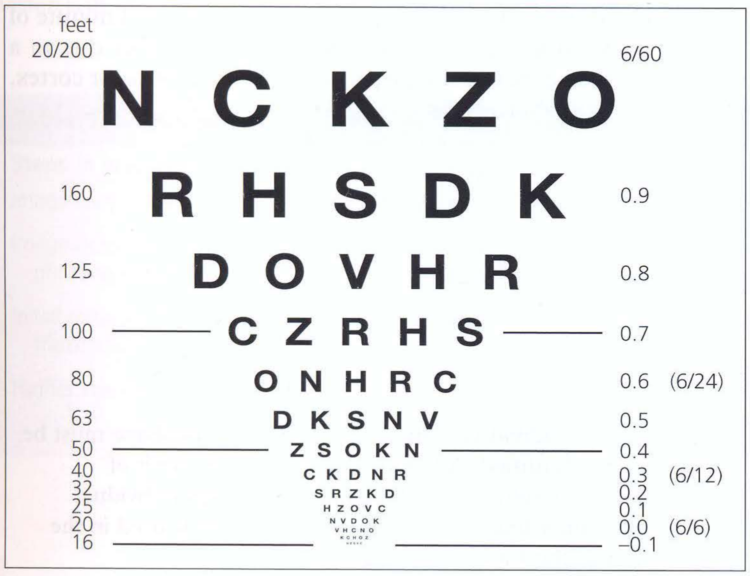

Fig. 1.6 Snellen charts also have the defect of different numbers of letters on each line causing crowding phenomena and nonproportional spacing between letters and lines. Furthermore, the measured range does not extend far enough into low visual acuity ranges. The Bailey–Lovie, Early Treatment Diabetic Retinopathy Study (ETDRS) or LogMAR (log of minimum angle of resolution) chart overcomes these problems. It gives a progressive linear assessment of acuity and has become the standard for clinical research. Each row has five letters with a doubling of the visual angle every three lines. It is read at 4 m and covers Snellen equivalents from 20/200 to 20/10. Each letter read is scored as -0.02 and each row as -0.1 (5 × -0.02). Visual acuity is given as the log value of the last complete row read plus -0.02 for each letter read on the row beneath. An acuity of 1.0 equates to 20/200, 0.3 to 20/40, and 0.0 to 20/20. This contrasts with Snellen charts in that the lower the value for visual acuity, the better the vision.

