Measuring Vision and Vision Loss

August Colenbrander, MD – San Francisco

This manuscript is similar to Chapter 51 in Volume 5
of Duane's Clinical Ophthalmology, 2001 edition

OUTLINE:

ASPECTS OF VISION LOSS

Since the visual system alone provides as much input to the brain as all other senses combined, it is not surprising that vision loss can have a devastating impact upon peoples lives. The various chapters in this section deal with the prevalence and remediation of such impacts. In this discussion, different observers have different points of view and therefore emphasize different aspects of vision loss and its consequences. Clarity about these differences is important ([1]). They will be discussed, using as a conceptual framework the four aspects of functional loss that were first introduced in the *WHO Classification of Impairments, Disabilities and Handicaps (ICIDH)* ([2]). The aspects are distinct, although different publications may use slightly different terms to describe them as shown in Table 1.

Two of the four aspects refer to the organ system, the other two refer to the person. The first aspect is that of anatomical and structural changes. The second aspect is that of functional changes at the organ level; examples are visual acuity loss and visual field loss. The next aspect describes the generic skills and abilities of the individual. The last aspect points to the social and economic consequences of a loss of abilities. In colloquial use, persons with vision loss are often described as “blind”; this terminology is inappropriate since most people with vision loss are not *blind,* but have residual vision. We will return to this issue when discussing ranges of vision loss.

TABLE 1 – Aspects of Vision Loss

	THE ORGAN		THE PERSON	
ASPECTS:	Structural change, Anatomical change	Functional change at the Organ level	Skills, Abilities of the individual	Societal, Economic Consequences
Neutral terms:	Health Condition	Organ Function	Skills, Abilities	Social Participation
Loss, Limitation	Disorder, Injury	Impairment	Disability	Handicap
ICIDH-80([2]):	Disorder	Impairment	Disability	Handicap
ICF([3]):	Structural change	Functional change, Impairment	Activity + Performance code	Participation + Performance code
Application to VISION:	Eye diseases	"visual functions" measured quantitatively *E.g.: Visual Acuity*	"functional vision" described qualitatively *E.g.: Reading ability*	Vision-related Quality of Life

Legend: Vision loss can be approached from different points of view *(see text)*. The different aspects are sometimes described by different names.

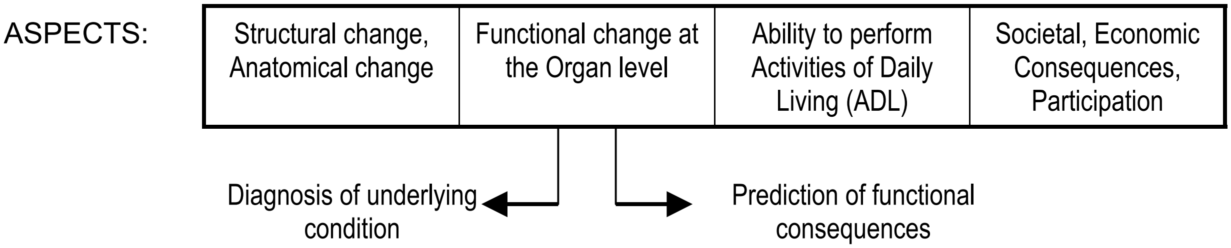
Anatomical and Structural Changes

This aspect describes the underlying disorders or diseases at the organ level. Ophthalmoscopy and slitlamp biomicroscopy have given ophthalmology tools to describe anatomical changes in more detail than is possible for many other organ systems. Most of the ophthalmic literature, including this textbook, is devoted to this aspect. Yet, these changes give us relatively poor cues to the severity of their functional consequences.

Visual functions

This aspect describes **functional changes at the organ level**. Here again, ophthalmology has developed unique tools that can measure *visual functions,* such as visual acuity and visual field, in great detail. These tools are well developed and give objective measurements. These measurements can be used for two purposes: to assist in diagnosing the underlying disorder or to predict the functional consequences *(see Table 2).* E.g.: Tests such as ERG and VEP are helpful in diagnosing the underlying condition, but are poor predictors of the functional consequences. Since visual acuity loss can have many different causes, visual acuity testing adds little to the differential diagnosis, but can help in predicting the impact on Activities of Daily Living (ADL). The Ishihara color test is good at diagnosing even minor red-green deficiencies for genetic studies, but overestimates the functional consequences. The D15 color test on the other hand, was designed to be insensitive to minor deficiencies and to detect only those that might have functional consequences. The discussion in this chapter will be oriented towards the functional consequences.

TABLE 2 – Use of Visual Function Measurements



Legend: Different tests serve different purposes *(see text)*.

Functional vision

This aspect reaches beyond the description of organ function by describing the **skills and abilities of the individual**. It describes how well the individual is able to perform *Activities of Daily Living (ADL)*, given the vision loss. This aspect has been described under different names. In the field of vision, the term *functional vision* is used. In ICIDH-80 ([2]) loss (or lack) of ability was described as *dis-ability*. Its successor, ICIDH-2 ([3]) provides a taxonomy of *activities* and of the ability to perform them. The use of the term disability is discouraged since it may have different meanings in different contexts. (Having a disability may be a synonym for having an impairment; being disabled points to a loss of ability; being on disability points to an economic consequence.) In the AMA *Guides to the Evaluation of Permanent Impairment* ([4]) the term impairment refers to organ function, impairment rating refers to an estimate of the ability to perform activities of daily living.

Societal and Economic Consequences

The last aspect describes the societal and economic consequences for the individual caused by an impairment or by a loss of ability. In ICIDH-80 this aspect was described as *handicap* and measured in terms of *loss of independence*; in ICIDH-2 it is described under the heading *participation.* Handicaps do not preclude participation. The story of Helen Keller is one example of how some people can achieve full participation in spite of extraordinary handicaps.

Measurement

The different aspects are measured in very different ways. Visual functions are measured with clinical tests, such as a letter chart, a tangent screen, a color test, etc. Functional vision is assessed by the ability to perform generic *Activities of Daily Living* (ADL). Different impairments will have different effects. Visual acuity loss will affect activities such as reading ability and face recognition. Visual field loss will be manifested primarily by difficulties in Orientation and Mobility (O&M) tasks. The participation aspect looks beyond the ADL abilities to the actual environment. How well is the individual able to hold a job and to earn a living? What "reasonable accommodations" are mandated by statutes such as the Americans with Disabilities Act (ADA)? Do difficulties in face recognition limit a person's social activities? This aspect is not limited to generic daily living skills, but can consider the effect of specific environmental conditions and demands. Uncorrected myopia, for instance, would be a severe handicap for a hunter, but might be an asset for a watchmaker.

Rehabilitation

Improving the participation aspect is the ultimate goal of all medical and social interventions. There clearly are links between the aspects: a disorder may cause an impairment, an impairment may cause a loss of abilities, a loss of abilities may cause a lack of participation. However, these links are not rigid. Medical and surgical interventions can reduce the impairment caused by a disorder. Assistive devices may improve abilities in the face of a given impairment. Changes in the human and physical environment may increase participation, regardless of reduced abilities. The art of rehabilitation is to manipulate each of these links so that a given disorder results in the least possible loss of participation.

The outcome of various interventions must be measured in different ways. Visual acuity measurement is very useful as an outcome measure for medical and surgical interventions, but cannot be used to measure the outcome of rehabilitative interventions. Rehabilitative effects must be judged by an improved ability to perform ADL activities. This can be expressed in an ability profile.

This chapter will pay much attention to visual acuity and visual acuity measurement. The reader should keep in mind, however, that visual acuity is only one of many organ functions and that organ function is only one of the many aspects of vision loss. Particularly among the elderly, measuring functions such as contrast sensitivity, glare sensitivity, vision at low luminance may reveal deficits that are missed by the usual visual acuity measurement at high contrast ([5]).

ASSESSMENT of VISUAL ACUITY

The visual function that is measured most often is visual acuity. Here again, different users may measure different aspects of visual acuity. Various basic aspects of visual acuity, such as detection, resolution, hyperacuity are discussed elsewhere. In this chapter we will discuss the clinical testing of visual acuity, which is based on *letter recognition*. Letter recognition is a rather complex function, it requires not only the optical ability to resolve the image, but also the cognitive ability to recognize it, and the motor ability to respond. In young children, in developmentally delayed individuals and in elderly with a stroke, it may be their inability to respond, rather than optical factors, that limits their test performance.

Historical developments

Reading tests have been used since before the Middle Ages to test the function of the eye. Major changes started to occur in the middle of the 19th century.

1843. In 1843 Kuechler, a German ophthalmologist in Darmstadt, wrote a treatise advocating the need for standardized vision tests ([6]). He developed a set of three charts, to avoid memorization. Unfortunately, he was a decade too early. His work was almost completely forgotten.

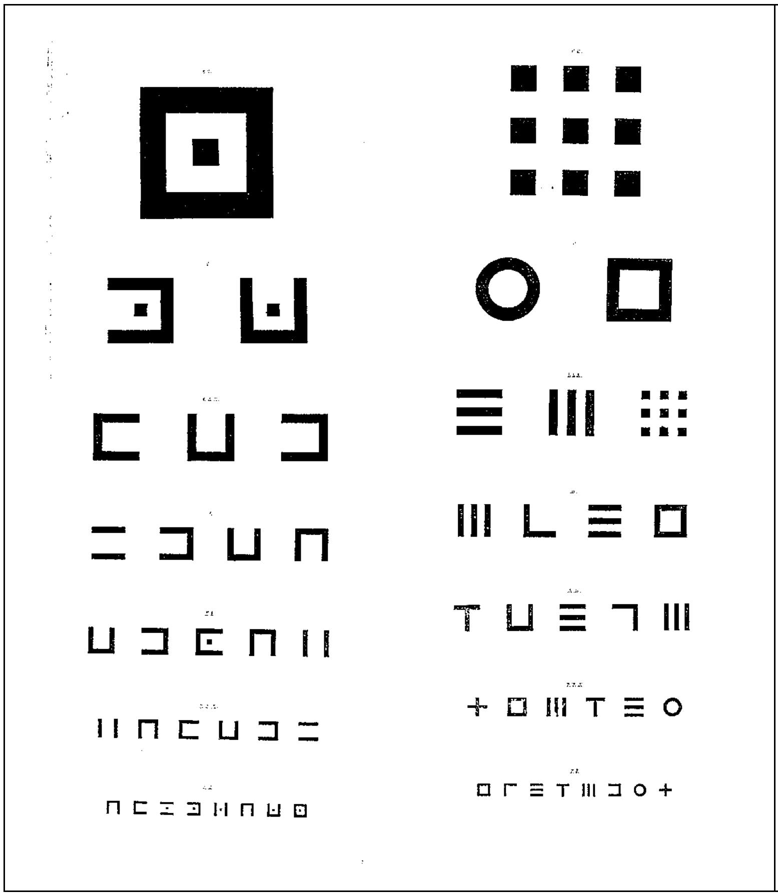
1850. Around 1850 started what later would be called the Golden Age of Ophthalmology. In 1850, Franciscus Donders, from Utrecht, the Netherlands, visited William Bowman, of anatomical and histological fame, at an international conference in London. There he met Albrecht von Graefe, who would become the father of German clinical ophthalmology. Donders and von Graefe became lifelong friends (*). With Bowman and Hermann von Helmholtz, who invented the ophthalmoscope in 1851, they became the foursome that would lead ophthalmology to become the first organ-oriented specialty. In 1850 von Graefe had just opened his famous eye clinic in Berlin. In 1852 Donders would open what would later become the Royal Dutch Eye Hospital in Utrecht.

> _Footnote_
> *(*) Donders later wrote: "I had just seen Jaeger (Friedrich, Eduard's 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."*

1854. Thus, the scene had changed considerably when, in 1854, Eduard von Jaeger, the son of a well-known ophthalmologist in Vienna, published a set of reading samples ([7]). His reading samples were first published as an appendix to his book about *Cataract and Cataract Surgery* ([8]). They became an immediate success as a means to document functional vision. Since Vienna was an international center, he published samples in German, French and English and in a variety of Central European languages. He used fonts that were available in the State Printing House in Vienna and labeled them with the numbers from the printing house catalogue.

1861. Meanwhile Donders, who was a professor of physiology before he decided to concentrate on ophthalmology, was working on his epoch making studies on Refraction and Accommodation. He clarified the nature of hyperopia as a refractive error, rather than as a form of "asthenopia" and brought the prescription of glasses from trial and error at the county fair to a scientific routine. His work would be published in London in 1864 ([9]). For this work, Donders not only needed reading samples for presbyopes, but also distance targets to use in the refractive process of myopes and hyperopes. Initially, he had used some of the larger type samples from Jaeger's publication as a distance target. However, he felt the need for a more scientific method and for a measurement unit to measure visual function. He coined the term "visual acuity" to describe the "sharpness of vision" and defined it as the ratio between a subject's performance and a standard performance. In 1861, he asked his co-worker and later successor Herman Snellen to devise a measurement tool.

1862. In 1862 Snellen published his letter chart ([10]). His most significant decision was not to use existing typefaces, but to design special targets, which he called optotypes. He experimented with various targets designed on a 5x5 grid *(Figure 1)*. Eventually, he chose letters *(Figure 2)*. Some others published charts based on Donders' formula in the same year, using existing typefaces rather than optotypes. Snellen's chart prevailed and spread quickly around the world. One of the early big orders came from the British army, wanting to standardize the testing of recruits.



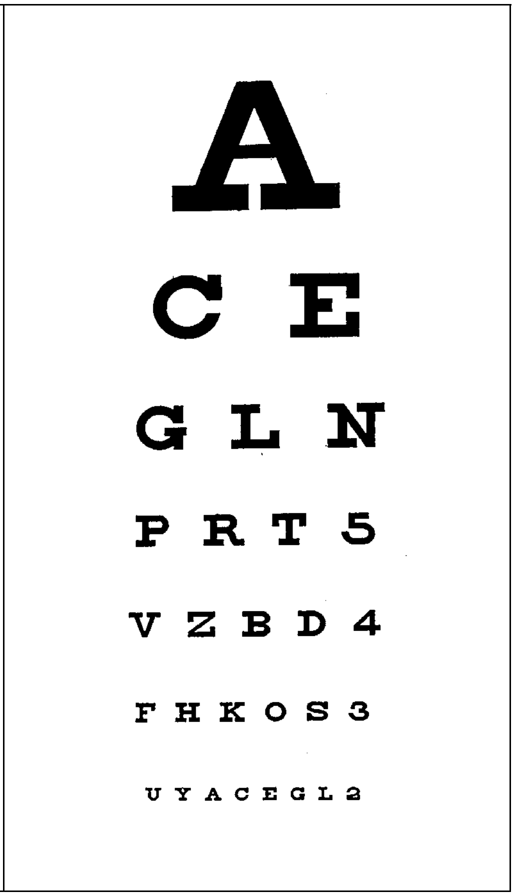


Figure 1 Snellen – Experimental Charts – 1861

Snellen apparently experimented with various targets designed on a 5x5 grid, prior to choosing letters as optotypes. This chart remains in the Museum of the University of Utrecht.

