# VA testing in optometric practice

## Part 1: The Snellen chart

**In this two-part article on visual acuity testing in practice, Professor David Thomson looks into the development and mechanisms of modern day test charts.**

*"This will be your consulting room. I think you will find everything that you need". Apart from the décor, it resembled most of the other consulting rooms I had worked in as a locum – chair, back-illuminated test chart unit, trial set, slit lamp, field screener, a yellowing near chart, an Amsler chart and an aged Ishihara book.*

*My first patient was a 14-year old boy who had been brought in for a routine check-up. He read the 6/5 line on the Snellen chart with ease. I wondered what his true visual acuity was – I had no way of finding out. If I could not measure it today, how would I know if his visual acuity had decreased in the future?*

*Later that same day, I saw a man with early stage keratoconus. When I asked him to read the Snellen chart, he read three letters on the 6/18 row, three on the 6/12 row and two on the 6/9 row. What do I record, I wondered? "6/18-1 +3 +2"? A glance at his previous record showed that the visual acuity recorded at the last visit was "6/12-". I was left pondering whether his vision had got better or worse.*

*My final patient of the day had age-related macula degeneration. I asked her to read the top letter on the chart with her right eye. "I can't really see it but I remember that it was an A from last time", she reported helpfully.*

*As I sat in the patients' chair finishing off my paperwork for the day, I glanced up and noted with some surprise that I could read the 6/5 line with ease. As it had been some years since I had achieved the lower reaches of the test chart, I got my tape measure out. My suspicions were confirmed – 4.8 metres! My end of day report read – "Visual acuity testing in optometric practice – could do better!"*

***Figure 1***
The Snellen chart

From the moment we open our eyes in the morning, we enjoy a remarkably accurate perception of our environment. We instantly sense the position of objects around us and recognise what those objects are. We sense their brightness and colour, and judge their distance and movement with impressive accuracy.

The apparent ease with which the visual system transforms the information contained within the retinal images into this rich perception belies the immense complexity of the underlying task. Unravelling the processes responsible for this transformation has occupied scientists for centuries, and yet there are many aspects of visual perception which remain a mystery.

Given the complexity of visual perception, the approach of vision scientists and clinicians alike has been to isolate specific facets of perception such as colour, contrast, motion, depth, resolution etc, and to develop tests to measure these functions individually. Tests of colour vision, contrast (visual fields) and stereopsis are regularly employed in clinical practice. However, visual acuity (VA), more specifically Snellen acuity (**Figure 1**), is the one test which has emerged as the clinician's favourite.

Visual acuity is measured during almost every optometric and ophthalmological examination. It is used in the legal definition of blindness and partial sight and forms part of every occupational vision standard. It is used to monitor the progression of a wide range of eye conditions and is often used as the final arbiter for medical/surgical intervention. It is undoubtedly the most commonly performed and important test of visual function.

The primary reason that VA has achieved this status is that it works! It is simple to measure and in the majority of cases, measurements of visual acuity correlate very well with patients' perceived visual status. Refractive errors, media opacities, macula defects and many neurological conditions all affect visual acuity. While it is true that defects in the peripheral field do not always affect visual acuity, these conditions tend to have a lesser impact on patients' functional vision.

Despite the importance of visual acuity, it is often measured very badly. The majority of clinicians still use Snellen charts, despite the fact numerous studies have shown that this chart suffers from a number of serious design flaws. Inadequate attention is often given to viewing distance, chart illumination, instructions given to the patient, learning effects and termination rules. Furthermore, decisions about the significance of changes in visual acuity are often made without a full appreciation of the precision of the test.

To understand the desirable characteristics of a visual acuity test, it is necessary to consider the optical, neural and psychological factors involved in reading a test chart.

### What is visual acuity?

The term 'visual acuity' was introduced by Donders in the late 19th century to describe 'sharpness' of vision. However, it has come to mean the capacity of the visual system to resolve fine detail and, specifically, to read small high contrast letters. Optometrists tend to use visual acuity to describe the smallest letters read with the optimal refractive correction, while 'vision' is the term used to describe the smallest letters that can be read without refractive correction. However, this convention is not strictly adhered to and the terms 'corrected vision' and 'uncorrected visual acuity' are often used.