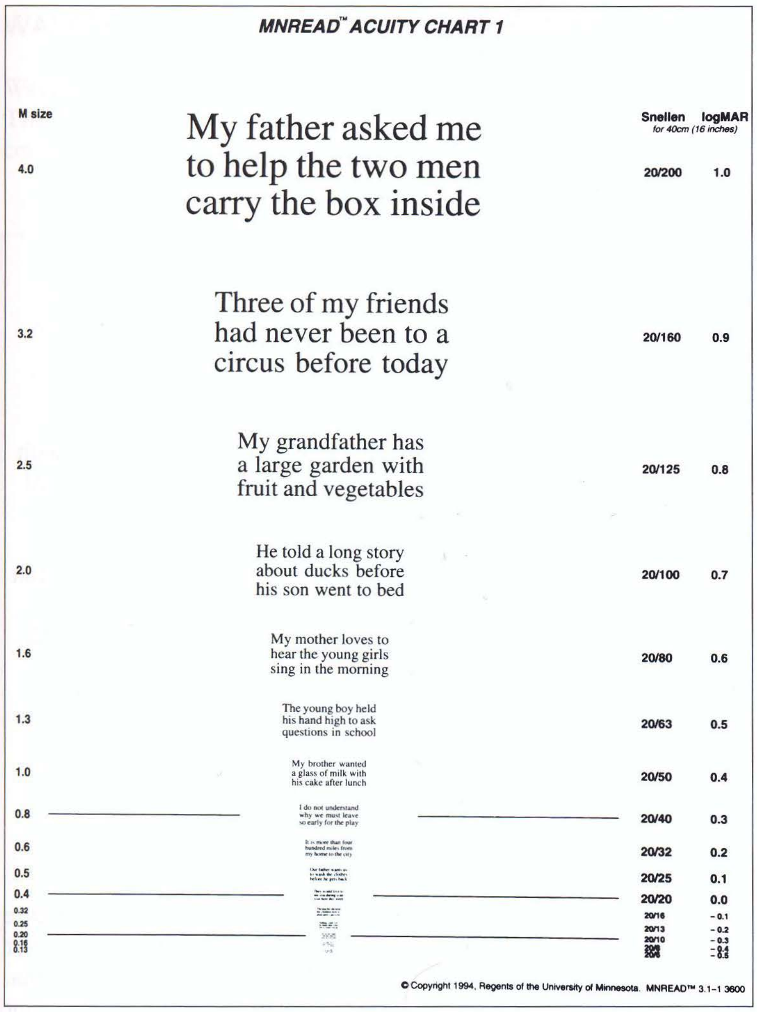

Fig. 1.7 Traditionally near vision testing is done using the appropriate reading correction with a chart of different font sizes. This has, however, no physiological basis and a more scientific method is to use a reduced LogMAR chart such as the MN Read card at a standardized distance and illumination. The text in this chart conforms to LogMAR principles; in addition each paragraph is standardized for length of words, sentences and grammatical complexity. It also allows for reading speed to be measured. Patients need to read at 80 words a minute or better to have functional near vision at that size of print.
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TESTING ACUITY IN CHILDREN

Visual acuity assessment in children presents particular problems. Good results can be achieved only with time and patience and by selecting the right test for the age of the child. These include qualitative tests such as the child turning to fixate a face or light, suppression of optokinetic nystagmus following rotation or objecting to occlusion of one eye. While semiquantitative measurements are available, for instance picking up 'hundreds and thousands' sweets or following small balls quantitative tests are most informative. For infants forced-choice preferential looking or visual evoked potentials (VEPs) can be used; both give different results. Older verbal children can use picture cards (Cardiff cards, Kay's pictures) and from the age of three may manage matching letter tests (e.g. the Sheridan–Gardiner test; see Ch. 18). Caution is necessary when using Snellen charts with single letters because of the phenomenon of 'crowding' – being able to see single letters more easily than rows of letters – which can overestimate true acuity.

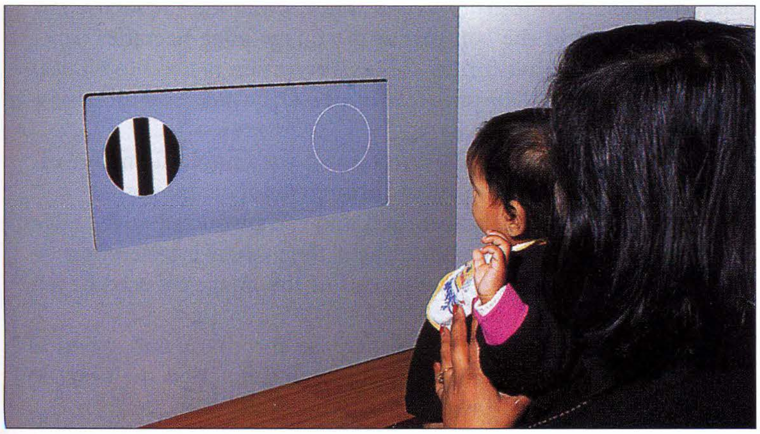

Fig. 1.8 With preferential viewing techniques the child is shown two cards: one has a grating, the other has the same uniform overall luminance. If the child can distinguish the grating, he or she looks at this 'preferentially' – presumably because it is more interesting.
By courtesy of Professor A Fielder.