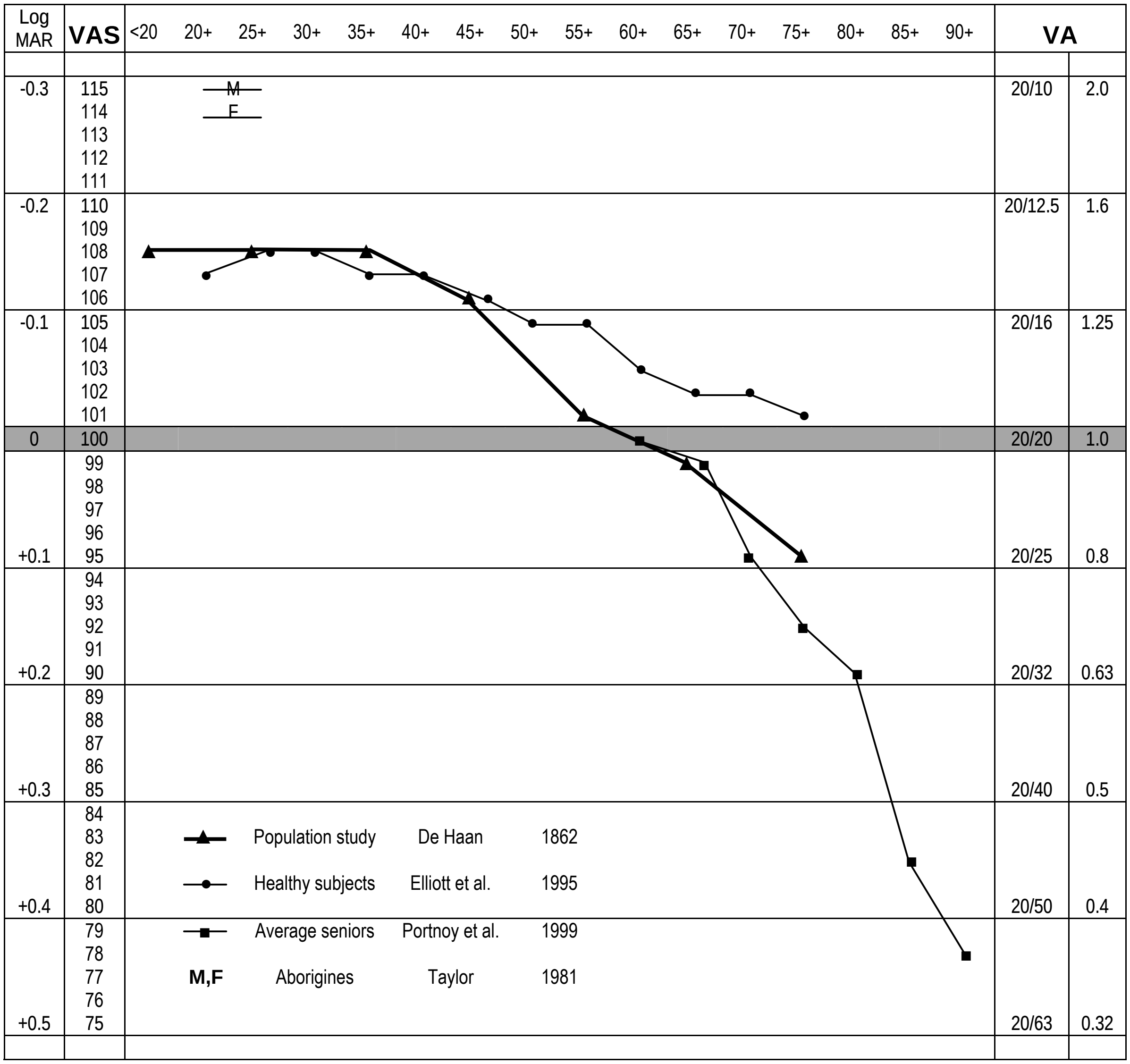
Figure 2 Snellen's chart as published in 1862

To implement Donders' formula, Snellen defined "standard vision" as the ability to recognize one of his optotypes when it subtended 5' of arc. This choice was inspired by the work of the English astronomer Robert Hooke, who, two centuries earlier ([11]), had found that the human eye can separate double stars when they are 1' apart. Since Snellen chose an external, physical standard, others could accurately reproduce his charts. This was different from Jaeger's samples, which were based on existing typefaces. When others wanted to reproduce them, they had to use whatever typefaces were available locally. This accounts for the wide variability among "Jaeger" samples.

Donders and Snellen were well aware that their standard represented less than perfect vision and that most normal healthy eyes could do better. Thus, it is wrong to refer to "20/20" *(1.0)* vision as “normal”, let alone as “perfect” vision. Indeed, the connection between normal vision and standard vision is no closer than the connection between the standard American foot and the average length of “normal” American feet. The significance of the 20/20 *(1.0)* standard can best be thought of as the “lower limit of normal” or as a screening cut-off. When used as a screening test, we are satisfied when subjects reach this level and feel no need for further investigation, even though the average visual acuity of healthy eyes is 20/16 *(1.25)* or 20/12 *(1.6)*.

While Snellen was preparing his chart, Donders already commissioned a study by one of his PhD students to document the normal changes in visual acuity with age ([12]), using prototypes of Snellen’s symbols. The study was published in 1862, the same year that Snellen published his chart. The similarity with more recent data *(Table 3)* is remarkable.

TABLE 3: Visual Acuity Changes with Age



Legend, Table 3: The chart demonstrates that it is a mistake to consider 20/20 as “average”, “normal” or “perfect” vision. The gray band indicates standard vision (20/20, 1.0). Average adult visual acuity is significantly better and does not drop to 20/20 until after age 60.

The “▲” markers represent a study (12) using prototypes of Snellen’s test letters, published in 1862. The “●” markers represent a recent meta-analysis of healthy eyes from several different studies (13). The “■” markers represent recent findings from an elderly population (including eyes with age-related changes) (5). The “M” and the “F” markers represent data from male and female Australian Aborigines (14), which were found to have statistically significant better acuity than comparable Caucasians.

The 1862 findings are remarkably similar to the recent data for healthy adults in the younger age groups and to those for unselected seniors in the older groups.

Since Snellen’s days few major improvements in visual acuity measurement have been made. Many tried to devise better optotypes, but, as A. G. Bennet remarked in an exhaustive review of historical developments (15) while preparing for the British standard (16), “the road of visual acuity measurement is littered with stillborn charts”. Some developments, however, are worth mentioning.

1868. In 1866 John Green of St. Louis had spent some time with Donders and Snellen and had written a small paper there about the measurement of astigmatism. He developed his own chart, which he presented it to the American Ophthalmological Society in 1868(17), modifying a prior proposal from 1867.

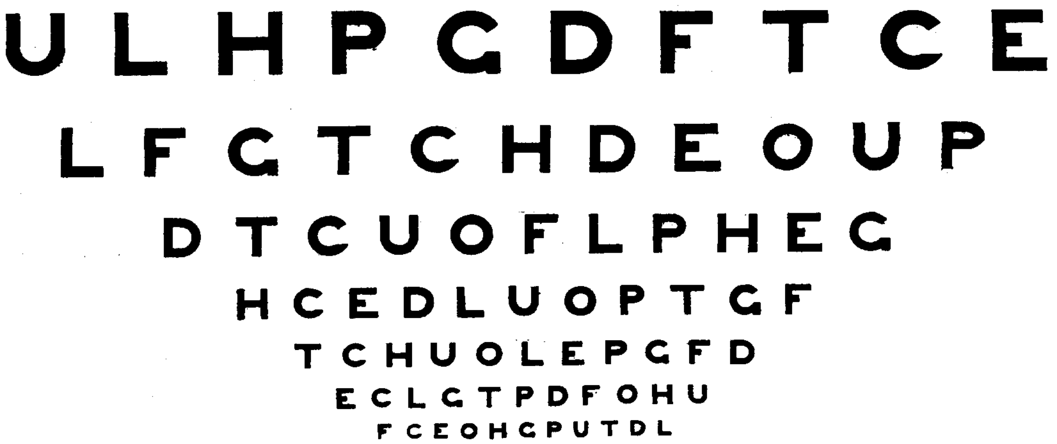


Figure 3 Segment of Green’s Chart, proposed in 1868.

Legend: Note that Green combined sans-serif letters and proportional spacing with a geometric progression, using what later would be known as the “preferred numbers” series *(see text)*.

Green’s proposals were not accepted. A century later, his principles would be incorporated in international standards.

Green’s chart featured sans-serif letters (Snellen used letters with serifs), proportional spacing of the characters and a geometric progression of letter sizes (10 steps = 10x), three features that are now part of standardized letter chart design. He was a century too early; his proposals gained little acceptance. Green went back to letters with serifs, because letters without serifs were said to “look unfinished”. A century later, the British standard would choose sans-serif letters, because letters with serifs “look old fashioned”.

1875. Snellen originally calibrated his charts in Parisian feet. At the time there were some twenty different measurement systems used in Europe. It is not surprising that the uniform Metric system (18) was gaining ground. Snellen soon changed from 20 Parisian feet to 6 meters or, for adherents of the decimal system, to 5 meters. Today, the 20 ft distance prevails in the U.S.A., 6 meters prevails in Britain, 5 or 6 meters are used in continental Europe. Conversion between these different measurements is awkward. In 1875 Felix Monoyer (*) of Lyons, France, proposed to replace the fractional Snellen notation with its decimal equivalent. (E.g. 20/40 = 0.5, 6/12 = 0.5, 5/10 = 0.5) (19). Decimal notation makes it simple to compare visual acuity values, regardless of the original measurement distance and is used in large parts of Europe. *(see Table 4)*

> Footnote
>
> *(*) Monoyer is also know for the introduction of the diopter (20) in 1872. The diopter is the reciprocal of any metric distance; it greatly simplified lens formulas. Earlier, the power of a lens was expressed by its focal distance (f). Changing to the reciprocal of the focal distance (D) simplified the awkward formula* $1/f_1 + 1/f_2 = 1/f_3$ *to* $D_1 + D_2 = D_3$. *We will see later that the Diopter notation can also simplify Snellen’s formula when used for near vision.*

TABLE 4 – Equivalent Notations

Equivalent Notations

Parts of Europe		Britain		U.S.A.		decimal		Low Vision
5/5	=	6/6	=	20/20	=	**1.0**	=	1/1
5/10	=	6/12	=	20/40	=	**0.5**	=	1/2
5/25	=	6/30	=	20/100	=	**0.2**	=	1/5
5/50	=	6/60	=	20/200	=	**0.1**	=	1/10

See also Table 8

Legend: Various notations may be used to express equivalent visual acuity values *(see text, see also Table 8)*.

1888. Edmund Landolt had worked with Snellen in Utrecht and later became professor of ophthalmology in Paris. In 1874 Snellen and Landolt had cooperated in publishing a major chapter on “Optometrology” (21), the science of measuring vision. They recognized that not all of Snellen’s optotypes were equally recognizable. This led Landolt to propose the broken ring symbol (1888), a symbol that has only one element of detail and varies only in its orientation (22). Landolt’s C’s would become the preferred visual acuity measurement symbol for laboratory experiments, but gained only limited acceptance in clinical use.

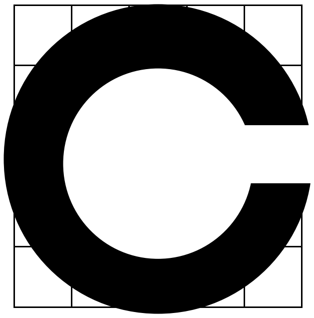


Figure 4 Landolt C

> **Legend:** Recognizing the differences in recognizability among letter optotypes, Landolt, in 1888, proposed the "Landolt C" or broken ring (22). The various targets have only one critical detail and vary only in orientation. They are widely used in laboratory studies and have been accepted as the standard against which other optotypes should be calibrated (23).

1909. Relatively little happened in the period that followed. Efforts at standardization were made, such as a standard proclaimed by the International Council of Ophthalmology in 1909 (24). Such documents were filed and never gained a wide following. That clinicians did not feel an urgent need for standardization can be explained by the fact that the everyday letter chart uses do not require it. For refractive correction any set of targets will do, since the only question is "better or worse?". For screening the distinction between "within normal limits" and "not within normal limits" is the most important. We have seen that Snellen's standard is well positioned for screening purposes. At the lower end, the difference between 20/200 *(0.1)* and 20/400 *(0.05)* is unimportant for screening purposes.

After 1945 the interest in Low Vision rehabilitation was gaining ground. It was recognized that the majority of those considered "industrially blind" actually had some level of useable vision. In 1952 the first Low Vision services were opened in New York at the Industrial Home for the Blind and at the New York Lighthouse. For rehabilitation purposes the difference between 20/200 and 20/400, which was unimportant for screening, became very important, since the patient with 20/400 needs twice as much magnification as the patient with 20/200. It is not surprising then, that major refinements in clinical visual acuity measurement came from individuals involved in Low Vision rehabilitation.

1959. In 1959 Louise Sloan, the founder of the Low Vision service at the Wilmer Eye Institute of Johns Hopkins University designed a new optotype set of 10 letters (25) *(see Figure 7).* She chose sans-serif letters, while maintaining Snellen's 5x5 grid. This in contrast to the British standard (16), which selected a 4x5 grid for its sans-serif letters. She recognized that not all letters were equally recognizable. To avoid this problem she proposed to use all ten letters on each line. The larger letter sizes thus required more than one physical line.

Louise Sloan also proposed a new letter size notation (26).

To implement Donders' definition of visual acuity as the ratio between a subject's performance and a standard performance, Snellen had used the following formula:

$$\mathbf{V} = \frac{\mathbf{d}}{\mathbf{D}} = \frac{\text{distance at which the \textit{subject} recognizes the optotype}}{\text{distance at which a \textit{standard eye} recognizes the optotype}}$$

Sloan simplified this rather verbose definition and made use of the metric system implicit by introducing the term **"M-unit"** for the "distance in meters at which a standard eye recognizes the optotype" (i.e. at which the optotype subtends 5 minutes of arc). The formula then becomes:

$$\mathbf{V} = \frac{\mathbf{m}}{\mathbf{M}} = \frac{\text{test distance} \quad \textit{(in meters)} \qquad \textit{note lower case m}}{\text{letter size} \quad \textit{(in M-units)} \qquad \textit{note upper case M}}$$

In line with other definitions of measurement units in the SI system, this terminology allows us to define the measurement unit for visual acuity more easily by stating that:

standard acuity *(1.0, 20/20)* represents
the ability to recognize a **standard letter size** *(1 M-unit)*
at a **standard distance** *(1 meter)*.

The relationship between the three variables: letter size, viewing distance and visual acuity can be demonstrated in the nomogram in Table 5. Connecting the markers for any two of the variables with a straight line will point to the marker for the third variable. It demonstrates that any letter size can represent any visual acuity value, depending on the viewing distance. The gray scales represent the preferred, metric notations, as will be discussed later. The non-metric scales are given for comparison. The Jaeger numbers in this table are based on Jaeger's original print samples (27).

1974. In the 1960's the WHO had surveyed national definitions of "legal blindness" and found that 65 countries used as many different definitions. In 1974 the World Health Assembly approved the 9th Revision of the International Classification of Diseases (ICD-9) (28). In it, the old dichotomy between "legally sighted" and "legally blind" was abandoned for a series of (numbered) ranges of vision loss. In the same year, the International Council of Ophthalmology (ICO) (29) adopted the same ranges, extended them to include normal vision, and used the naming convention used in ICD-9-CM (30) and in this chapter.

1976. In 1976, **Ian Bailey** and **Jan Lovie** (then at the Kooyong Low Vision Service in Melbourne) published a new chart (31), featuring a novel layout with five letters on each row and spacing between letters and rows equal to the letter size. This layout standardized the crowding effect and the number of errors that could be made on each line. Thus, the letter size became the only variable between the acuity levels. Their charts have the shape of an inverted triangle and are much wider at the top than traditional charts. Like Sloan, they followed a geometric progression of letter sizes.

That same year, Hugh Taylor, also in Melbourne, used these design principles for an illiterate E chart (32), used to study the visual acuity of Australian Aborigines. He found that, as a group, Australian Aborigenes had significantly better visual acuity than Europeans (14). This is another reason not to regard 20/20 visual acuity as "normal" or as "perfect" vision. *(see Table 3).*

1982. Based on the above work, Rick Ferris et al. of the **National Eye Institute** chose the Bailey-Lovie layout, implemented with Sloan letters, to establish a standardized method of visual acuity measurement for the Early Treatment of Diabetic Retinopathy Study (ETDRS) (33). These charts were used in all subsequent clinical studies, and did much to familiarize the profession with the new layout and progression *(see Figure 5)*. Data from the ETDRS were used to select letter combinations that give each line the same average difficulty, without using all letters on each line. Since the Sloan letters (designed on a 5x5 grid, like Snellen's) are wider than the British letters (designed on a 4x5 grid) used by Bailey and Lovie *(see Figure 9)*, the ETDRS chart was designed for a 4m distance, not the 6m used by Bailey and Lovie.

