The Historical Evolution of Visual Acuity Measurement

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Today I would like to speak not so much about a single historical individual, as about the historical evolution of a subject that is so familiar that we rarely stop to think about its background. That subject is Visual Acuity Measurement.

Before 1850

In antiquity there are already references that measured the sharpness of vision by the ability to resolve double stars. In 1623 Daça de Valdes described an often-quoted method based on the ability to resolve mustard seeds.

Today, we will mainly focus on the mid-19th century and the historical context in which Snellen introduced his letter charts in 1862.

a German physician in Darmstadt, had argued convincingly for the need for standardization of vision tests and had produced three charts to avoid memorization and provided a standardized set of instructions.. Note the similarity to the set of three ETDRS charts and their instructions today. However, he was a decade too early, the profession was not ready – his work is almost completely forgotten.

Around 1850

Around 1850 major changes started to happen in ophthalmology.

In 1851, Donders from Utrecht, Holland, who at the time was a professor of physiology with some interest in vision, visited London where he met Bowman (from London) and von Graefe (from Berlin). They became lifelong friends and Donders firmly decided to make ophthalmology his life's interest.

> *Donders wrote later:*
> *"I had just seen Jaeger (the father, ed.) performing cataract surgery alternately with the left and the right hand, when a young man stormed into the room embracing his preceptor. It was Albrecht von Graefe. Jaeger thought that we would fit well together and we soon agreed. Those were memorable days. Von Graefe was my guide for all we heard in practical matters, and in scientific matters he listened eagerly to the smallest detail. We lived together for a month to separate as brothers. To have William Bowman and Albrecht von Graefe as friends became an incredible treasure on my life's path."*

With von Helmholtz, who in the same year invented the ophthalmoscope, they became a foursome that would usher in a period that would later be called the Golden Age of Ophthalmology and would make Ophthalmology the first organ-oriented specialty.

For this audience, I do not need to elaborate on the contributions of Sir William Bowman or of Herman von Helmholz or of Albrecht von Graefe.

Donders
Franciscus Cornelis Donders (1818 – 1889) from the Netherlands appears to be somewhat less well known. He grew up in a poor family and received his first education in a village school, where the village schoolmaster triggered his lifelong intellectual inquisitiveness. He went on to study at the University and at age 29 saw a special chair in Physiology created for him in the Medical School of Utrecht University, the total faculty of which had only four members at the time. He developed an interest in the physiology of the eye and after the experience quoted earlier, decided to devote his life to Ophthalmology. He not only was an excellent scientist, he also had a strong social conscience. In 1852, after his return from London he privately founded an "Eye Infirmary for the Indigent", which in 1858 became an independent foundation.

Donder's most renowned work would become his book on *"Refraction and Accommodation"*, which was published in London in 1864. In it he unraveled the difference between asthenopia and hyperopia and put the correction of refractive error on a scientific footing.

Jaeger's reading samples
Thus, the scene had changed considerably since Kuechler's days, when, in 1854, Eduard von Jaeger *(Donders had met his father in London)* in Vienna published a series of reading samples.

Since Vienna was an international city, he published them in several languages. Unlike Kuechlers tests, a decade earlier, they spread like wildfire.

Strong points of Jaeger's reading samples were that they were published in many languages and with excellent print quality, since he used typefaces from the State Printing House in Vienna. The well known "Jaeger numbers" refer to the item numbers in the Printing House catalogue and have no numerical meaning.

However, the use of existing, locally available typefaces also had its drawbacks. Since there was no external standard, future imitations also had to rely on locally available typefaces. The result is that today a print size that is labeled as #4 on one card, may be labeled as #7 on another one, while another print size labeled as #7 on one card may be #10 on another one.

Also, Jaeger's test were for reading only, not for distance vision.

Donders' needs

Donders, meanwhile, was working on his studies about Refraction and Accommodation. He needed not only near tests to determine accommodation, but also distance tests to determine refractive error. Initially, he had used the larger Jaeger samples for distance vision, but he needed a more scientific measurement.