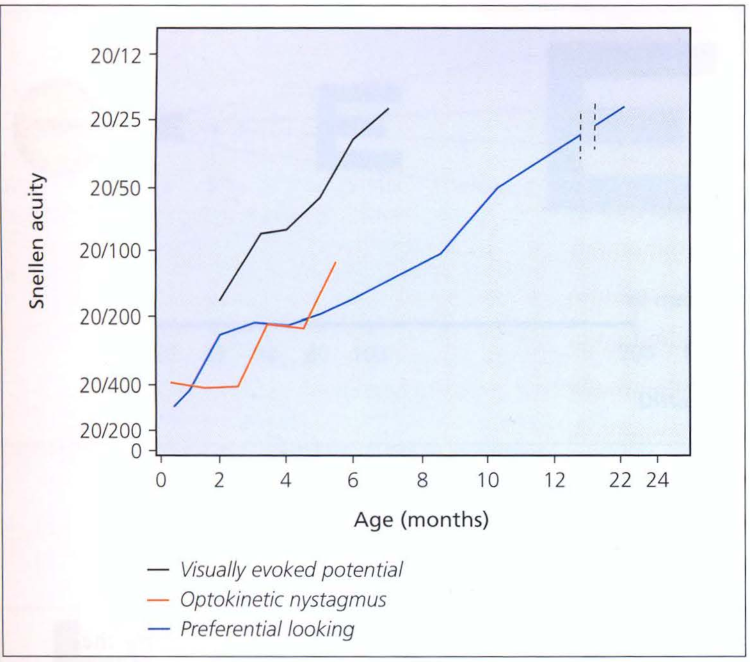

Fig. 1.9 What is known of the development of visual acuity with age depends to some extent on which method of testing was used in studies as VEPs, optokinetic reflexes or preferential looking techniques all give different results. The latter is the most commonly used technique; it shows that infants do not reach adult levels of acuity until 2–3 years of age.
By courtesy of the Editor, Survey of Ophthalmology *1981; 25: 325–332.*

PHYSIOLOGICAL LIMITATION OF ACUITY

The physiological limits of visual acuity are essentially set by the sources of error in the system uncorrectable by standard refraction. Light rays passing through the eye are degraded by inbuilt optical aberrations, thereby increasing the blur at the margins of the images. This loss in edge contrast reduces the resolving power of the visual system. Apart from refractive error (sphere and cylinder), the main optical factors are higher-order aberrations, chromatic aberration and diffraction. Glare disability is produced from forward light-scatter from the ocular media and opacities. It casts a veiling luminance over the macula, reducing image contrast. A good clinical example is posterior subcapsular cataract where acuity is relatively well preserved but the patient has a disabling glare in bright light.

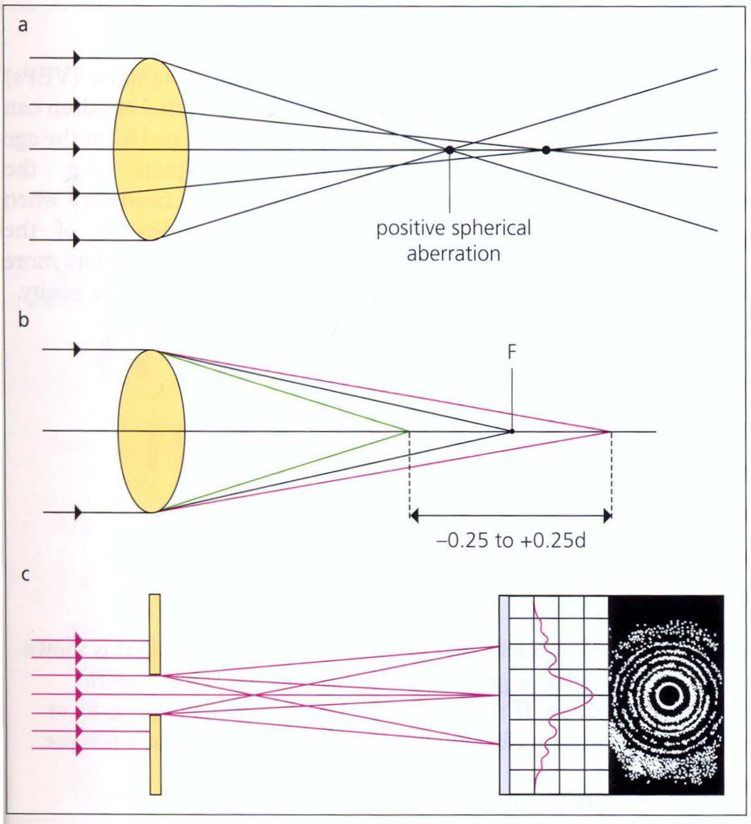

Fig. 1.10 (Top) Spherical aberration. The refractive surfaces of the eye have more effective power at the periphery than at the central paraxial zones. This causes the edge of an image to be blurred by the resulting 'line spread'. Spherical aberration increases with pupillary dilatation. The eye normally has a positive spherical aberration (see Ch. 11).