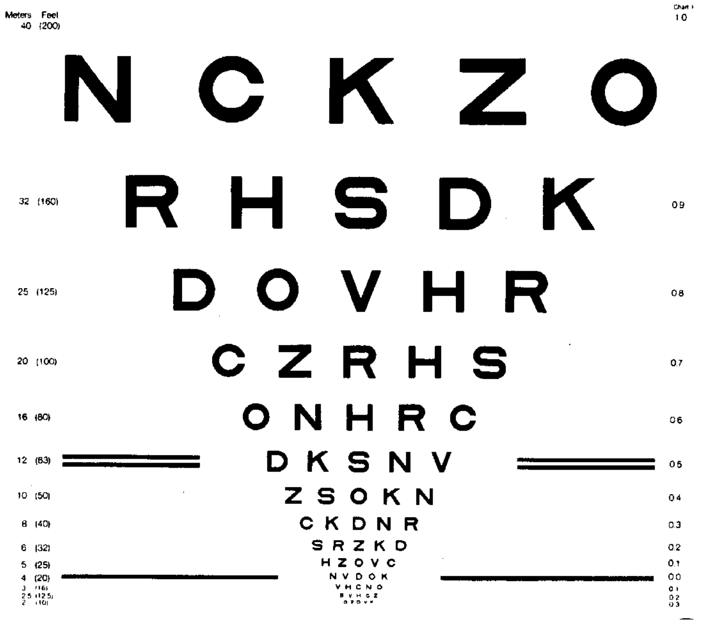


Figure 5 ETDRS chart

Legend: This chart ([33]) combines the Bailey-Lovie layout with the Sloan letter set. It is used in many clinical studies and is considered a U.S. standard.

1984. The **International Council of Ophthalmology** approved a new 'Visual Acuity Measurement Standard', also incorporating the above features ([23]).

Legend for Table 5.

This table demonstrates the relationship between the three variables: letter size, viewing distance and visual acuity. Connecting the markers for any two of the variables with a straight line will point to the marker for the third variable.

The first column identifies the *letter size*, in M-units, printer's points and J-numbers. The Jaeger sizes are based on Jaeger's original samples ([27]). Note that these differ from the ranges of J designations found on contemporary charts, as shown in Table 9.

The second column indicates the *viewing distance*. Expressed in diopters *(see text)*, in metric units and in U.S. units.

The third column indicates the *visual acuity*. Notations include the Snellen fraction for 1 meter *(see text)*, decimal notation and U.S. notation. The numbers in the markers indicate the Visual Acuity Score (VAS) *(see section on Assessment of Functional Vision and Table 13)*.

The grey columns indicate the preferred metric measurements. In the range of normal and near-normal vision, the traditional visual acuity notations and distance measurement in meters are preferred. For the Low Vision range, the 1-meter Snellen fraction is easier to use *(see text)*. For reading vision (closer than 1 meter) it is useful to record the viewing distance in diopters, using the modified Snellen formula 1/V = M x D *(see text)*.

The numbers in the markers for letter size and viewing distance allow the visual acuity score to be broken down into its components: letter credit + distance credit = visual acuity score *(see text)*. These linear values can be averaged and are helpful for statistical manipulations.

TABLE 5 - Nomogram for the Calculation of Visual Acuity Values

LETTER SIZE				VIEWING DISTANCE				VISUAL ACUITY				ICD
40 M	-30				80 m	145	250 ft	1/0.5	2.0	115	20/10	Range of Normal Vision
					60 m	140	200 ft					
30 M	-25		J#24	0.02 D	50 m	135	160 ft	1/0.6	1.6	110	20/12	
					40 m	130	120 ft					
25 M	-20		J#23		30 m	125	100 ft	1/0.8	1.2	105	20/16	
					25 m	120	80 ft					
20 M	-15		J#22	0.05 D	20 m	115	60 ft	**1/1**	**1.0**	**100**	**20/20**	
					16 m	110	50 ft					
16 M	-10		J#21		12 m	105	40 ft	1/1.2	0.8	95	20/25	
				0.10 D	10 m	100	30 ft					
12 M	-5	100 p	J#20		8 m	95	25 ft	1/1.6	0.6	90	20/30	Near-normal Vision
					6 m	90	20 ft					
10 M	0	80 p	---		5 m	85	16 ft	1/2	0.5	85	20/40	
				0.25 D	4 m	80	12 ft					
8 M	5	60 p	J#19		3 m	75	10 ft	1/2.5	0.4	80	20/50	
					2.5 m	70	8 ft					
6 M	10	50 p	J#18	0.5 D	2 m	65	6 ft	1/3	0.3	75	20/60	
					1.6 m	60	5 ft					
5 M	15	40 p	---		1.2 m	55	50”	1/4	0.25	70	20/80	Moderate Low Vision
				1 D	**1 m**	**50**	**40”**					
4 M	20	32 p	J#17		80 cm	45	30”	1/5	0.2	65	20/100	
			(16)		60 cm	40	25”					
3 M	25	24 p	J#15	2 D	50 cm	35	20”	1/6	0.16	60	20/120	
				2.5 D	40 cm	30	16”					
2.5 M	30	20 p	J#14	3 D	30 cm	25	12”	1/8	0.12	55	20/160	
				4 D	25 cm	20	10”					
2 M	35	16 p	J#13	5 D	20 cm	15	8”	1/10	0.1	50	20/200	Severe Low Vision
				6 D	16 cm	10	6”					
1.6 M	40	12 p	J#12	8 D	12 cm	5	5”	1/12	0.08	45	20/250	
			(11)	10 D	10 cm	0	4“					
1.2 M	45	10 p	J#10	12 D	8 cm	-5	3“	1/16	0.06	40	20/300	
			(8,9)	15 D	6 cm	-10	2.5”					
1 M	**50**	**8 p**	**J# 7**	20 D	5 cm	-15	2”	1/20	0.05	35	20/400	
			(6)	25 D	4 cm	-20	1.6”					
0.8 M	55	6 p	J# 5	30 D	3 cm	-25	1.2”	1/25	0.04	30	20/500	Profound Low Vision
			(4)	40 D	2.5 cm	-30	1”					
0.6 M	60	5 p	J# 3	50 D	2 cm	-35	0.8”	1/30	0.03	25	20/600	
				60 D	1.6 cm	-40	0.6”					
0.5 M	65	4 p	J# 2	80 D	1.2 cm	-45	0.5”	1/40	0.025	20	20/800	
				100 D	1 cm	-50	0.4”					
0.4 M	70	3 p	J# 1	125 D	0.8 cm	-55	0.3”	1/50	0.02	15	20/1000	

Formulas used:

1/M		**x**		**m**	**= m / M =**		**V**	(visual acuity)
M		**x**	**D**		**= M x 1/m =**	**1/V**		(magnification need)
	Size credit	**+**		Distance credit	**=**		Acuity score	

Visual Acuity Measurement – Distance vision

Ranges of vision loss

Vision loss is not an all or none phenomenon. Since the 1970's the WHO has recognized this by replacing the simplistic dichotomy between those who are considered "legally blind" and those who are considered "legally sighted" with a set of ranges. In ICD-9 ([28]) and ICD-9-CM ([30]) the range of "Low Vision" took its place between the ranges of normal (or near-normal) vision and blindness (or near-blindness). The word *low* indicates that these individuals do not have normal vision, the word *vision* indicates that they are not blind. The ranges used in ICD-9-CM are listed in Table 6.

Although these changes were made a quarter century ago, the use of the term "blindness" to denote partial vision loss is still prevalent. This is regrettable, since it fosters misconceptions among patients and practitioners. Patients tend to accept the statement that they *are* "legally blind" as an irreversible verdict of hopelessness. Telling them that they *have* "Severe Low Vision" (the corresponding ICD-9-CM term) tells them that they have a problem, but that there are ways to cope with this problem. To call a patient with a severe vision loss "legally blind" is as preposterous as calling a patient with a severe heart ailment "legally dead".

Measurement considerations

Letter recognition, upon which clinical visual acuity measurement is based, is a rather complex function, which involves not only optical factors, but also cognitive and motor abilities. When choosing our test parameters we strive to keep the cognitive and motor requirements minimal, so that we measure mainly optical factors. Within the group of optical factors, we strive to keep factors such as contrast and illumination optimized, so that the main remaining variable is magnification.

Visual acuity can be thought of as the reciprocal of the magnification threshold for letter recognition. Magnification is the factor on which Snellen's formula is based. If a subject needs letters that are twice as large or twice as close than those needed by a standard eye, the visual acuity is said to be 1/2 (20/40, 0.5), if the magnification need is 5x, the visual acuity is 1/5 (20/100, 0.2), etc.

It is not always possible to avoid the cognitive factors. This is the case for infants *(see Table 11)* and for pre-school children who do not yet know the entire alphabet. Here we often use other methods such as grating detection or picture recognition. It is important to realize that these are different tasks, which may have different magnification requirements. Similar considerations exist for developmentally delayed individuals. Sometimes it appears that the motor concept of directionality that is required to respond to tumbling E's is a limiting factor. Testing with different modalities may help to give an insight into these non-optical factors. In elderly patients with a stroke and macular degeneration, the question may arise whether inability to read is the result of the macular degeneration or of the stroke. Failure to respond to larger print may point to cognitive, rather than optical factors. In the following discussions it will be assumed that cognitive and motor factors are indeed trivial. Even so, many choices remain to be made. We will discuss the choice of test distance, the choice of letter size progression, the choice of criterion, the choice of contrast and illumination, the choice of visual acuity notation, and the choice of test symbols.

TABLE 6 – Ranges of Visual Acuity Loss

RANGES of Vision Loss (ICD-9-CM)		VISUAL ACUITY			STATISTICAL ESTIMATES OF READING ABILITY
		Decimal notation	US notation	1 m notation	
(Near-) Normal Vision	Range of Normal Vision	1.6 1.25 1.0 0.8	20/12.5 20/16 20/20 20/25	1/0.63 1/0.8 1/1 1/1.25	Normal reading speed Normal reading distance *Reserve capacity for small print*
	Near-Normal Vision	0.63 0.5 0.4 0.32	20/32 20/40 20/50 20/63	1/1.6 1/2 1/2.5 1/3.2	Normal reading speed Reduced reading distance *No reserve for small print*
Low Vision	Moderate Low Vision	0.25 0.2 0.16 0.125	20/80 20/100 20/125 20/160	1/4 1/5 1/6.3 1/8	Near-normal with reading aids *Uses low power magnifier or large print books*
	Severe Low Vision	0.1 0.08 0.06 0.05	20/200 20/250 20/320 20/400	1/10 1/12.5 1/16 1/20	Slower than normal with reading aids *Uses high power magnifiers*
	Profound Low Vision	0.04 0.03 0.025 0.02	20/500 20/630 20/800 20/1000	1/25 1/32 1/40 1/50	Marginal with reading aids *Uses magnifiers for spot reading, but may prefer talking books*
(Near-) Blindness	Near-Blindness	0.016 0.012 0.010 less	20/1250 20/1600 20/2000 less	1/63 1/80 1/100 less	No visual reading *Must rely on talking books, Braille or other non-visual sources*
	Total Blindness	No Light Perception			

Legend: Ranges of vision loss as defined in ICD-9-CM, based on recommendations of the WHO and the International Council of Ophthalmology (ICO). Note that the scale is not truncated at 20/20 *(1.0)*; the range of normal vision includes 20/16 *(1.25)* and 20/12 *(1.6)*. *(See also Table 3).* These ranges replace the outdated dichotomy between those who are “legally sighted” and those who are “legally blind”. The level previously designated as “legally blind” is now designated as “Severe Low Vision”.

The various ranges correspond to eligibility ranges for various benefits. In the U.S. special education assistance is generally available for those with Moderate Low Vision, a broader range of benefits is available at the Severe Low Vision level (formerly “legal blindness”). In Europe and in WHO statistics, blindness benefits generally start at the Profound Low Vision level.

See Table 13 for a comparable table of ranges of Visual Field loss.

Choice of test distance for Normal and near-normal vision

The vast majority of patients seen in ordinary practice has visual acuities in the range of normal and near-normal vision *(20/60 or better, ICD-9-CM, see Table 6)*. For these patients the most commonly used testing distances are 20 ft, 6 m and 5 m. These distances were chosen, not because they are especially appropriate for visual acuity measurement, but because at these distances the optical difference with infinity may be ignored. Remember that the stimulus for the development of the letter chart came from Donders' work on refraction. Traditional chart designs reflect the emphasis on screening and on refractive use. In the near-normal range the steps between letter sizes are small, for lower acuities they become larger, for acuities worse than 20/200 *(0.1)* vague statements such as "count fingers" and "hand motions" are used.

In 1973 Hoffstetter proposed the use of a 4-meter test distance ([34]) for use in smaller rooms. For visual acuity measurement this distance is as valid as any other distance, provided that it is properly entered into the Snellen formula. Sloan liked the 4-m distance because it made for easy conversion to a 40-cm reading distance. The ETDRS charts adopted it because charts with the Bailey-Lovie layout would have to be substantially wider if designed for 5 m or 6 m. At 4 meters, however, the accommodative demand becomes 0.25 diopters and can no longer be ignored. Another option for small rooms is the use of mirrors.

For young children, a test distance of 10 ft or 3 m is often recommended, because it is easier to hold their attention at the shorter distance.

Choice of test distance for Low vision

A much smaller group of patients has visual acuities in the Low Vision range *(less than 20/60, ICD-9-CM, see Table 6)*. For this group, the magnification need for visual rehabilitation becomes an important objective. Kestenbaum ([35]) pointed out that the magnification need can be found by taking the reciprocal of the visual acuity (e.g.: 20/100 requires 100/20 = 5x, 20/200 requires 200/20 = 10x). Bringing the chart from 20 ft. *(6 m)* to 10 ft. *(3 m)* can double the measurement range, but bringing the chart to 1 meter extends it by a factor 6x. Measuring at 1 meter has the additional advantage that the Snellen fraction is as simple as possible (1/...) and can be converted easily to an equivalent for any other distance by multiplying numerator and denominator by the same number (e.g.: 1/20 = 20/400 = 5/100 = 6/120 = 0.05). The 1-meter column in Table 6 shows that a 1-meter chart with letters up to 50 M can cover the entire Low Vision range down to 1/50 *(20/1000, 0.02)*. Taking the same chart to 10 ft. would extend the measurement range only to 20/300 *(0.06)*.

At short distances, such as at 1 meter, it becomes critically important to maintain the viewing distance accurately. A movement of only 10 cm (4") would introduce a 10% error. This can be prevented with a 1-meter cord attached to the chart. Such charts can be homemade or purchased commercially ([36]).

Optical correction for refractive error is very important for this group, but the question "better or worse" looses significance when the patient cannot see the letters on a chart at 20 ft. Being able to see several lines on a 1-meter chart can provide major encouragement and better responses to subjective refraction. Presbyopic patients need a 1 D correction for the 1-meter distance. This is easier to provide than a 1/3 D correction for a 10 ft *(3m)* distance ([37]).