In 1861 Donders proposed a formula defining the "sharpness of vision".

He did more. He asked his co-worker and later successor, Snellen, to devise a standardized measurement tool. Snellen published his chart the next year.

Realizing that visual acuity changes with age. Donders also commissioned one of his doctoral students to do a study of the effect of age on visual acuity. That thesis, using prototypes of Snellen's optotypes came out in 1862 also.

Let us take a look at each of these three contributions.

Donders' formula

First of all, Donders defined a measurement standard. He defined a "standard eye" as capable of recognizing letters that are 5' high. He then compared the patient's performance to that of a standard eye.

This gives us the MAGNIFICATION needed by that patient to reach the same performance as a standard eye. The reciprocal of the Magnification need is the VISUAL ACUITY.

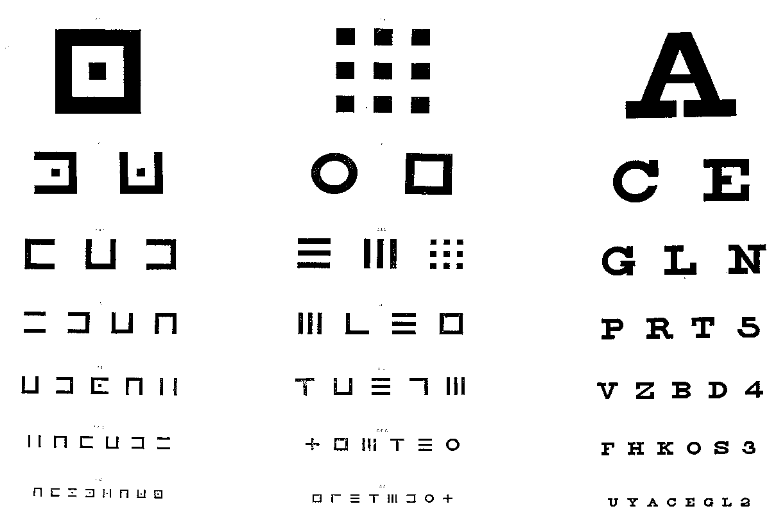
Size seen by patient / Size seen by "standard eye" = **Magnification need**

Visual Acuity = 1 / Magnification need

Magnification need:	2x	Visual Acuity:	1/2	0.5
	4x		1/4	0.25
	10x		1/10	0.1

Snellen's chart

Donders had chosen Herman Snellen, Sr. (1834 – 1908) as his co-worker, who would later become his successor. Donders was a scientist, Snellen was more practically oriented and an excellent surgeon.



To implement Donders' formula, Snellen first experimented with various abstract shapes (shown here courtesy of the University Museum in Utrecht) and then decided on letters as being more practical.

(left: two unpublished prototypes, right: Snellen's chart as published)

What were Snellen's innovations?

- First of all, rather than using existing type faces, he designed special characters, which he called optotypes for the specific purpose of visual acuity measurement.
- He arranged these optotypes in a letter chart format to be used as a test of distance vision.
- He calibrated his characters based on an external standard (5' arc), so that others who wanted to reproduce them or design their own, could calibrate them to the same standard.

Finally, Snellen also published a booklet of reading tests, in multiple languages and calibrated to the same standard as the distance test.

Compare this to Jaeger, who published only reading samples and did not define any measurement unit.Snellen's tests were quickly adopted worldwide. Since Donders was a very modest man, he always left Snellen the full glory of developing the letter chart. That Donders had generated the original idea was rarely, if ever, mentioned.

Visual acuity changes with age

Realizing that visual acuity changes with age, Donders asked one of his doctoral students, de Haan, to do a population study, not as an afterthought, but published concurrently with Snellen's charts. Lest we think that population studies are a modern invention, what were the results of the study in 1862 ? *(See Table on next page)*

The data from 1862 are represented by the "▲ " markers.

The "●" markers show the results of a recent meta-analysis of healthy subjects participating in various research protocols. The coincidence in the younger age groups is striking.

In the older groups, the recent data show better visual acuity. This is because the research protocols selected only healthy eyes.