Chromatic aberration. The refraction of light varies according to its wavelength. Short wavelengths (blue) are refracted more than longer wavelengths (red), polychromatic white light is focused as a coloured blur, and the contrast at the image edge becomes degraded by coloured fringes. (This aberration is used to clinical advantage in the duochrome test to prevent overaccommodation in myopes.)

Diffraction. This becomes important with pupil diameters of less than 2 mm. Light projected through an aperture passes through the centre but is absorbed and retransmitted at the edges. The wavefronts of retransmitted light then cause interference patterns that increase the line spread of the image focused beyond the pupil.

As larger pupillary apertures increase chromatic and spherical aberration and smaller diameters increase diffraction the best compromise is achieved with a pupil diameter of 2.4 mm.

WAVEFRONT ANALYSIS

Wavefront analysis plots the total optical aberration of the eye. The low-order aberrations of sphere and cylinder can be corrected by simple optics; higher-order aberrations cannot be corrected by routine refraction. These used to be referred to as 'irregular astigmatism' and, in the case of irregular corneal astigmatism, can be corrected only by wearing a contact lens. Wavefront analysis allows detailed analysis of these aberrations; it has become important in understanding patient dissatisfaction following refractive surgery and, by correcting aberrations, offers the possibility of supranormal vision. This has yet to be achieved.

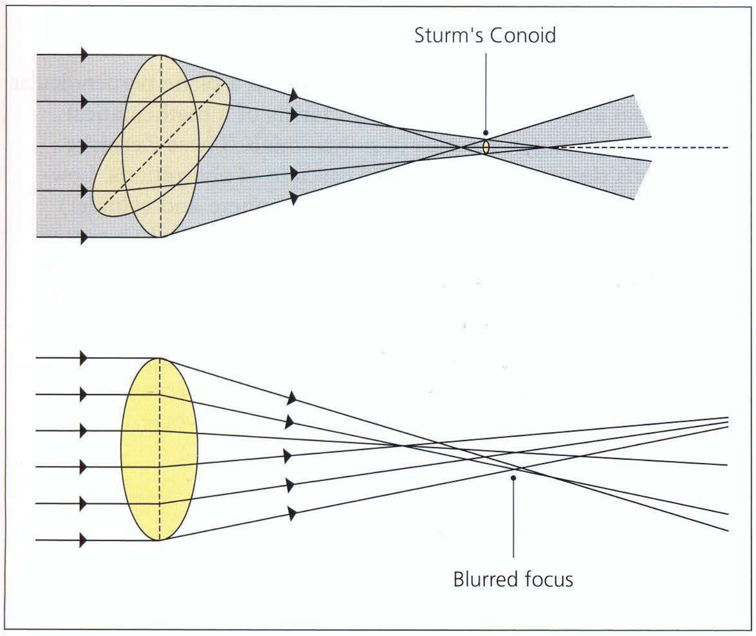

Fig. 1.11 With regular astigmatism, light is brought to focus at two points. Sturm's conoid is the circle of least confusion that can be brought to focus by a sphero–cylinder combination. With the imperfect optics of the eye light is bought to focus in an irregular manner. This caused by higher-order aberrations which can be demonstrated by wavefront analysis and described mathematically by Zernicke polynomial curve fitting equations.