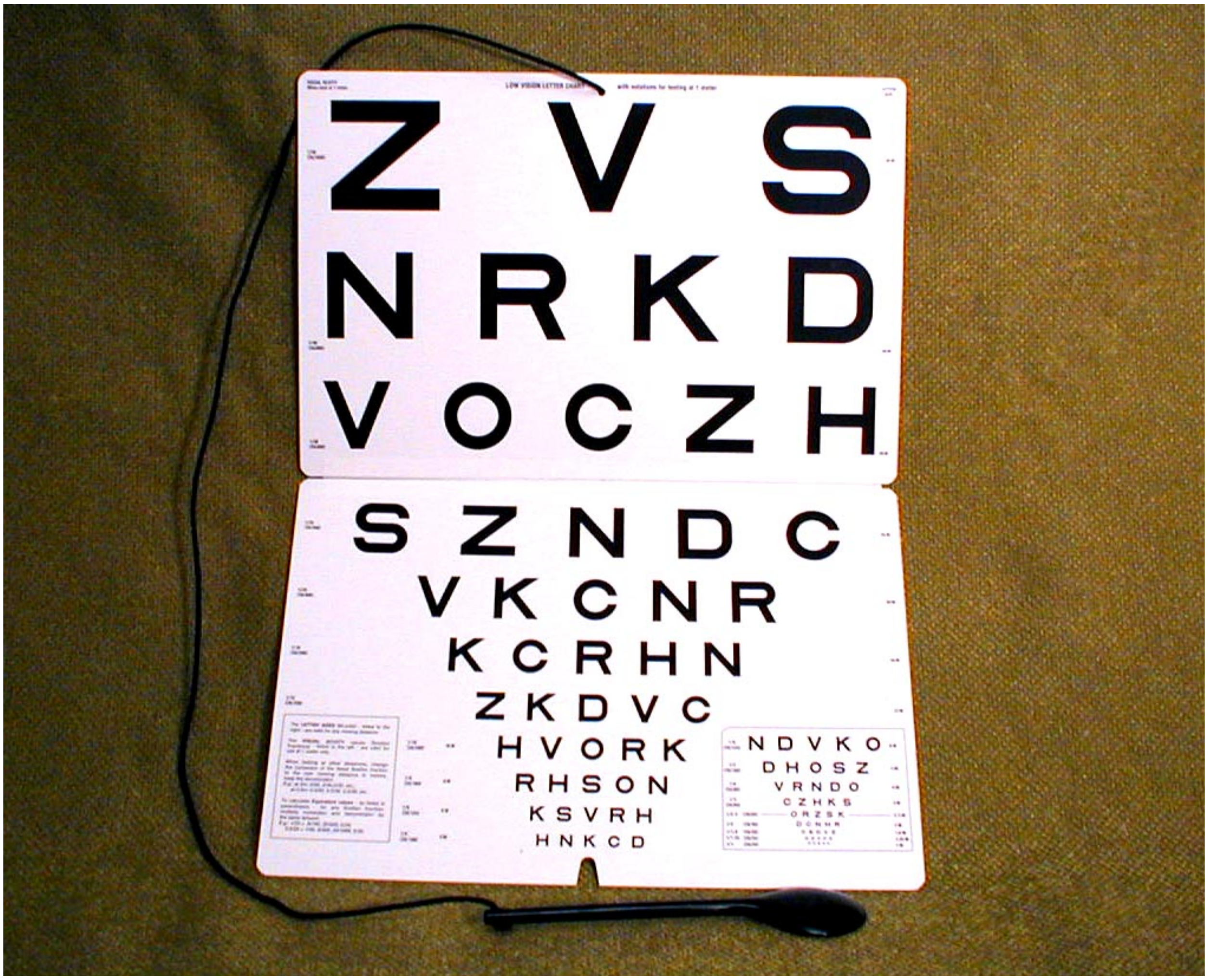


Figure 6 1-meter chart

Legend: This chart is designed for measurement at 1 meter in the Low Vision range. It allows accurate measurement of visual acuities from 1/50 (20/1000, 0.02) to 1/1 (20/20, 1.0). A 1-meter cord is attached to maintain the viewing distance ([36]).

Choice of Letter size progression

Snellen's original charts had small steps for the normal range and larger steps for the lower ranges. Introduction of the decimal acuity notation ([19])led to charts with visual acuity steps in 0.1 increments. On these charts the steps at the top of the scale, such as 0.9 – 1.0 – 1.1, are too small to be practical. If equal increments of the denominator were used, the steps at the bottom of the scale would be too small to be useful. The only scale which can span the full range is a logarithmic scale, based on equal ratios between each pair of successive lines. This is in accordance with Weber-Fechner's law ([38]), which states that geometric increments in stimulus give rise to linear increments in sensation. Westheimer ([39]) has shown that this also holds for visual acuity. Table 7 compares various progressions.

TABLE 7 – Various Letter size Progressions

Snellen's original progressions (feet and metric)

20/20 - 20/30 - 20/40 - 20/50 - 20/70 - 20/100 - 20/200

6/6 - 6/8 - 6/12 - 6/18 - 6/24 - 6/36 - 6/60

5/5 - 5/6.6 - 5/10 - 5/15 - 5/20 - 5/30 - 5/50

Decimal progression

1.2-1.1-1.0-0.9-0.8-0.7-0.6 - 0.5 - 0.4 - 0.3 - 0.2 - 0.1 - 0.0(NLP)
(*too dense)* (*too coarse)*

Geometric progression ("Preferred Numbers")

1.25 - 1.0 - 0.8 - 0.63 - 0.5 - 0.4 - 0.32 - 0.25 - 0.2 - 0.16 - 0.12 - 0.10 - 0.08

Legend: The spacing in this table is proportional to the step sizes *(see text)*. Only a geometric progression maintains the same step size throughout.

Use of Preferred numbers

Various geometric progressions are possible. The one that fits best with the decimal system is one in which 10 steps equal 10x, so that the same numbers repeat in each 10x interval, with only a shift in decimal place. A very convenient feature of this series is that 3 steps equal 2x. When this series includes the values 1.0 and 10, it is known as the "Preferred Numbers" series. It is extensively used in international standards (*) and, indeed, is the subject of an international standard itself ([40]). This is the series that Green used in 1868.

An important characteristic of the preferred numbers series is that the product or quotient of two preferred numbers is again a preferred number. Thus, if letter sizes and viewing distances follow the series, so will the resulting visual acuity numbers. A visual acuity chart based on this feature was published by M.C. Colenbrander ([41]) in 1937.

Sloan and Bailey both used the progression, but apparently were unaware of the preferred numbers standard. For the Sloan and ETDRS charts this does not make a difference, since 20 ft. and 4 m are both preferred numbers. Bailey anchored his series at a 6-m viewing distance, which is 5% off the closest preferred number (6.3); therefore his letter sizes include values such as 19, 48 and 95 instead of 20, 50 and 100 *(see Table 8).* For clinical use these 5% differences may be ignored. The tables in this chapter are based on the use of preferred numbers.

> Footnote
> *(*) Its use in standards goes back to Renard, a French army engineer, who used it in the 1870's to reduce the number of cables for hot-air balloons from 400 to 17. In his honor, the series is also known as Renard series.*

Choice of Contrast and Illumination

Contrast and illumination both influence visual acuity. Fortunately, in the range of commonly used values this influence is minimal. If contrast is reduced to a level where it does affect visual acuity, we speak of a contrast sensitivity test, which is discussed elsewhere. If illumination is lowered to threshold values, we may speak of a dark adaptation test.

Visual acuity is usually not affected until contrast drops below 20%. Normal visual acuity charts have contrasts of 80% or better. For use in a routine eye exam, *projector charts* in a dim or darkened room are generally preferred. In the U.S. the average projector chart has a luminance of about 85 cd/m^2; European charts are generally brighter, up to 300 cd/m^2. The lower luminance has the advantage that the pupil may be wider, so that refractive errors may be more obvious; the brighter charts have the advantage that they suffer less from stray light, which causes contrast degradation. The ICO Visual Acuity Measurement Standard ([23]) recommends a range, which includes both the lower and the higher values.

To predict the everyday performance of patients, a lighted *printed chart* in a lighted room is preferred. Front lighting is easiest to implement. Back lighting of a translucent chart on a light box gives the most even and most reproducible illumination. The usual backlit ETDRS chart has an illumination level of about 200 cd/m^2. For patients with conditions such as albinism or rod dystrophy, it should be possible to reduce the illumination, which may result in a significant increase in visual acuity.

A presentation method, which undoubtedly will gain more widespread use in the future, is presentation on a *computer screen*. This allows presentation of single letters, as well as presentation in a letter chart format. It also allows control over parameters such as crowding, contrast and brightness.

Choice of visual acuity notation

The result of the visual acuity measurement may be recorded in a variety of ways.

True Snellen fractions

The notation promoted by Snellen was that of a *true Snellen fraction*, in which the numerator indicates the actual test distance and the denominator indicates the actual size of the letter seen. The advantage of this notation is that it indicates the actual test conditions. The disadvantage is that it becomes awkward to compare visual acuity values, measured under different conditions. This is especially true for projector charts where the projector magnification is often adjusted to accommodate fractional viewing distances.

Snellen equivalents

To overcome this difficulty, *Snellen equivalents* are used. In Europe, the **decimal equivalent** of the Snellen value is used most often. This notation is clear, because there is no numerator or denominator. The notation becomes confusing when the decimal notation is converted back to a **pseudo-Snellen fraction**. E.g. 5/25 → 0.2 → 2/10; the 2/10 fraction would suggest that the subject saw a 10 M letter at 2 meter, instead of a 25 M letter at 5 meter.

In the **U.S. notation**, a 20 ft. fraction is usually used as a Snellen equivalent. E.g. in an examination lane of 18 ft. or 21 ft., the true Snellen fractions would be 18/18 or 21/21. Instead the visual acuity is recorded as 20/20 in both cases. Thus, seeing “20” as the numerator of a visual acuity fraction rarely implies that the actual measurement was made at 20 ft.

In Britain, the 6/6 notation is similarly used as a Snellen equivalent.

Visual angle notation was used by Louise Sloan. It refers to the visual angle of the stroke width of 5x5 letters. Thus, 1' equals 20/20 *(1.0)*, 2’ equals 20/40 *(0.5)*, etc. The visual angle is the reciprocal of the visual acuity value and equals the denominator of the 1-meter Snellen fraction. Others have used the term **MAR**. In the context of physiological optics this term is usually interpreted as ***M***inimal ***A***ngle of ***R***esolution and best describes grating acuity; in the context of psychophysics and clinical testing it might be better interpreted as ***M***inimum ***A***ngle of ***R***ecognition, while in the context of vision rehabilitation it might be interpreted as ***MA***gnification

Requirement. Since higher MAR values indicate poorer vision, MAR should be considered a measure of vision loss, not a measure of visual acuity.

LogMAR notation was introduced by Bailey ([31]). As the name implies it is the logarithm of the MAR value, thus converting a geometric sequence of letter sizes to a linear scale. Like MAR, logMAR is a notation of *vision loss* since positive logMAR values indicate reduced vision, while normal vision (better than 20/20, 1.0) is indicated by negative logMAR numbers. Standard vision *(20/20, 1.0)* equals 0 (i.e. no loss). On a standard chart each line is equivalent to 0.1 logMAR; thus +1.0 logMAR means 10 lines lost or 20/200 *(0.1)*, +2.0 logMAR means 20 lines lost or 20/2000 *(0.01)*.

Since Bailey used the logMAR notation with a geometric progression of letter sizes, the term "logMAR chart" is often used to imply a geometric progression. This is not necessarily so, a logarithmic scale could be applied to any progression. The decimal values and reverse scale do not make the logMAR notation particularly user-friendly. For everyday clinical practice Snellen equivalents are easier, since they relate directly to the measured quantities of letter size and viewing distance.

The logMAR notation has gained widespread use in psychophysical studies, for statistical calculations and for graphical presentation of the results of multi-center clinical studies. It provides a more scientific equivalent for the traditional clinical statement of "lines lost" or "lines gained", which is valid only when all steps between lines are equal.

Visual Acuity Rating (VAR, Bailey) ([42]) and **Visual Acuity Score** (VAS, Colenbrander) ([43]) are two names given to a more user-friendly equivalent of the logMAR scale. On the VAR or VAS 20/20 *(1.0)* is rated as "100", 20/200 *(0.1)* is rated as "50" and 20/2000 *(0.01)* is rated as "0". On an ETDRS type chart, each line thus represents a 5-point increment. The score can therefore be interpreted as a count of the total number of letters read, starting from 20/2000 *(0.01)*. See Table 8 to relate the VAS or VAR, MAR and logMAR notations to various visual acuity levels. The VAR relates only to visual acuity, the VAS is part of a broader scoring system *(see Functional Vision).*

The VAS, VAR and logMAR notations convert the geometric sequence of visual acuity values to a linear scale. This is important if visual acuity values are to be averaged or subjected to other statistical calculations. The difference between averaging on a geometric scale vs. a linear scale is best demonstrated with an example. *What is the average of 20/20 and 20/200?* Averaging the denominators yields 20/110, a value too close to 20/200 (see Table 8). Averaging the decimal equivalents (1.0 and 0.1) yields 0.55, a value too close to 1.0. On the VAS scale, the average of "100" and "50" is "75", which can be converted back to 20/63 or 0.32 (rounded to 20/60 or 0.3), exactly halfway.

Choice of criterion and rounding of values

The recorded visual acuity value can be influenced by the choice of completion criterion and by rounding. Most clinicians will record visual acuity in *line-increments* and consider a line read if more than half of the letters are read correctly (e.g. 3 of 5 on an ETDRS type chart). A suffix such as –1 or +2 may be added to indicate 1 letter missed or 2 letters read on the next line. These suffixes are most meaningful if the number of letters on each line is constant. On most charts the test-retest confidence limits are about +/- 2 letter-increments or about one half line-increment ([44]). For routine clinical use, where the patient generally reads each line only once, rounding to line values is common practice. It is appropriate, since the rounding errors are of the same order as the confidence limits.

For a finer gradation on an ETDRS-type chart *letter-increments* can be counted. The total number of letters read, starting from 20/2000 *(0.01)* is the VAR or VAS discussed above. Letter-increments are appropriate in research settings where measurements are repeated and then averaged to detect smaller changes.

Another factor that may affect the score is whether subjects are encouraged to guess. Since different subject may vary in their willingness to guess, forcing all to guess will produce more homogeneous results.

When a subject cannot read a line on a chart, some clinicians will present an isolated line or an isolated letter. This reduces the crowding effect, makes fixation easier and can improve de visual acuity score. Pointing to a letter may also make the task easier. One should be aware that using different presentation modes at different times reduces the comparability of the scores.

TABLE 8 – Visual Acuity Ranges and Visual Acuity Notations

ICD-9-CM RANGES		EQUIVALENT NOTATIONS		TRUE SNELLEN FRACTIONS (numerator = test distance)					Visual Angle Notations		VISUAL ACUITY SCORE
		Decimal	US	6.3 m	*6 m*	5 m	4 m	1 m	MAR (1/V)	Log MAR	
(Near-) Normal Vision	Range of Normal Vision	1.6	20/12.5	6.3/4	*6/3.8*	5/3.2	4/2.5	1/0.63	0.63	-0.2	110
		1.25	20/16	6.3/5	*6/4.8*	5/4	4/3	1/0.8	0.8	–0.1	105
		1.0	20/20	6.3/6.3	*6/6*	5/5	4/4	1/1	1.0	0	100
		0.8	20/25	6.3/8	*6/7.5*	5/6.3	4/5	1/1.25	1.25	+0.1	95
	Near-Normal Vision	0.63	20/32	6.3/10	*6/9.5*	5/8	4/6.3	1/1.6	1.6	0.2	90
		0.5	20/40	6.3/12.5	*6/12*	5/10	4/8	1/2	2.0	0.3	85
		0.4	20/50	6.3/16	*6/15*	5/12.5	4/10	1/2.5	2.5	0.4	80
		0.32	20/63	6.3/20	*6/19*	5/16	4/12.5	1/3.2	3.2	0.5	75
Low Vision	Moderate Low Vision	0.25	20/80	6.3/25	*6/24*	5/20	4/16	1/4	4	0.6	70
		0.20	20/100	6.3/32	*6/30*	5/25	4/20	1/5	5	0.7	65
		0.16	20/125	6.3/40	*6/38*	5/32	4/25	1/6.3	6.3	0.8	60
		0.125	20/160	6.3/50	*6/48*	5/40	4/32	1/8	8	0.9	55
	Severe Low Vision	0.10	20/200	6.3/63	*6/60*	5/50	4/40	1/10	10	+1.0	50
		0.08	20/250	6.3/80	*6/75*	5/63	4/50	1/12.5	12.5	1.1	45
		0.063	20/320	6.3/100	*6/95*	5/80	4/63	1/16	16	1.2	40
		0.05	20/400	6.3/125	*6/120*	5/100	4/80	1/20	20	1.3	35
	Profound Low Vision	0.04	20/500	6.3/160	*6/150*	5/125	4/100	1/25	25	1.4	30
		0.03	20/630	6.3/200	*6/190*	5/160	4/125	1/32	32	1.5	25
		0.025	20/800	6.3/250	*6/240*	5/200	4/160	1/40	40	1.6	20
		0.02	20/1000	6.3/320	*6/300*	5/250	4/200	1/50	50	1.7	15
(Near-) Blindness	Near-Blindness	0.016	20/1250	6.3/400	*6/380*	5/320	4/250	1/63	63	1.8	10
		0.0125	20/1600	6.3/500	*6/480*	5/400	4/320	1/80	80	1.9	5
		0.01	20/2000	6.3/630	*6/600*	5/500	4/400	1/100	100	+2.0	0
		---	---	---	---	---	---	---			---
	Blindness	No Light Perception (NLP)									

> **Legend, Table 8.** The visual acuity ranges (rows) in this table follow the “preferred numbers” series. Note that when the viewing distances (columns) also follow this series (1, 4, 5 or 6.3 m; 20 ft), the required letter sizes (numerator of the Snellen fraction) are also preferred numbers. When the chart is designed for 6 m (5% less then a preferred number) the required letter sizes also have to be reduced by 5% and no longer are preferred numbers.
>
> For chart design, the exact numbers, as shown in this table, should be followed. For clinical naming it is acceptable to round 32 to 30, 63 to 60, etc. The error involved is 5% or 1/5 line interval, and corresponds to 1 letter seen or not seen on a standard chart.
>
> Note that the MAR notation (Minimum Angle of Resolution or Recognition) equals the denominator of the 1-meter Snellen fraction. MAR = 1/V, therefore: log(MAR) = log(1/V) = – log(V). The minus sign indicates that logMAR values are best understood as measures of *vision loss*, rather than as measures of visual acuity.