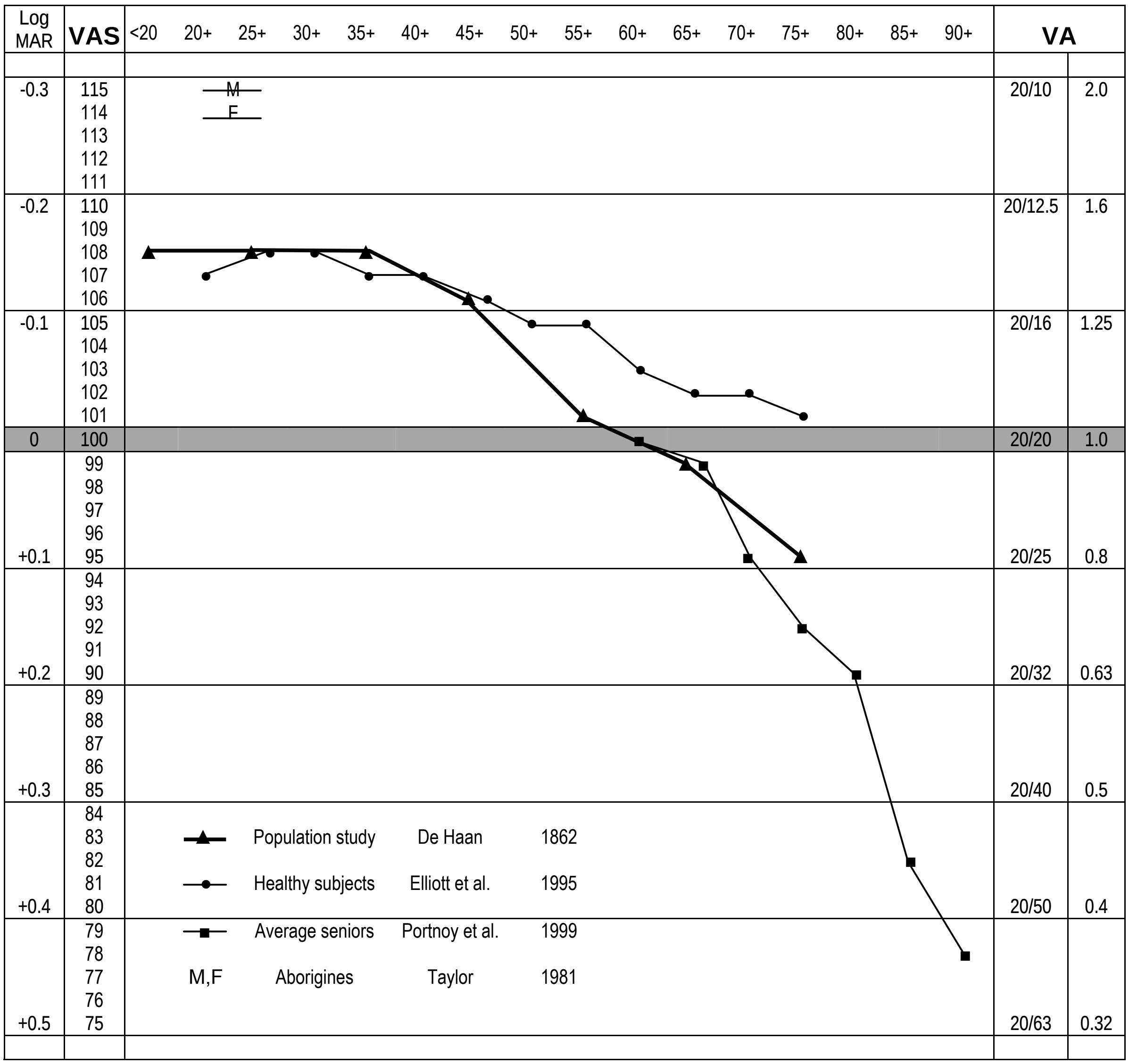
The "■" markers are taken from a recent study of an unselected older population.
The coincidence with the data from 1862, again, is striking. There has been no change in the average acuity with age over a century and a half.