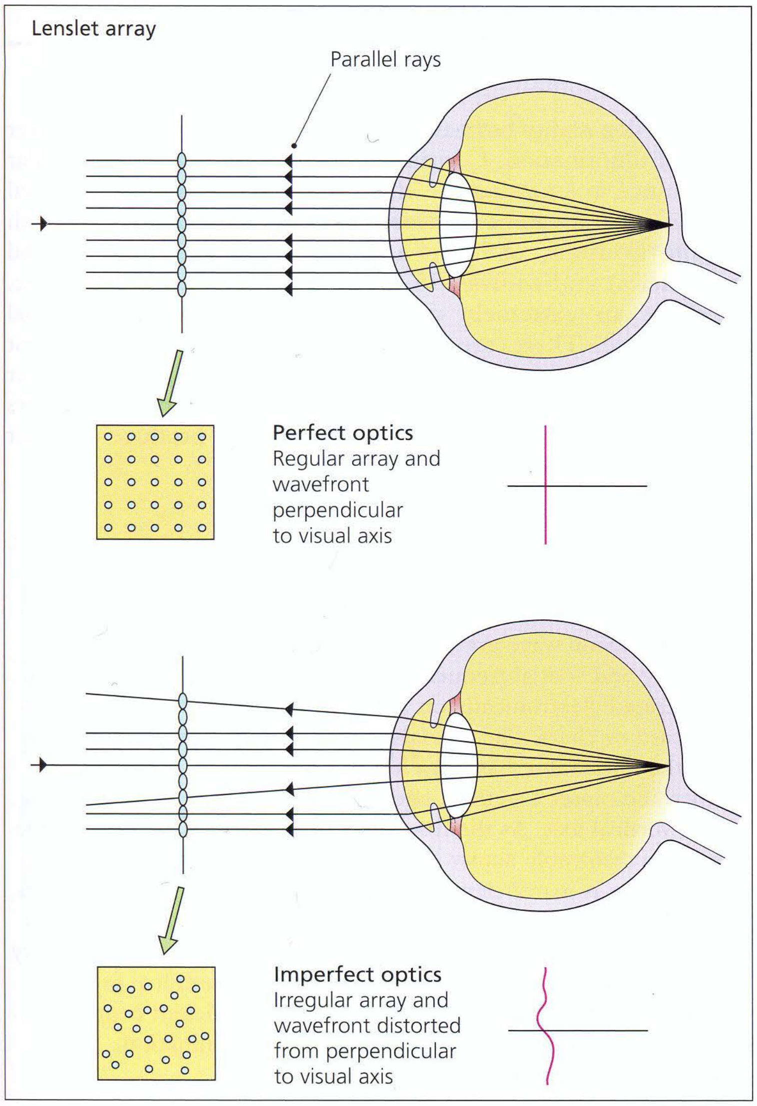

Fig. 1.12 In a perfect optical system rays of light exiting the eye from a spot projected on the fovea should exit the eye parallel to the visual axis with a wavefront perpendicular to the visual axis.

If these exiting rays are imaged through an array of lenslets their displacement from parallel to the visual axis is a measure of the optical errors in the visual pathway. This can be done with a Shack–Hartman aberrometer, a technique that has long been used in astrophysics. Light coming to focus in front of the plane is 'advanced' and that behind the plane is 'retarded'. In the eye most aberration is produced in the cornea.