Choice of test symbols

Most visual acuity charts utilize **letters**. For the patient, this choice gives a sense of immediate validity, when the primary objective is to read. For the practitioner, errors are easy to spot, since most practitioners know their chart by heart. Use of letters, however, is warranted only if the assumption may be made that familiarity with the alphabet plays a trivial role. The Sloan letter set is shown in Figure 7.

For less literate adults the use of a **number** chart may be more appropriate.

For illiterate patients and pre-school children, **pictures** may be used. However, it is difficult to judge the equivalence of letters and pictures and a child’s performance may depend on whether naming of pictures is a game that is played at home.

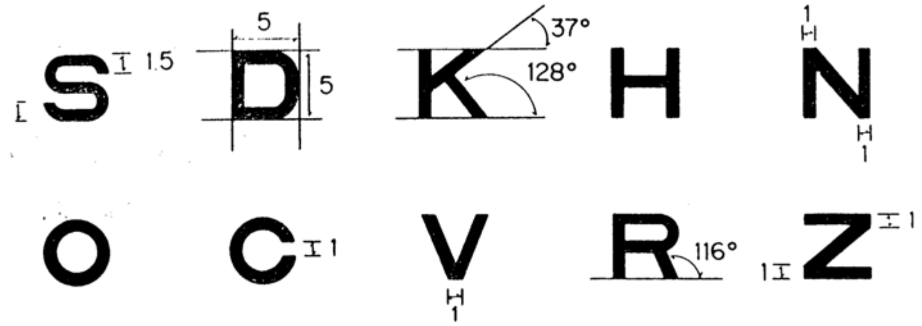


Figure 7 Sloan letters

> **Legend:** Sloan designed a series of letters without serifs that are widely used in the U.S. Their average difficulty approximates that of Landolt C’s.

LEA symbols*(Figure 8.)* were devised by Lea Hyvärinen (45). They form a set of four simple symbols (square, circle, house, apple) that require little naming ability. They are left-right symmetrical, so that left-right reversals in young children will not influence the results. They have been designed to blur equally and have been calibrated against Landolt C’s (46) *(see Figure 9)*. They form excellent tests for children, and can also be used for adults. The same symbols are used in a variety of tests, as a letter chart, as a contrast sensitivity chart, in a reading format, on single symbol cards, on a domino game for older children and as a jigsaw puzzle for the very young.

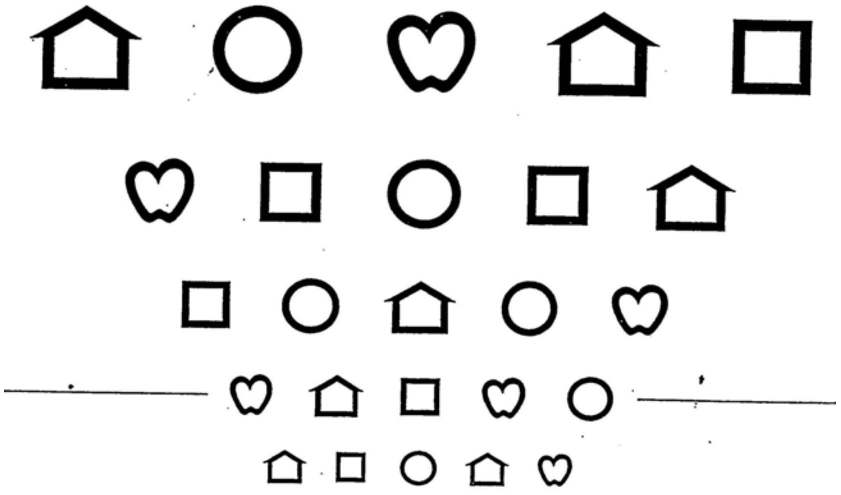


Figure 8 LEA symbols

Legend: This chart combines the Bailey-Lovie layout with LEA symbols ([45]) for use with children and illiterate subjects. See figure 9 to compare their calibrated size to other optotypes.

The **HOTV** test contains four symbols: H, O, T and V, also chosen because they have no characteristics that require a sense of laterality. To standardize the effect of contour interaction when the symbols are presented singly, they may be surrounded by crowding bars.

Tumbling E's are probably the symbols most often used for the testing of children. They do require a sense of laterality, which can be a stumbling block for young and for developmentally delayed children. They can be presented in a chart format or as single symbols. When comparing findings, it should be remembered that presentation as single symbols is an easier test than presentation in a chart format. Comparison of these different conditions and of findings on a closer spaced chart may give insight in the importance of crowding and of lateral contour interaction, which can be particularly informative in the treatment of amblyopia.

Tumbling E's also are the basis for the WHO Low Vision training kits, which are widely used in developing countries and in countries where the Roman alphabet is not used.

Landolt C's ([22]) have become the symbols of choice for many scientific measurements. They are much less frequently used in a clinical setting, except in Japan where the characters of the Kanji alphabet are too complex. When used in a chart format it is harder to detect errors, unless the observer points to the symbol. However, pointing, like single presentation, affects the difficulty of the test.

The Visual Acuity Measurement Standard of the International Council of Ophthalmology ([23]) requires that letter charts in non-Roman alphabets (Cyrilic, Arabic, Hindi, Kanji, Hebrew, etc.) be calibrated against Landolt C's for equal recognizability.

Grating acuity is another visual acuity measurement that is mostly used in the laboratory and mostly in connection with contrast measurements. For infants it can be used on cards as a **Preferential Looking** test. Preferential looking is a *detection* test and thus not strictly equivalent to a *recognition* test.

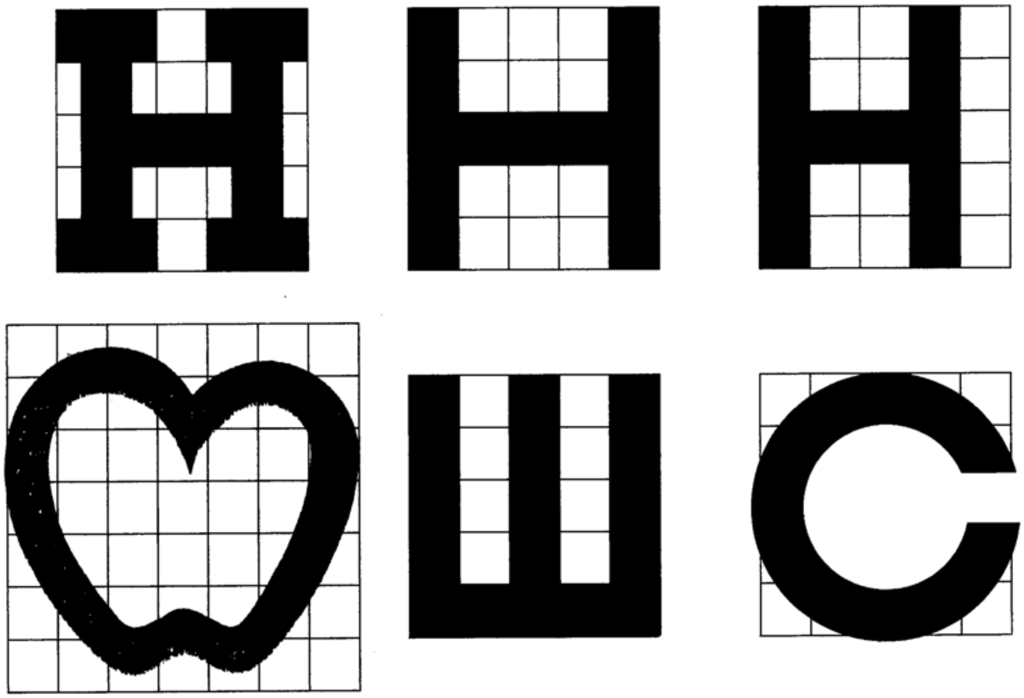


Figure 9 Various symbols

> **Legend:** This chart depicts a selection of commonly used optotypes. First row: Snellen H (with serifs, 5x5), Sloan H (no serifs, 5x5), British H (no serifs, 4x5). Other letter chart variations, such as charts with non-Roman alphabets and number charts are not shown. Second row: LEA symbol *(see also Figure 6)*, tumbling E, Landolt C. The latter groups have only four symbols each, so that the guessing level is higher than with letter charts.
>
> Most optotypes approximate the recognizability of Landolt C's; they represent 20/20 *(1.0)* acuity when their height subtends about 5'. Recognition within the LEA symbol set *(Figure 8)* is more difficult; calibration experiments established that the symbols need to be about 35% larger.

Summary

When recording visual acuity for patients in the range of normal vision, the preferred measurement tool will often be a projector chart at 5 m or 6 m or 20 ft. in a darkened room. The preferred notation will be a Snellen equivalent. In continental Europe this will most often be decimal notation, in Britain it will be the 6/6 equivalent, in the U.S. it will mean use of a 20/20 equivalent.

When recording visual acuity for patients in the Low Vision range, the preferred tool will be a lighted chart in a lighted room at a distance of 1 meter. The preferred notation will be a true Snellen fraction with 1 as the numerator. It is often useful to add the commonly used Snellen equivalent in parentheses. Thus, the ability to recognize an 8 M letter at 1 meter would be recorded as 1/8 (20/160) or 1/8 (0.125). If the same patient were tested on an ETDRS chart at 4 m the notation could be 4/32 (1/8, 20/160).

Visual Acuity Measurement – Near vision

Although the testing of reading vision predated the development of letter charts to measure distance vision, the methodology to accurately measure reading acuity has lagged behind. This is in part due to the fact that the prescription of a reading correction for normally sighted individuals is aimed more at achieving reading comfort than at accurate measurement. It is also due to the lack of accurate measuring tools. Reading distances are more often estimated than measured, while the “Jaeger numbers”, which are widely used in the U.S., have no numerical meaning. Under these circumstances, it is not surprising that many practitioners believe that reading acuity and distance acuity have little in common. We will show that this is not so.

As is the case for distance vision, accurate determination of near vision acuity requires measurement of two variables: letter size and viewing distance. For distance vision the viewing distances are standardized, so that only the letter sizes vary. For individuals in the normal visual acuity range reading distances may be standardized, but the standards vary. Some use 40 cm *(16”, 2.5 D reading add)*, or 14” *(35 cm, 2.75 D add)*, others use 33 cm *(13”, 3 D add)* or even 30 cm *(12”, 3.25 add)* or 25 cm *(10”, 4 D add, the reference point for the power of magnifiers)*. Individuals in the Low Vision range often need distances that are even shorter and certainly cannot be handled with a “one size fits all” distance. They need a formula in which both the letter size and the viewing distance can be varied easily.

Modified Snellen Formula

The standard Snellen formula **V = viewing distance / letter size** becomes awkward to use when the numerator (viewing distance in meters) is itself a fraction within a fraction. This can be overcome by using the reciprocal value of the viewing distance. The reciprocal of a metric distance is known as the **diopter** *(2 diopters = 1/2 m, 5D = 1/5 m, etc.)* (20).

The traditional formula: $\mathbf{V = \frac{m}{M}}$ thus becomes: $\mathbf{1 / V} = \frac{M}{m} = M \times \frac{1}{m} = \mathbf{M \times D}$

or: **1 / V = M x D** = letter size *(in M-units)* x viewing distance *(in diopters)*

Use of this modified Snellen formula has several advantages.

- Use of reciprocal values turns the usual Snellen *fraction* into a *multiplication,* while the viewing distance changes from a fraction into a whole number. Both changes make the formula far easier to calculate in one’s head.
- The value 1/V relates directly to the letter chart acuity measured at 1 meter; the numerator indicates the amount of magnification needed to bring the subject to standard performance.
- Expressing the reading distance in diopters relates directly to the amount of accommodation and/or the reading add that must be used for this distance.

The results of these calculations are listed in Table 9. This table is based on the use of preferred numbers, so that the same values appear for the viewing distances, the letter sizes and the resulting visual acuity values.

Many reading cards are calibrated for a specific reading distance, i.e. for a specific column in Table 9. This has led to the habit of using visual acuity values to refer to letter sizes. For instance, a letter size that would represent 20/100 at 40 cm might be referred to as a “20/100 letter”. The table shows that the same letter at 25 cm would represent an entirely different acuity value. A “20/100 letter” on a 20 ft. chart is very different again.

TABLE 9 – Modified Snellen Formula 1 /V = M x D for Near Vision

Letter Size		Viewing Distance (glasses to text, not valid for magnifiers)													ICD-9-CM
		5cm 2” 20 D	6.3cm 2.5” 16 D	8cm 3.2” 12.5D	10cm 4” 10 D	12.5cm 5” 8 D	16cm 6.3” 6.3 D	20cm 8” 5 D	25cm 10” 4 D	32cm 12.5” 3.2 D	40cm 16” 2.5 D	50cm 20” 2 D		100 cm 40” 1 D	
3.2p J 1	**0.4 M**	8 20/160	6.3 20/125	5 20/100	4 20/80	3.2 20/63	2.5 20/50	2 20/40	1.6 20/32	1.25 20/25	1 20/20	0.8 20/16		**0.4** **1/0.4**	Above
4p J 1	**0.5 M**	10 20/200	8 20/160	6.3 20/125	5 20/100	4 20/80	3.2 20/63	2.5 20/50	2 20/40	1.6 20/32	1.25 20/25	1 20/20		**0.5** **1/0.5**	
5p J 1,2	**0.63M**	12.5 20/250	10 20/200	8 20/160	6.3 20/125	5 20/100	4 20/80	3.2 20/63	2.5 20/50	2 20/40	1.6 20/32	1.25 20/25		**0.63** **1/0.63**	Normal range
63p J 2-5	**0.8 M**	16 20/320	12.5 20/250	10 20/200	8 20/160	6.3 20/125	5 20/100	4 20/80	3.2 20/63	2.5 20/50	2 20/40	1.6 20/32		**0.8** **1/0.8**	
8p J 3-6	**1 M**	**20** 20/400	**16** 20/320	**12.5** 20/250	**10** 20/200	**8** 20/160	**6.3** 20/125	**5** 20/100	**4** 20/80	**3.2** 20/63	**2.5** 20/50	**2** 20/40		**1** **1/1**	
10p J 4-7	**1.25M**	25 20/500	20 20/400	16 20/320	12.5 20/250	10 20/200	8 20/160	6.3 20/125	5 20/100	4 20/80	3.2 20/63	2.5 20/50		**1.25** **1/1.25**	
12p J 7-10	**1.6 M**	32 20/630	25 20/500	20 20/400	16 20/320	12.5 20/250	10 20/200	8 20/160	6.3 20/125	5 20/100	4 20/80	3.2 20/63		**1.6** **1/1.6**	Near-normal
16p J 7-10	**2 M**	40 20/800	32 20/630	25 20/500	20 20/400	16 20/320	12.5 20/250	10 20/200	8 20/160	6.3 20/125	5 20/100	4 20/80		**2** **1/2**	
20p J10-12	**2.5 M**	50 /1000	40 20/800	32 20/630	25 20/500	20 20/400	16 20/320	12.5 20/250	10 20/200	8 20/160	6.3 20/125	5 20/100		**2.5** **1/2.5**	
25p J 14	**3.2 M**	63 /1250	50 /1000	40 20/800	32 20/630	25 20/500	20 20/400	16 20/320	12.5 20/250	10 20/200	8 20/160	6.3 20/125		**3.2** **1/3.2**	
32p J 16	**4 M**	80 /1600	63 /1250	50 /1000	40 20/800	32 20/630	25 20/500	20 20/400	16 20/320	12.5 20/250	10 20/200	8 20/160		**4** **1/4**	Moderate L.V.
40p J -	**5 M**	100 /2000	80 /1600	63 /1250	50 /1000	40 20/800	32 20/630	25 20/500	20 20/400	16 20/320	12.5 20/250	10 20/200		**5** **1/5**	
50p J -	**6.3 M**	125 /2500	100 /2000	80 /1600	63 /1250	50 /1000	40 20/800	32 20/630	25 20/500	20 20/400	16 20/320	12.5 20/250		**6.3** **1/6.3**	
63p J -	**8 M**	160 /3200	125 /2500	100 /2000	80 /1600	63 /1250	50 /1000	40 20/800	32 20/630	25 20/500	20 20/400	16 20/320		**8** **1/8**	
80p J -	**10 M**	200 /4000	160 /3200	125 /2500	100 /2000	80 /1600	63 /1250	50 /1000	40 20/800	32 20/630	25 20/500	20 20/400		**10** **1/10**	Low Vision
100p J -	**12.5M**	250 /5000	200 /4000	160 /3200	125 /2500	100 /2000	80 /1600	63 /1250	50 /1000	40 20/800	32 20/630	25 20/500		**12.5** **1/12.5**	
		Near-total Visual Acuity Loss							Profound Low Vision				Severe		

Legend:
Columns indicate reading distances. Rows indicate letter sizes. The resulting reading acuity values are found at the intersections. The large number in each box represents the MxD value (magnification requirement). The small number represents the visual acuity value. Note that the visual acuity values are arranged in diagonal bands. The same visual acuity value can be represented by many different combinations of viewing distance and letter size. For each diagonal band the outer edge of the table indicates the ranges of vision loss in ICD-9-CM.