The horizontal lines represent one-line increments on a standard chart. The dark band represents STANDARD VISION (20/20, 1.0).

The data also show that "normal" vision was and is substantially better than "standard" vision. Normal vision does not drop to the standard level until 60 or 70 years of age. Snellen was well aware of this and described the "20/20" level not as threshold or perfect vision, but as a level that is "easily recognized" by normal eyes.

The "M" and "F" symbols near the top of the chart represent average acuities found among aborigines. Thus, there are obvious racial differences, the reason for which has not yet been explained.

Visual Acuity Changes with Age – 1862 and current data



Very little changed in the next century. In 1965, Bennet remarked, in a paper in preparation for the British visual acuity standard, that “The road of visual acuity measurement is littered with still-born charts.

A few innovations may be mentioned:

In 1875, Monoyer (of Lyon) introduced the decimal notation that is used in much of Europe today.

In 1888 Landolt (in Paris) proposed his broken ring symbol, which has become a standard in the laboratory.

One proposal is particularly interesting

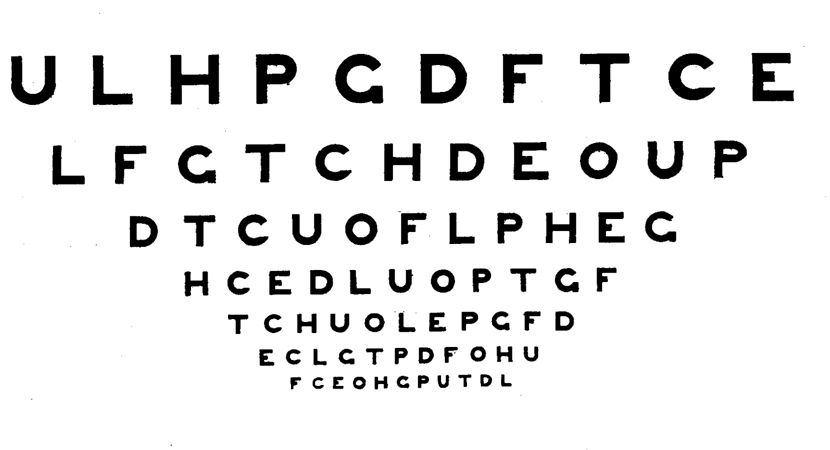
John Green's chart

John Green, Sr. (1835 – 1913) had studied in Harvard. In 1865 and 1866 he traveled to London, Paris, Utrecht and Vienna. In Utrecht he did a brief study on astigmatism.

When he returned he proposed a new chart to the American Ophthalmological Society, first in 1867 and with a slight modification in 1868.

He practiced in St. Louis for the rest of his life.

The illustration shows the lower part of Green's chart of 1868. His chart is remarkable for several features.



First of all, he used a geometric progression.

Secondly, his letter and line spacing was not fixed, but proportional to the letter size.

Lastly, he used non-serif letters (Snellen had used letters with serifs).

How does that compare to the CURRENT STANDARD?

Green – 1868	**Current Standard** (ETDRS)
Proportional spacing	Proportional spacing
Geometric progression	Geometric progression
Non-serif letters	Non-serif letters
Up to 11 letters / line	5 letters each line
Too early – forgotten	*International standard*

Note that the only difference is the number of letters per line (people were less hurried at the time). However, Green was a century too early, the ophthalmic world was not ready for his proposals and his work was largely ignored.

The current Standard

We saw that the watershed events around 1850 made all the difference for the lack of acceptance of Kuechler's proposals and the overwhelming acceptance of Jaeger's reading samples.

How did the new standard come about?

- In 1959, Louise Sloan (of the Wilmer Institute in Baltimore) designed a new set of non-serif letters. She also introduced the term "M-UNIT" to make Snellen's definition less verbose.
- In 1976, Bailey and Lovie (then in Melbourne) proposed a new layout with proportional spacing and five letters on each line.
- In 1982, the National Eye Institute combined the Sloan letter set with the Bailey-Lovie layout to produce charts for use in the Early Treatment of Diabetic Retinopathy Study. These charts became known as the ETDRS charts and did much to popularize the new format.