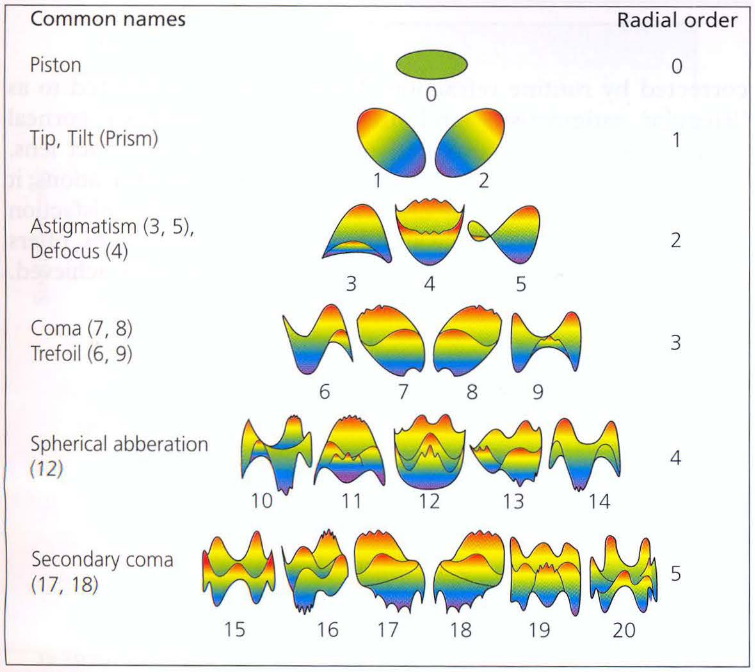

Fig. 1.13 The wavefront deformation from a plane perpendicular to the visual axis can be expressed in terms of a mathematical equation consisting of a series of polynomials. These Zernicke polynomials describe an increasing cascade of aberrations. Low-order aberrations (first and second order: sphere and cylinder) account for more than 90 per cent of refractive error in a normal eye. Third order is coma and fourth order is spherical aberration. Spherical aberration is the clinically most important after sphere and cylinder. Higher orders account for less and less of the aberration. The system becomes extremely complicated as some aberrations can cancel out others; treating one aberration in the absence of all can therefore actually make vision worse.

CONTRAST SENSITIVITY

The eye can detect objects by responding to the differing levels of luminance between a target and its background. This is defined in terms of the maximum and minimum luminance at the detected edge.

$$\text{Contrast} = \frac{\text{Target luminance - background luminance}}{\text{Target luminance + background luminance}}$$

Standard visual acuity tests measure acuity under high contrast conditions but do not tell us anything about visual performance under different circumstances such as driving at night or reading in poor light which are often more appropriate to daily life and cause clinical symptoms. It is thus possible for patients to retain good Snellen acuity but have reduced contrast sensitivity at lower levels of illumination. Contrast sensitivity testing is of particular importance in assessing the effect of refractive surgery on visual performance. It can be measured at either a fixed target size with varying contrast or over a range of target sizes (spatial frequencies) and contrast to derive a contrast sensitivity curve, which is an extremely useful way to assess overall visual performance. There are a number of different ways to test contrast sensitivity; they fall into two groups – either differentiating bars, stripes and gratings or, alternatively, letters against a background. Letter tests usually produce a better performance than gratings.

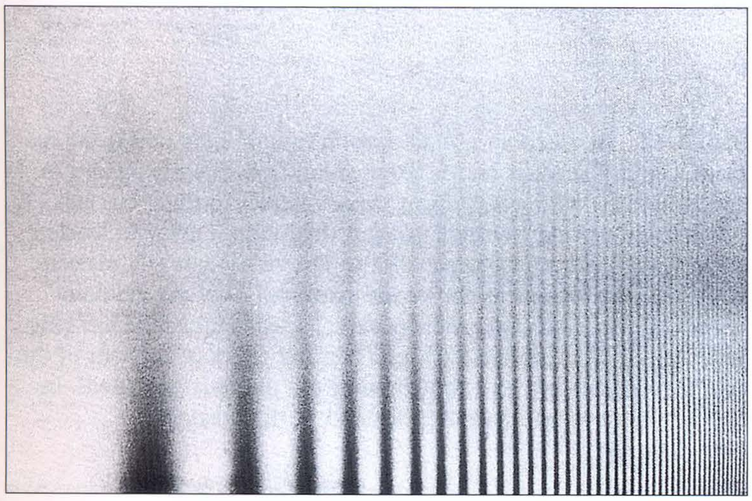

Fig. 1.14 Sine wave gratings can be used to assess contrast sensitivity and spatial frequency simultaneously. The patterns can be generated electronically on a television screen or graphically on a test card or chart. The spatial frequency of the stripes increases along the horizontal axis from left to right (that is, the stripes get thinner and closer together) and the contrast decreases on moving up the vertical axis. As the frequency of the stripes increases to the minimum resolvable acuity (30–40 cycles per second or 1–0.5 min of arc), there is insufficient contrast to distinguish the stripes from the background. As a result the highest resolvable frequencies can be seen only at high contrast (this equates to standard visual acuity tests). Beyond this point the grating appears as uniform greyness. As the spatial frequency decreases there is insufficient contrast to distinguish the stripes from the background illumination.
By courtesy of Mr JW Howe.

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