The J-designations in the first column refer to values found on current charts. Note that these are different from Jaeger's original sizes, which are shown in Table 5.

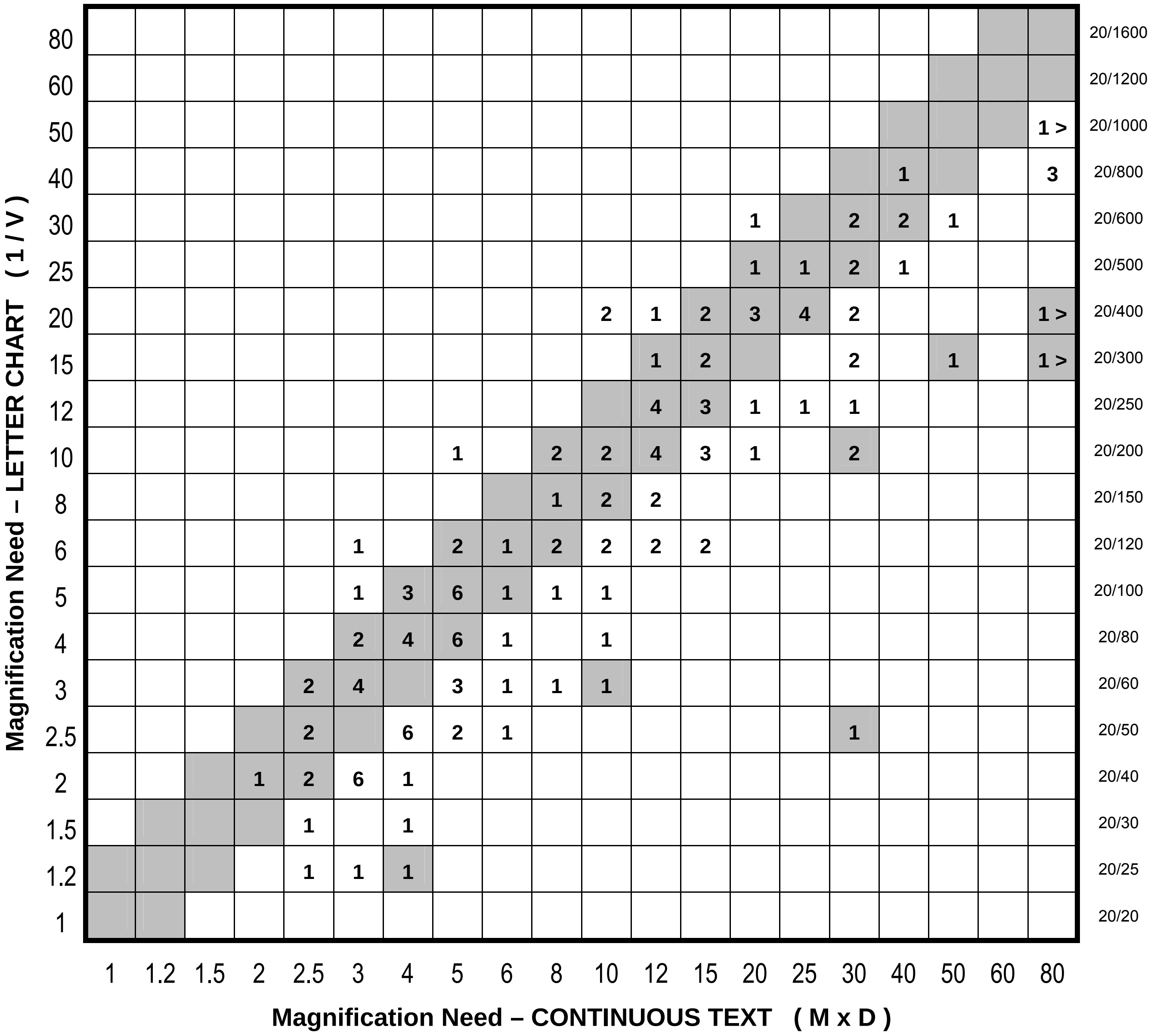
As visual acuity drops (MxD increases), subjects can compensate in two ways. They may move to a different column, i.e. bringing the same print size closer by increasing the reading add (or the amount of accommodation in younger people). They can also move to a different row, i.e. enlarging the print size, while maintaining the reading distance. Large print books enlarge the physical print size; various magnification devices enlarge the virtual print size.

Under most circumstances letter chart acuity and reading acuity – if measured appropriately and with the proper refractive correction – will be similar. However, when measuring letter chart acuity, subjects are often pushed for threshold or marginal performance, whereas reading tests more often aim at a level of comfortable performance. For this reason, the magnification requirement for reading acuity may be somewhat greater than that for letter acuity. The difference, known as the “magnification reserve” ([47]), is needed for reading fluency.

While 20/20 *(1.0)* acuity implies the ability to read 1 M print at 1 m, comfortable reading of newsprint (1 M) is generally done at 40 cm, indicating a 2.5x magnification reserve *(4 line-intervals)*. Traditionally, the power of magnifiers is referenced to the ability to read at 25 cm *(10”).* 1 M at 25 cm denotes 20/80 *(0.25)*. Note that this is the top value in the Low Vision band.

To verify the relationship between reading acuity and letter chart acuity, the two values were compared for 150 consecutive patients from the author’s Low Vision service. The results are shown in Table 10. It shows that there is a close relationship between letter chart acuity and reading acuity and that this relationship holds up at all visual acuity levels. Usually, the two are within one line from each other (diagonal gray band); for some patients the magnification need for reading is larger than the magnification need for letter recognition (spread to the right of the diagonal). This difference is the magnification reserve, defined above. Since the objective of visual acuity measurement in the Low Vision range is to help patients function with their own fixation ability, the author does not push patients for maximum letter chart acuity by pointing to letters or by isolating letters *(see the earlier discussion under choice of criterion)*. Had he used these techniques to improve the letter chart acuity, the magnification reserve for reading fluency would probably have appeared somewhat greater.

TABLE 10 – Magnification Need for Letter Chart Acuity and Reading Acuity



Magnification Need – LETTER CHART (1 / V)

	1	1.2	1.5	2	2.5	3	4	5	6	8	10	12	15	20	25	30	40	50	60	80	
80																					20/1600
60																					20/1200
50																				1 >	20/1000
40																	1			3	20/800
30														1		2	2	1			20/600
25														1	1	2	1				20/500
20											2	1	2	3	4	2				1 >	20/400
15												1	2			2		1		1 >	20/300
12												4	3	1	1	1					20/250
10								1		2	2	4	3	1		2					20/200
8										1	2	2									20/150
6						1		2	1	2	2	2	2								20/120
5						1	3	6	1	1	1										20/100
4						2	4	6	1		1										20/80
3					2	4		3	1	1	1										20/60
2.5					2		6	2	1							1					20/50
2				1	2	6	1														20/40
1.5					1		1														20/30
1.2					1	1	1														20/25
1																					20/20

Magnification Need – CONTINUOUS TEXT (M x D)

Legend: The table compares the magnification need found for letter chart testing (1/V) with the magnification need for continuous text reading (MxD) for 150 consecutive Low Vision patients. The numbers indicate the number of patients in each cell. For most patients the two values are the same or differ by only one line interval (gray diagonal band). For a number of patients the magnification need for continuous text is somewhat greater; this is known as the magnification reserve needed for reading fluency. For a few patients the magnification need for continuous text was significantly greater (isolated gray cells). These patients represent exceptional cases; for most of them letter acuity was obtained in a small island surrounded by scotoma, while reading acuity utilized a larger, more eccentric area, requiring more magnification.

Letter size notations for continuous text

For letter charts with metric notation the unit for letter size measurement is the M-unit, as it was defined by Snellen and named by Sloan. A corresponding “F-unit” for charts with feet notation was never defined, and would probably only lead to confusion since calculating with non-metric measurements is so much harder. The situation for continuous text letter sizes is more diverse.

Jaeger numbers

In the U.S. **Jaeger numbers** are widely used. We have seen that these numbers have no numeric meaning since they refer to item numbers in a printing house catalogue in Vienna in 1854. They cannot be used for calculations. Furthermore, since Jaeger did not establish an external reference, those who wanted to produce similar samples had to approximate Jaeger’s samples with fonts that happened to be available at their local print shop. The result is great inconsistency in the use of Jaeger numbers. The first column in Table 9 indicates the range of Jaeger ratings that were found to represent the same physical letter size, when comparing a number of contemporary “Jaeger” cards.

Other countries have used similar samples, such as “de Wecker” samples in Germany and “Parinaud” samples in France.

Printer’s points

The need for a numerical designation lead some practitioners to the use of **printer’s points**. This might have been useful if printer’s points referred to the letter height; instead they refer to the height of the slug on which letters used to be mounted. On average, lower case letters tend to be about 50% of the slug height. Thus:

1 point (slug height) = 1/72 inch   1 point (letter size) = about 1/144 inch

However, this relationship varies with the type font. E.g. in the TrueType family of computer fonts an Arial letter of 8 points has the same size as a Times New Roman letter of 9-points. Another problem is that the point notation does not apply to the optotypes used for distance vision, so that comparison of far and near measurements is impossible.

A and N series

On British type samples the size in printer’s points is designated by the notation N = … . British cards often also carry an A = … notation. The A series is based on the logarithm of the letter size. As such, it is related to the “letter size credit” mentioned in Table 5 (A = 17 – letter size credit/5)

M-units

The **M-unit** is the only letter size unit that applies to distance charts as well as to reading samples. It is the only unit that allows comparisons between the two tests. It is the letter size unit used in this chapter and on an increasing number of newer reading cards. It is convenient that 1 M is the size of average news print.

By definition 1 M-unit subtends 5’ of arc at 1 meter and equals 1.454 mm. Useful equivalents are: 7 M = 10 mm *(error –2% or 0.1 line-interval)* and 1 M = 1/16 inch *(error +10% or 0.4 line-interval)*. Based on the size of lower case letters without ascenders or descenders (x-height), 8 points = 1 M for the TT-Arial and TT-Courier computer fonts, but for the TT-Times New Roman computer font 1 M = 9 points.

Reading Fluency

For reading tests it is important to record not only the letter size and the distance at which the subjects can just decipher the text, but also the level at which they can read with reasonable fluency. Most reading cards have short paragraphs with large letters and longer paragraphs with smaller letters. On such cards only a subjective comparison of reading fluency with different levels of magnification is possible.

Cards on which all paragraphs have the same length offer the opportunity to measure the reading speed objectively. This layout was pioneered by the MN-read cards ([48]) and is now also available in other cards in multiple languages ([36]).

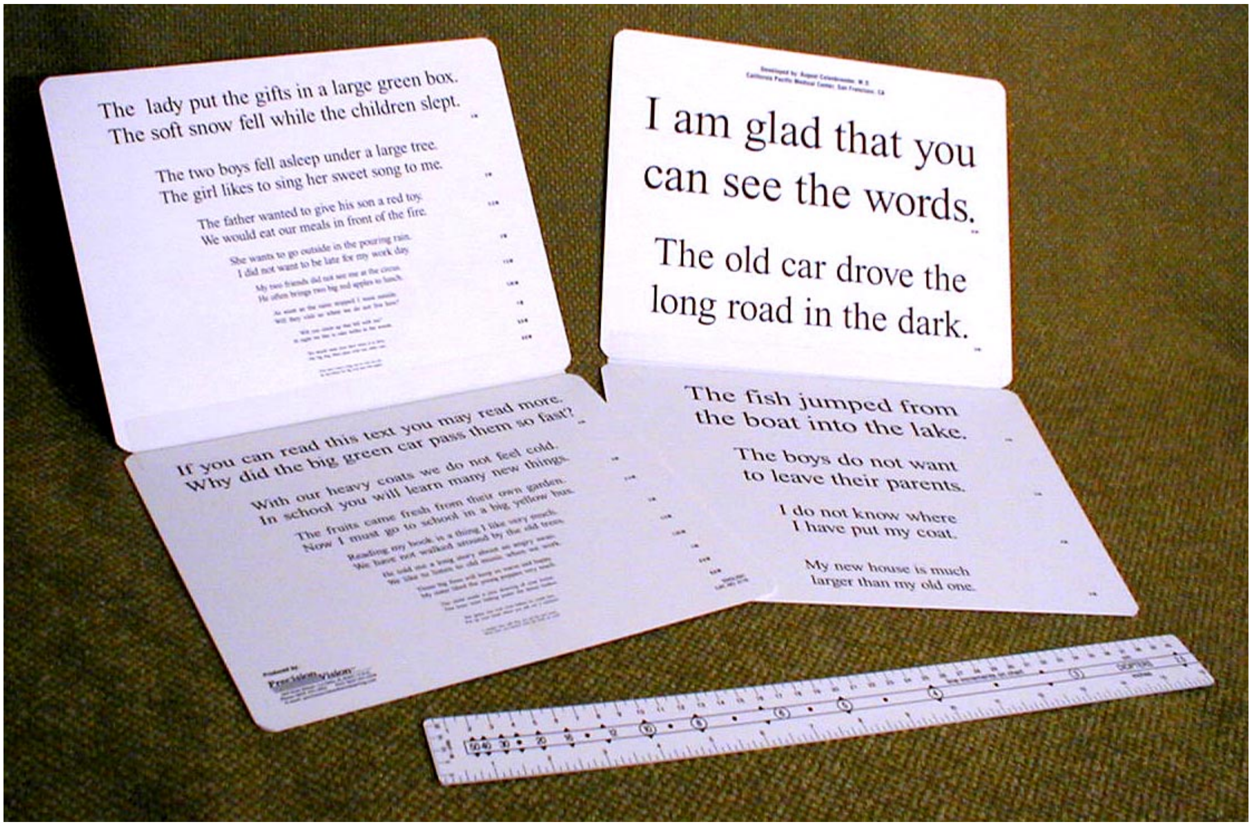


Figure 10 Reading card with proportional paragraphs.

Legend: All paragraphs on this chart have the same length, so that reading times and reading fluency can be compared. The set of smaller paragraphs is duplicated to avoid memorization. A ruler with a diopter scale is provided to compare the reading distance to the reading add and to facilitate the use of the modified Snellen formula: 1/V = M x D *(see text)*. Various languages are available. The same text appears on the back of the chart in Figure 6 ([36]).

When the reading time is recorded for each print size, the usual pattern will be that the subject reads at a reasonably stable rate at larger print sizes. At smaller sizes reading becomes slower and then impossible (“fast – fast – slow”). The print size just before the reading speed starts to drop off is the critical print size. Providing magnification of ordinary print to the critical print size will give the best reading performance with the least magnification (largest field of view).

Some subjects will show a different pattern that can be characterized as “slow – fast – slow”. This pattern occurs when macular degeneration patients read in a small island of vision within a peri-central scotoma. For large text the island is not large enough to cover a whole word; this slows reading down. At medium print sizes more letters are covered and reading speeds up. At the smallest sizes reading slows down again. The same pattern can be seen in patients with extreme tunnel vision in end-stage glaucoma or RP. In these cases it is very important not to prescribe too much magnification. Underlining technique to facilitate tracking along the line may also be beneficial.