The apparent ease with which we can read letters suggests that the task is entirely straightforward. However, before a letter can be named, it must first be detected, its components resolved and the letter recognised. This involves image formation, transduction of light into neural activity, retinal processing and transmission to the visual areas of the brain and complex analysis in the visual cortex and higher centres. Interference with this chain of events at any stage will have some effect on the visual acuity recorded. However, a degraded retinal image is the single most common cause of reduced visual acuity.

### Optical factors

Even in the absence of a refractive error, a point source in object space will not be formed into a point image on the retina. Diffraction at the pupil margins will cause the point to spread out into an Airy disc surrounded by faint annuli. The diameter of the Airy disc is determined by the pupil size and the wavelength of light.

This spreading of the image sets the first physical limit on the resolution/acuity of the visual system. Raleigh proposed that two point objects can just be resolved when the centres of the Airy discs are separated by half their diameter. Within the eye, this sets a physical resolution limit of approximately 45 seconds of arc

(0.0125˚). In other words, this is the best resolution that could ever be achieved even by an eye with no refractive error, no aberrations and a very high density of foveal cones.

In practice, the eye suffers from a number of aberrations (notably spherical and chromatic), which together with scatter conspire to further degrade the retinal image. The actual pattern of light incident on the retina from a point object is described by the point spread function. Refractive errors and media opacities increase the width of the point spread function and, therefore, have a direct effect on resolution.

## Neural factors

It is reasonable to assume that in order to resolve two spots of light, each spot must fall on two different photoreceptors with a relatively unstimulated photoreceptor between them. At the fovea, the cones are separated by approximately two microns and, therefore, the centre of the two spots must be separated by at least four microns. This sets a theoretical resolution limit very close to that set by diffraction (approximately 45 seconds of arc).

This analysis is only valid if each cone has its own 'private line' to the brain. If more than one cone converges onto a ganglion cell, neural resolution will be compromised. At the fovea, there is no convergence and so the estimate of neural resolution based on cone size is defensible.

The final perception of the two spots depends on many other complex processes in the visual cortex and beyond. However, the fact that measurements of resolution approximate so well to the theoretical limits set by optical and retinal factors suggests that this higher level processing does not impose any further restrictions on resolution in the normal visual system.

## What about letters?

A wide range of stimulus configurations has been used to measure resolution/acuity including dots, bars and gratings. However, in clinical practice, letters have emerged as the preferred stimulus.

The first attempts to measure visual acuity using letters date back to the beginning of the 19th century but it was a German ophthalmologist, Herman Snellen, who popularised this form of vision assessment. Snellen argued that if a normal eye can just resolve a gap of one minute of arc (60 seconds), then a human observer should just be able to read a letter consisting of strokes subtending one minute of arc (**Figure 2**). A letter 'E' constructed in this way therefore subtends five minutes of arc vertically (assuming the gap width is also set at one minute of arc). On this basis, Snellen designed a set of letters on a 5x5 grid with a stroke width of one unit.

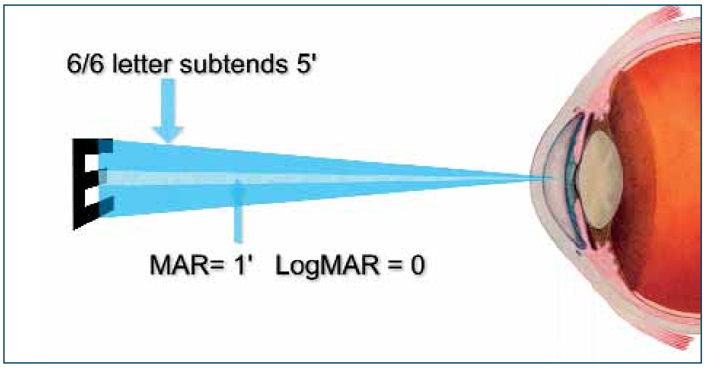



***Figure 2***
A 6/6 letter subtends an angle five minutes of arc at the eye. This corresponds to a minimum angle of resolution (MAR) of 1 and a logMAR of 0

The original charts used a Serif style where the letters were 'decorated' with bars at the end of the strokes. This design was widely used in clinical practice until relatively recently. Despite a letter being a far more complex target than pairs of lines, dots or gratings, Snellen's original hypothesis that an individual with normal vision should be able to read a letter subtending five minutes of arc, has proved to be remarkably robust and letters have become the preferred stimulus for assessing acuity.