Why was the ophthalmic world now ready to accept this standard and were similar proposals from Green forgotten?

The answer lies in part in the interest in Low Vision Rehabilitation, which gradually grew in the second half of the century. In 1952 the first Low Vision centers opened in New York, at the Industrial Home for the Blind and at the New York Lighthouse.

Why does Low Vision rehabilitation provide a new perspective?

Visual acuity measurement can be used for many different purposes. One use is to detect underlying disorders. Since visual acuity can be affected by so many disorders, it is a good screening test, but does not help us in the differential diagnosis.

THE ORGAN		THE PERSON	
Disorder	Impairment	Abilities	Consequences

Visual Acuity Measurement

Diagnosis of underlying condition ← → Prediction of functional consequences

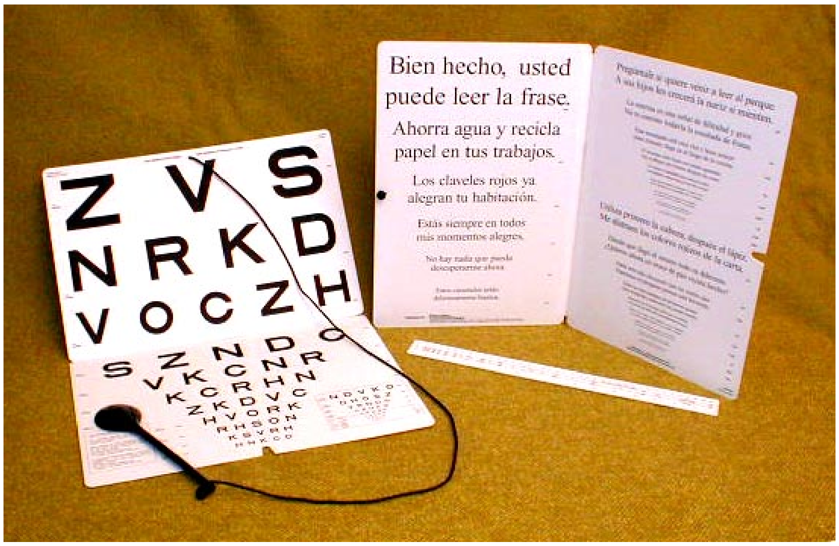
Detects disorders	**Use for Rehabilitation**
Does not differentiate	Predicts Magnification need
Accuracy not critical	Need for Accuracy
Narrow range	Need for Wide range
Few calculations	Need for Calculations

The other use is to predict visual functioning. This is the use in Low Vision Rehabilitation.

While the discussion of underlying functions in the psychophysical laboratory is dominated by terms like spatial frequency and point-spread function, which do not have too much appeal for the average clinician, the keyword for discussion of functional consequences is magnification need. We have seen that the measurement of magnification need was the basis for Donders' definition of visual acuity and for Snellen's letter chart. Magnification need is an eminently practical concept. In the rehabilitation context, accuracy over a wide range becomes important, as do calculations to compare measurements under different circumstances.

Therefore, it is no accident that it were Low Vision professionals such as Sloan and Bailey and Lovie, who contributed the essential components for the recent visual acuity measurement standards. These improvements were thus readily available when the NEI needed them for broader implementation and standardization in its cooperative clinical trials. The ETDRS implementation made the standards known well beyond the Low Vision community.

The wide acceptance of the ETDRS standards has, in turn, led to improvements in cards used for the Low Vision range. The illustration shows a letter chart for use at 1 meter, following the ETDRS layout. This chart allows accurate measurement s from 1/50 (20/1000) to 1/1 (20/20) on one chart and thus obviates the need for guesstimates such as Count Fingers or Hand Movements.



The back of the chart contains reading segments, which are similarly proportionally spaced, to allow for reading speed measurements. These reading cards are now standardized and available in multiple languages. The illustration shows the Spanish text.