Occasionally, the pattern is “slow – slow – slow”. This pattern, which can be seen in patients with scattered drusen, indicates that magnification alone will be of limited benefit. In these patients, other means such as underlining to facilitate tracking, together with training and practice in the most effective use of the available retinal areas can lead to more improvement than the use of magnification alone.

Infant vision testing

In infants, both the physical basis of visual acuity and the cognitive skills to use it are still developing. Standard visual acuity testing is impossible, yet early detection of deficits is extremely important. Not acting on a suspicion of vision loss may cause developmental delays, since it deprives the infant of its most abundant source of stimulation.

Instead of adult vision testing techniques, we must use behavioral observations. The list in Table 11 was provided by Dr. Lea Hyvärinen. It provides a transition to the discussion of the next aspect of vision loss, that of Functional Vision.

TABLE 11 – Visual Behavioral Milestones

What I See – Visual milestones for the first and second year

0 – 3 months
As a newborn infant, I look at light sources and turn my eyes and head toward them. I develop **eye contact** between 6-8 weeks and follow objects that move slowly, first horizontally, later vertically. By the end of the second month, I become interested in looking at mobiles.

3 – 6 months
I discover my hands, reach towards objects, then **grasp** hanging objects. I watch toys fall and roll away. My visual interest sphere widens gradually. If my vision is equal in both eyes, I don't mind it if you cover my eyes with a cap or a patch, one at a time.

7 – 10 months
I notice small bread **crumbs**. First I touch them, then I try to grab them. I like to watch you draw simple pictures for me. I also recognize objects that are partially hidden.

11 – 12 months
I love to **play hide and seek** and know my way around my home. I can look out the window and recognize people. I also start to recognize some people.

18 months
I can **play with simple puzzles**. I am interested in books and pictures and I can recognize that pictures are representations of real objects. I like to watch you draw while you tell stories. I may be able to name pictures and objects (such as my LEA puzzle shapes: apple, house, block and ball).

24 months
I love to scribble and color. I understand that pictures can be large and small and still represent the same thing. I can also arrange similar pictures in groups. At this age, my vision can be tested while I play – if I am in the mood! When my vision is tested, I see small pictures equally well with my right and left eye.

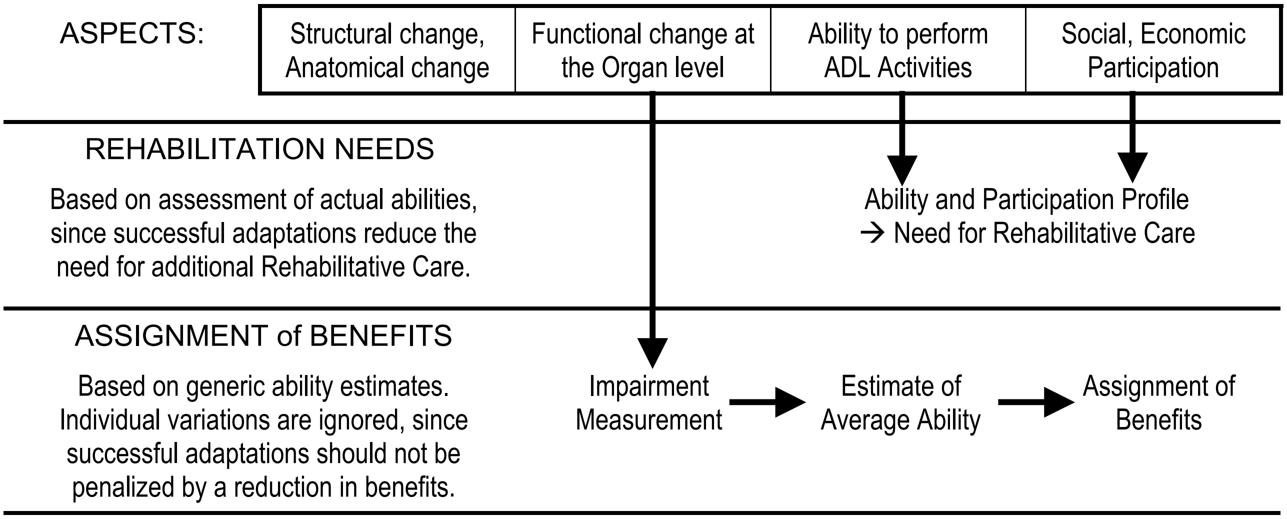
Courtesy of Lea Hyvärinen, MD

ASSESSMENT of FUNCTIONAL VISION

In the introduction (Table 1), a distinction was made between *visual functions* and *functional vision*. Visual functions (such as visual acuity) can be measured for each eye separately. Functional vision is a property of the person, for adults it denotes the ability to perform Activities of Daily Living (ADL) such as reading. Measuring reading fluency begins to measure such an ability, although full reading proficiency includes other factors such as reading comprehension and reading endurance as well.

When we embark upon an individualized rehabilitative plan, for instance to improve reading proficiency, we need to *measure* the individual's performance directly and then compare the findings before and after the intervention. For other purposes, however, it may be sufficient to *estimate* the reading ability based on the *measured* visual acuity *(see Table 12)*. Such estimates are necessarily based on statistical averages and ignore individual differences. This approach has some advantages if the purpose is the assignment of disability benefits, since we want to avoid penalizing those who have made a successful adjustment by reducing their benefits.

TABLE 12 – Rehabilitation Needs vs. Assignment of Benefits



ASPECTS:

Structural change, Anatomical change | Functional change at the Organ level | Ability to perform ADL Activities | Social, Economic Participation

REHABILITATION NEEDS

Based on assessment of actual abilities, since successful adaptations reduce the need for additional Rehabilitative Care.

Ability and Participation Profile
→ Need for Rehabilitative Care

ASSIGNMENT of BENEFITS

Based on generic ability estimates. Individual variations are ignored, since successful adaptations should not be penalized by a reduction in benefits.

Impairment Measurement → Estimate of Average Ability → Assignment of Benefits

Legend: Determination of Rehabilitation Needs is different from the assignment of benefits. The difference in purpose explains a difference in approach *(see text)*.

Functional Vision Estimates

Use of statistical ability estimates is meaningful only if a reasonable correlation can be established between visual function measurements and functional vision. Ophthalmology was one of the first fields were attempts were made to establish such a correlation. Best known, although not the first, is the *Visual Efficiency Scale* developed by Snell in 1925. Snell had done a survey, establishing that persons with 20/200 *(0.1)* visual acuity had lost 80% of their employability in 1925 ([49]). He combined this with a study about progressive visual blur to come up with a formula assigning a Visual Efficiency % rating to every visual acuity level ([50]). In the same year, his report was adopted by the AMA Committee on Compensation for Eye Injuries ([51]).

In 1958, this report was one of several published as *Guides to the Evaluation of Permanent Impairment (52);* later these reports were published in book form (4). Several editions followed in which some additions were made, but in which the basis of Snell's scale remained unchanged. This was the situation up to the 4th edition (1993) of the AMA *Guides*. The Visual Efficiency scale can be found quoted in many publications.

The AMA Vision chapter in the 5th edition (2000) incorporates radical changes. The Visual Efficiency system has been replaced by the Functional Vision Score system. The major change is that 20/200 *(0.1)* visual acuity is no longer rated as an 80% loss (of employability in 1925) but as a 50% loss of the generic ability to perform Activities of Daily Living. This statistical estimate, combined with individual factors such as specific job requirements can then contribute to an administrative decision about the assignment of benefits, which is a separate step, not covered by the AMA *Guides*. Other changes in the 5th edition involve some changes in the rules for combining losses and the elimination of various inconsistencies, which had crept in over the years.

General Ability Score

To compare performance across dissimilar abilities (reading ability, hearing ability, walking ability, etc.) a set of generic ability ranges is needed. A useful scale is:

.	100 +/- 10	Normal range	Normal function, with reserve capacity
.	80 +/- 10	Mild loss	Normal function, but loss of reserve capacity
.	60 +/- 10	Moderate loss	Normal function, but need for some aids
.	40 +/- 10	Severe loss	Restricted function, slower than normal, even with aids
.	20 +/- 10	Profound loss	Restricted function, marginal performance, even with aids
.	0 +/- 10	(Near-)total loss	Cannot perform, needs substitution skills.

This scale recognizes that most functions have reserve capacity. When the reserve capacity is lost, peak performance will suffer, but average performance will still be acceptable. When loss proceeds further some assistive devices will be needed to enhance the function (enhancement aids). When loss proceeds beyond the mid-point of the scale, performance is restricted and finally impossible. At that point enhancement aids are no longer useful, the patient needs substitution aids to replace the lost function (talking books instead of magnifiers, lip reading instead of a hearing aid, a wheelchair instead of crutches, etc.).

Visual Acuity Score

In Table 6 the set of ICD-9-CM visual acuity ranges was compared to a set of reading ability ranges. We found a good fit. The *Visual Acuity Score*, discussed under visual acuity notations, fits equally well with the visual acuity ranges as with the General Ability Scale quoted above. We may conclude that the Visual Acuity Score *(Table 13)* provides a reasonable statistical estimate of the generic ability to perform tasks requiring detail vision.

Converting the visual acuity value to a **Visual Acuity Score** (VAS) is the first step in a three step process. It converts the non-linear list of visual acuity values to a linear scale, which can be used for averaging and for other calculations.

The next step is to combine the scores obtained for the right eye, the left eye, and binocularly to a statistical ability estimate: the **Functional Acuity Score** (FAS). This is done by averaging. Since normal vision is binocular vision, the binocular score receives 60% of the weight; the right eye and left eye receive 20% each. Thus, the formula is: $\text{FAS} = (3 \times \text{VAS}_{\text{OU}} + \text{VAS}_{\text{OD}} + \text{VAS}_{\text{OS}}) / 5$.

The last step is to combine the Functional Acuity Score (FAS) with a similarly derived Functional Field Score (FFS) to a single **Functional Vision Score** (FVS) as indicated in Table 14.

TABLE 13 – Ability Score and Ranges of Estimated Ability Loss

Ranges		Ability Score	Visual Acuity	ESTIMATED Reading Ability	Field radius	ESTIMATED Skills for Orientation and Mobility
(Near-) Normal Vision	Range of Normal Vision	110 105 100 95	20/12.5 20/16 20/20 20/25	Normal reading speed Normal reading distance *Reserve capacity for small print*	60°	Normal Visual Orientation Normal Mobility skills
	Near-Normal (Mild Loss)	90 85 80 75	20/32 20/40 20/50 20/63	Normal reading speed Reduced reading distance *No reserve for small print*	50° 40°	Normal “O+M” performance Needs more scanning *Occasionally surprised by events on the side*
Low Vision	Moderate Low Vision	70 65 60 55	20/80 20/100 20/125 20/160	Near-normal with reading aids *Low power magnifiers and large print books*	30° 20°	Near-normal performance *Requires scanning for obstacles*
	Severe Low Vision	50 45 40 35	20/200 20/250 20/320 20/400	Slower than normal with reading aids *High power magnifiers*	10° 8°	Visual mobility is slower than normal *Requires continuous scanning* *May use cane as adjunct*
	Profound Low Vision	30 25 20 15	20/500 20/630 20/800 20/1000	Marginal with aids *Uses magnifiers for spot reading, may prefer talking books*	6° 4°	Must use long cane for detection of obstacles *May use vision as adjunct for identification*
(Near-) Blind-ness	Near-Blindness	10 50 0	20/1250 20/1600 20/2000 ---	No visual reading *Must rely on talking books, Braille or other non-visual sources*	2° less	Visual orientation unreliable *Must rely on long cane, sound, guide dog, other blind mobility skills*
	Total Blindness		NLP			

Legend. The first block lists the ranges of vision loss as defined in ICD-9-CM with the General Ability Score discussed in the text. This score is also used as the Visual Acuity Score (VAS) and Visual Field Score (VFS). The second block lists the corresponding visual acuity levels with estimated ranges of reading performance. The third block lists the corresponding visual field ranges with estimated ranges of Orientation and Mobility (O&M) performance. There is reasonable correspondence between the performance ranges in all three blocks.

Visual Field Score

A similar scoring system can be developed for visual field loss. While visual acuity loss may manifest itself primarily in a loss of reading ability, visual field loss will affect another set of ADL skills, commonly covered under the term *Orientation and Mobility* (O & M) skills. The importance of these skills is obvious, but designing a good measurement tool for O & M skills is difficult. The technical aspects of visual field measurement have been discussed elsewhere. Modern static perimetry plots are a great help in defining the underlying disorder; they are harder to interpret with regard to the functional consequences. Traditional Goldmann isopters were easier to interpret in this regard. Also, for diagnostic purposes, the central 30° are the most informative, whereas a full-field plot is needed to predict O & M skills. Capturing all aspects of visual field loss in a single number is a serious oversimplification of a complex reality. Nevertheless, it has been attempted because of administrative demand.

The old AMA *Guides* offered two options; (a) a formula-based calculation, and (b) use of overlay grids. The formula gave equal weight to upper and lower field and to peripheral and central loss. The overlay grids, designed by Esterman (53), gave double weight to the lower field and concentrated most weight in the Bjerrum area. The two methods do not give the same result and differ from the traditional "legal blindness" criterion *(20° diameter, 10° radius)*.

The new AMA *Guides* use a method, which can be implemented with paper and pencil or with an overlay grid, and has the potential of being implemented on an automated perimeter (54). 50 points are assigned to the central 10° radius (20° diameter), since this area corresponds to about 50% of the primary visual cortex; the other 50 points are assigned to the periphery. The points are arranged along ten meridians, three in each of the lower quadrants and two in each of the upper quadrants. This gives the lower field 50% extra weight. Measuring along meridians within the quadrants, rather than along the principal meridians, avoids special rules for hemianopias. Along each of the ten meridians 5 points are counted from 0° to 10° and 5 points from 10° to 60°. This maintains the traditional equivalence between a visual acuity loss to 20/200 *(0.1)* and a visual field loss to 10°, and assigns 100 points to a field of 60° average radius. The assignments are summarized in Fig. 11.

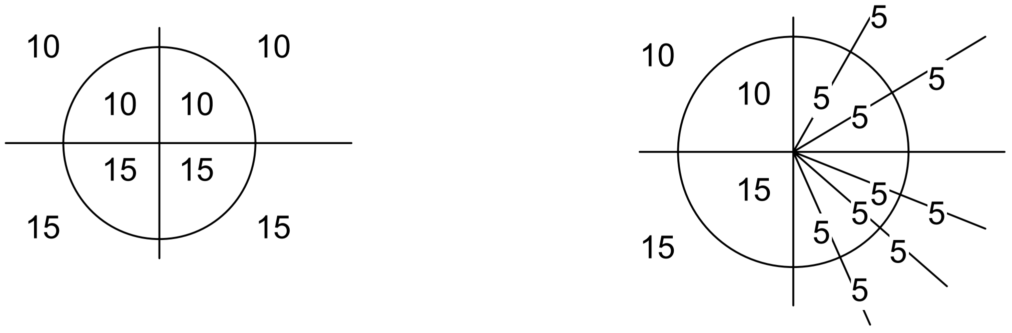


Figure 11 Diagrams for field scores

Legend: These diagrams depict the test points for the Visual Field Score. Note that the central 10° radius scores 50 points and that the lower field scores 50% more than the upper field.