Using letters to measure visual acuity has a number of advantages. Reading letters is a familiar task for most patients, and enables the clinician to rapidly ascertain the smallest letters which can be resolved. Also, having 26 possible alternatives reduces the probability of guessing correctly. The principal challenge when using letters to measure visual acuity is to minimise the difference in legibility (difficulty) between letters. Snellen soon realised the letters that he had designed were not equally recognisable, and there have been many attempts since to design a set of optotypes of equal legibility.

A number of alternatives to letters have been proposed, such as the Illiterate E (now known as the Tumbling E) and the Landolt C. These optotypes have the advantage that they use the same shapes in different orientations, thereby maintaining the same legibility. For this reason, the Landolt C is often used as the gold standard against which all others are compared. However, the Landolt C chart has been criticised for only having four alternatives (or eight if oblique orientations are used) thus increasing the probability of guessing correctly. Reporting the orientation of the C also tends to take longer than reading a letter, and there is evidence that some orientations are easier to see than others, even in the absence of refractive error.

For these reasons, letters remain the preferred stimulus in clinical practice. Two sets of letter designs have become predominant. The Sloan letters are based on a 5x5 matrix and consist of the letters S, D, K, H, N, O, C, V, R and Z. The British letters as specified by BS4274, are based on a 5x4 matrix and include the letters D, E, F, H, N, P, R, U, V and Z. In both cases, letters have been selected and their design modified in a bid to minimise differences in legibility and maintain equal discriminability between letters. This has been only partially successful and a number of studies have shown that some of these letters are significantly easier to read than others. This problem can be addressed to some degree by ensuring that the average legibility of letters does not vary from one row to another.

## Snellen chart

The Snellen chart rapidly became the standard method for assessing visual acuity and with relatively minor modifications, the original design is still used in the majority of clinics and consulting rooms throughout the world. However, as a psychophysical test of visual function, the Snellen chart design is considered to be seriously flawed.

### Number of letters per row

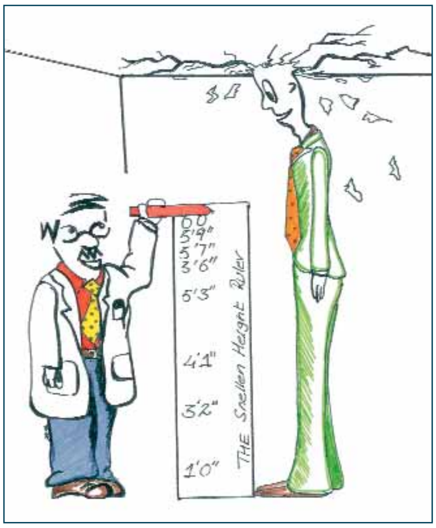
The number of letters per row varies from one letter, i.e. 6/60 to 8+, i.e. 6/4. While this means that the chart fits neatly into a compact rectangle, it introduces a number of confounding variables. For example, it is well known that it is easier to read a letter on its own than one surrounded by other letters (a phenomenon often referred to as 'crowding' but more accurately described as 'contour interaction'). As there are fewer large letters per row, they will be affected less by contour interaction than the smaller letters, thus varying the nature of the task as the chart is read from top to bottom.

Having a different number of letters per row also complicates the process of interpolated scoring (see later). The limited number of large letters on a Snellen chart is also a disadvantage when assessing patients with a visual impairment.

### Letter spacing

The spacing of the letters on each row of the Snellen chart bears no systematic


» **Figure 3**
"Your Snellen height is 5'3'' minus!"




» **Figure 4**
"Your Snellen height is 6' but I think that there may be a ceiling effect!"

relationship to the letter width and, in fact, varies between approximately 40% and 120% on most charts. Furthermore, the vertical spaces between the rows of letters are not logically related to the height of the letters. Consequently, the degree or contour interaction varies erratically from one row to the next which, in turn, affects the difficulty of the task.

### Progression of letter sizes

Another flaw in the Snellen chart design is the irregular progression of letter sizes. For example, 6/5 to 6/6 represents an increase in size of 120%, whereas the jump from 6/36 to 6/60 is 167%. This is analogous to a ruler which is marked with different length graduations (with no graduations between) (**Figure 3**). This means that the precision of measurements depends on the patient's visual acuity, rendering statements such as, "A two line change in acuity", meaningless – because it will depend on where those two lines are. It also invalidates measurements taken at different viewing distances; a patient with 6/36-1 would not necessarily achieve 3/18-1 because the scale increments are different.

The irregular progression of letters sizes also precludes the use of parametric statistics to analyse visual acuity data. For this reason, the Snellen chart is now rarely used in research studies.

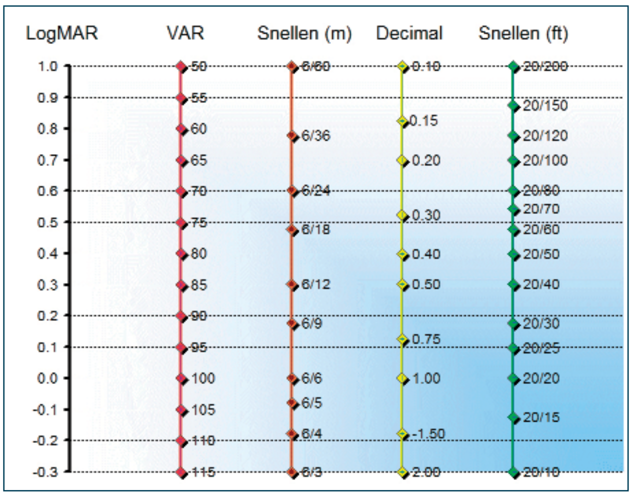
Another problem with the Snellen chart design is truncation. Many younger patients have visual acuities better than 6/4 and yet many charts do not include letters smaller than 6/5. While this may not be an issue within the context of vision screening, it does prevent a true measure of visual acuity from being obtained and may make it difficult to detect small changes in these patients' vision over time (**Figure 4**).

### Notation

The Snellen fraction is widely used for recording visual acuity but its derivation and exact meaning are less well understood. The numerator of the fraction describes the chart viewing distance (usually six metres in Europe and 20 feet in the USA). The denominator refers to the distance at which the letter subtends five minutes of arc (vertically). Thus, a 6/6 letter subtends five minutes of arc at six metres, while a 6/12 letter subtends five minutes of arc when viewed from 12 metres. Therefore, if a 6/12 letter is viewed from six metres, it subtends 10 minutes of arc.

This rather convoluted notation does have the advantage that the viewing distance is recorded, but has little else to commend it. Nonetheless, it has been the universally accepted standard for over a century and the clinical community has proved remarkably resistant to change. Even the general public has become familiar with the terms 6/6 or 20/20 vision. The Snellen fraction is often expressed in decimal form in many other parts of Europe. Thus, 6/6 equates to 1.0, 6/12 to 0.5, etc (**Figure 5**).

» **Figure 5**
Conversion chart for LogMAR, VAR, Snellen (m), Decimal and Snellen (ft)




### Scoring

The Snellen chart is scored by recording the lowest line of letters which the patient can recognise. As long as the patient reads all of the letters on the chart down to a certain line and no letters on the line below, this method of scoring is acceptable. However, in practice, the difference in legibility between letters, combined with various subject variables, means that when approaching their threshold acuity, patients can often read some letters and not others. The clinician is left to record this in the form of "6/12+2, 6/9-, 6/6 part", etc. If the endpoint spreads over more than one line, there is no satisfactory way of recording the result. Without a standard methodology and notation to address this issue, it is often difficult to judge whether a patient's vision has changed – particularly if the pervious visual acuity was recorded by somebody else.

Part 2 will look at newer test chart designs.

## About the author

David Thomson is Professor of Optometry and Visual Science in the Department of Optometry and Visual Sciences, City University, London.

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