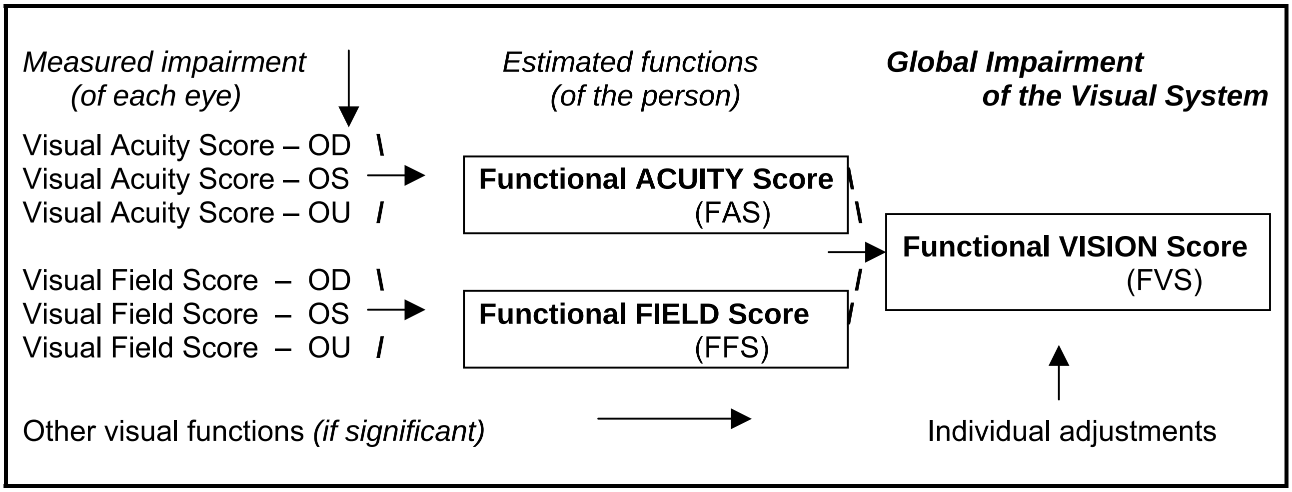
Similar to the Visual Acuity Score, which can be calculated as the number of letters read on a standardized chart, the **Visual Field Score** can be calculated as the number of points seen on a standardized grid. Table 13 compares the Visual Acuity Score with ranges of reading skills and the Visual Field Score with ranges of O & M skills. There is reasonable agreement, indicating that the Visual Field score is a reasonable estimate of O & M ability.

The next step is to combine the Visual Field Scores (VFSs), obtained for the right eye, the left eye, and binocularly, to obtain a statistical ability estimate: the **Functional Field Score** (FFS). As for the Functional Acuity Score (FAS) this is done by averaging. The formula is: FFS = (3 x VFS_{OU} + VFS_{OD} + VFS_{OS}) / 5. The binocular visual field is not measured directly, but constructed by superimposition of the monocular fields.

Combining Visual acuity and visual field values

After the Functional Acuity Score and the Functional Field Score have been calculated, they must be combined to a single *Functional Vision Score* for the whole person. The formula is: FVS = FAS x FFS / 100. The process is summarized in Table 14. For more detailed rules, the reader is referred to the AMA *Guides* ([4]).

TABLE 14 – Calculating the Functional Vision Score



Legend: The Functional Acuity Score is based on the visual acuity values for each eye and binocularly; combined with a similarly derived Visual Field Score, it determines the Functional Vision Score *(see text)*.

Direct Assessment of Visual Abilities and Functional Vision

While the statistical estimates of Functional Vision as outlined above can be useful for administrative purposes, the planning of individual rehabilitation efforts, requires a more detailed assessment of the individual's abilities. This can take the form of an **Ability Profile** in which the ability to perform each of a series of ADL activities is rated. Such profiles can be simple or complex.

A simple, yet effective, visual ability profile is used by Lea Hyvärinen ([55]). Her model is particularly effective for children and infants, since it contains only four ADL groups:

Visual Communication
Daily Living skills,
Orientation and Mobility and
Sustained Near vision (incl. reading)

and three performance levels:

Performs like a Sighted person
Performs like a Low Vision person
Performs like a Blind person.

The early recognition of vision defects and their remediation or compensation is important, since vision alone provides as much input to the brain as all other senses combined. Loss or reduction of this input can have a profound effect on all aspects of an infant's development (see Table 11).

Overall visual functioning can be affected by several types of impairments. With regard to rehabilitation efforts, it is important to make a distinction between **Ocular Visual Impairment** (OVI, caused by pre-chiasmal lesions, such as a macular scar) and **Cerebral** (or Cortical) **Visual Impairment** (CVI, caused by post-chiasmal lesions). Cerebral lesions can also cause defects in the higher visual functions: **Visual Perceptual Impairment** (VPI). CVI and VPI are harder to quantify, but the newer neuro-imaging techniques have helped our understanding of these processes.

In children the major cause of CVI and VPI is peri-natal asphyxia and ischemia. Since this affects all parts of the brain, such children will often have other, non-vision related problems, which make the diagnosis more difficult. Nevertheless, it has been possible to identify types of visual processing that are affected in some children and not in others. A child can be said to have VPI if its visual processing capability is more restricted than its general developmental (not chronological) age would suggest[56]. VPI can be task specific and can exist in the presence of normal acuity. Thus, the fact that a child's visual acuity is not in the Low Vision range (Table 13) does not mean that the child does not need rehabilitative interventions. Unfortunately, many agencies and professionals are not yet aware of this fact.

Visual Perceptual Impairments can also exist in the adult (e.g. after a stroke in the elderly). In the adult brain the effects may be less generalized. It is important to separate the VPI from a possibly coexisting OVI (e.g. macular degeneration), since the rehabilitative efforts have to be very different.

For adult vision rehabilitation plans, the various activities and performance levels will need to be specified in more detail. Colenbrander has proposed a profile ([43]) with ten ADL groups:

Self care	personal care, clothing, health care
Meals	preparation, cooking, appliances, eating
Home management	housework, gardening, small repairs
Reading	personal, informational, recreational
Communication	handwriting, typing, word processing, telephone

Financial management	handling cash, checks, bill paying, banking
Consumer interactions	retail services, public services
Orientation, Mobility	orientation, walking, driving
Leisure	active, passive, social interactions
Education / Vocational	blackboard, notes, tests, reading assignments, or: specified vocational tasks.

To rate performance for each of these activities the 100-point scale used for the visual acuity and visual field scales is too detailed and should be reduced to a 10-point ability scale. Although the scores for the 10 activity groups could be combined to a 100-point global score, this is not recommended, since the purpose of an ability profile is to highlight differential performance, and hence different rehabilitation needs, in different areas.

Other groups have devised numerous other lists, often directed at specific problems. ICIDH-2 ([3]) provides a very detailed taxonomy of activities, from which relevant ones can be selected.

Direct Assessment of Participation

To judge the actual impact of vision loss on a person's *Quality of Life*, an even broader perspective is needed. In ICIDH-80 this aspect was described as *handicap* and measured in terms of *loss of independence*; in ICIDH-2 it is described under the heading *participation.* These terms describe different sub-aspects. Handicap describes the barriers that need to be overcome, participation describes the result of overcoming them. Loss of independence seems to imply full independence as an ideal; participation also stresses interdependence.

How well different individuals can overcome their barriers, depends not only on the impairment and on the abilities of the individual, but also on the society and the environment in which the individual operates. The Americans with Disabilities Act (ADA) has drawn much needed attention to accommodations that can be made in the workplace. The story of Helen Keller is one example of how some people can achieve full participation in spite of extraordinary handicaps.

Improving the *Quality of Life* and the *Participation* aspect remains the ultimate goal of all rehabilitative interventions. For this reason, the National Eye Institute has developed a **Visual Function Questionnaire** (VFQ) ([57]) with 50 or 25 items. The NEI-VFQ is used in many NEI sponsored clinical studies and also in private studies. Other groups have developed similar instruments and more activity in this field may be expected.

Summary

The assessment of vision loss can be approached from different points of view. *Visual functions* such as visual acuity are easily measured and are often used to characterize patients or patient groups. *Functional Vision* and the ability to perform Activities of Daily Living (ADL) are more difficult to measure.

For administrative uses, a statistical estimate of the ADL ability may be derived from the visual function measurements. For individual rehabilitation plans the individual abilities must be evaluated in an Ability Profile.

Improving the *Participation* aspect is the ultimate goal of all rehabilitative efforts. Instruments such as the NEI-VFQ can be used to assess this aspect.

REFERENCES

---

[1] *Dimensions of Visual Performance*, A. Colenbrander - Low Vision Symposium, American Academy of Ophthalmology, Transactions AAOO, 83:332-337, 1977.

[2] *International Classification of Impairments, Disabilities and Handicaps* (ICIDH-80), World Health Organization, Geneva, 1980.

[3] *International Classification of Functioning, Disability and Health* – (ICF), World Health Organization, Geneva, 2001.

[4] *Guides to the Evaluation of Permanent Impairment* – American Medical Association, Chicago. 1st Ed., 1971; 2nd Ed., 1984; 3rd Ed., 1988; 3rd Ed.rev., 1990, 4th Edition, 1993. 5th edition expected in 2000.

[5] *Seeing into Old Age: Vision Function Beyond Acuity,* Haegerstrom-Portnoy G, Schneck ME, Brabyn JA. Optom. And Vision Sci. 76(3): 141-158 (1999).

[6] *Schriftnummerproben für Gesichtsleidende*, Küchler, Darmstadt, 1843.

[7] *Schriftskalen*, Eduard von Jaeger . 1854 (first edition). *Also:* 1857 (second edition with texts in German, French, English, Italian, Czech (then part of the Austrian Empire), Russian, Hebrew).

[8] *Ueber Staar und Staaroperationen,* Jaeger E. Vienna, LW Seidel, 1st ed. 1854.

[9] *On the Anomalies of Accommodation and Refraction*, Donders FC. New Sydenham Society, London, 1864.

[10] *Letterproeven tot Bepaling der Gezichtsscherpte*, Snellen H. Utrecht, Weyers, 1862 (Dutch edition, also single language editions in German, French, Italian)
Also: Optotypi ad Visum Determinandum. Repeated international editions (with texts in Dutch, French, German (gothic and roman type), English, Italian, and Latin), incl. 23rd edition, 1937.

[11] Robert Hooke - Posthumous works, published 1705.

[12] *Onderzoekingen naar de invloed van de leeftijd op de gezichtsscherpte (Research on the influence of age on visual acuity),* de Haan V – Doctoral Dissertation, Utrecht, 1862.

[13] *Visual Acuity changes throughout adulthood in Normal Eyes: Seeing beyond 6/6.* Elliott DB, Yang KCH, Whitaker D. Optom. Vision Sci. 72:186-191 (1995).

[14] *Racial Variations in Vision,* Taylor HR. Am. J. Epidemiol. 113 (1): 62-80.

[15] *Ophthalmic test types,* Bennet AG. Br. J. Physiol. Optics, 22:238-271 (1965).

[16] *British Standard - Test Charts for Determining Distance Visual Acuity* BS 4274. London, British Standards Institution (1968)

[17] *On a new series of test-letters for determining the acuteness of vision,* Green J. Transact. Amer. Opth. Soc. 4th meeting (1868), p 68-71. *Also: Test letters,* Green, Ewing. St. Louis, 1886.

[18] Metric System. Proposed in France in 1789. Legally accepted in France in 1799. Accepted worldwide (including U.S.A.) through the Treaty of the Meter in 1875.

[19] *Echelle typographique décimale pour mesurer l'acuité visuelle*, Monoyer F. Gaz. Med. Paris 21:258 (1875)

[20] Monoyer F. - Ann. Oculistiques (Paris) 68:101 (1872) - proposed diopter notation.

[21] *Bestimmung der Sehschärfe,* Snellen H, Landolt E, in: *Die Functionsprüfungen des Auges* in: *Graefe-Saemisch Handbuch*, first edition, vol. 3 (1874). Also published as: '*Optometrologie'* (1874).

[22] *Bestimmung der Sehschärfe,* Landolt E in: *Die Functionsprüfungen des Auges* in: *Graefe-Saemisch Handbuch*, second edition (1904)

---

[23] *Visual Acuity Measurement Standard* - International Council of Ophthalmology, 1984, in: Italian J. Opht., pp. 1-15, II/I (1988).

[24] Hess. XI Int. Congress of Ophth., Naples (1909)

[25] *New Test Charts for the Measurement of Visual Acuity at Far and Near Distances,* Sloan LL. Am J Ophth. 48:807-813 (1959).

[26] *Reading Aids for the Partially Blind*, Sloan LL, Habel A. Am. J. Ophth. 42:863-872 (1963).

[27] *Eduard Jaeger's Test-Types (Schrift-Scalen) and the Historical Development of Vision Tests,* Runge PE. AOS thesis, 2000.

[28] *International Classification of Diseases, 9th Revision (ICD-9)*, World Health Organization, Geneva, 1977.

[29] *Proc. XXIII International Congress of Ophthalmology.* – 1978, pp 69-74. Elsevier, Amsterdam.

[30] *International Classification of Diseases, 9th Revision - Clinical Modification (ICD-9-CM)*. First edition: Commission on Professional and Hospital Activities, Ann Arbor, 1978. Later editions by: U.S. Public Health Service, 1980, and others.

[31] *New Design Principles for Visual Acuity Letter Charts,* Bailey IL, Lovie JE.. Am J Optom & Physiol Opt 53:740-745 (1976).

[32] *Applying new Design Principles to the Construction of an Illiterate E chart,* Taylor HR. Am J Optom Physiol Optics 55:348-351 (1978).

[33] *New Visual Acuity Charts for Clinical Research,* Ferris FL, Kassov A, Bresnick GH, Bailey I. Am J Ophthalmol 94:91-96 (1982). Also:
Measurement Guidelines for Collaborative Studies. National Eye Institute (NEI), Bethesda, MD.

[34] *From 20/20 to 6/6 or 4/4?,* Hofstetter HW. Am. J. Optom. 50(3):212-221 (1973).

[35] *Reading Glasses for Patients with Very Poor Vision,* Kestenbaum A, Sturman RM. Arch. Ophth. 56:451-470 (1956), also Am. J. Ophth. 36:1143-1144 (1953).

[36] *Low Vision Test Chart.* One side: Letter chart from 50M to 1M, representing acuity values from 1/50 (20/1000, 0.02) to 1/1 (20/20, 1.0); 1m cord attached. Other side: standardized reading segments (10M to 0.6M) for reading rate measurements; diopter ruler included. Available in English, Spanish, Portuguese, German, French, Dutch, Swedish, Finnish. From: Precision Vision, 944 First Street, LaSalle, IL 61301, USA. Telefax: 1-815-223-2224.

[37] *Visual Acuity Measurements in Low Vision Patients.* Colenbrander A, Fletcher DC. Journal of Vision Rehabilitation, 4(1): 1-9 (1990).
Also: The Basic Low Vision Examination, Colenbrander A. In: *Low Vision Rehabilitation*, Colenbrander, Fletcher eds., Ophth. Clinics of North America (1994), 7-2: 151-162.

[38] *De tactu: annotationices et physilogicae,* Weber EH (1834), brought to wider attention in: *Elemente der Psychophysik,* Fechner GT (1860).

[39] *Scaling of Visual Acuity Measurement*, Westheimer G. Arch. Ophth. 97:327-330, 1979.

[40] *Preferred Numbers,* ISO standard # 3. Also: DIN standard # 323.

[41] *Neue Probetafel zur bestimmung der Sehschärfe*, Colenbrander MC. Klin. Monatsbl für Aug. 99:213 (1937) and Ophthalmologica 99:402 (1940)

[42] *Measurement of visual acuity – Towards standardization,* Bailey, IL.. In Vision Science Symposium - Tribute to Gordon Heath. Indiana University, 1988.

[43] *The Functional Vision Score. A Coordinated Scoring System for Visual Impairments, Disabilities and Handicaps,* Colenbrander A. In: *Low Vision - Research and New Developments in Rehabilitation*, Kooijman et al. eds., Studies in Health Technology and Informatics, IOS Press, Amsterdam, 1994, pp. 552-561.

---

[44] *Repeatability of Visual Acuity Measurement,* Raasch TW, Bailey IL, Bullimore MA. Optom. And Vision Sci. 75(5): 342-348.

[45] *New visual acuity test for pre-school children,* Hyvärinen L, Näsänen R, Laurinen P. Acta Ophthalmol. 58:507-511 (1980).

[46] LEA symbol calibration data are available at: www. lea-test.sgic.fi/en/vistests/

[47] *Visual requirements for reading,* Whittaker SG, Lovie-Kitchin J. Optometry and Vision Science 70: 54-65 (1993).

[48] *Psychophysics of reading. XV. Font effects in normal and low vision.* Mansfield JS, Legge GE, Bane MC. Investigative Ophthalmology & Visual Science, 37, 1492-1501, (1996). The MNREAD Acuity Chart (Lighthouse Low Vision Products, Inc., Long Island City, New York)

[49] *Visual Efficiency of Various Degrees of Subnormal Visual Acuity, its Effect on Earning Ability,* Snell AC J AMA 85(18): 1367-1373.

[50] *The Percentage Evaluation of Macular Vision*, Snell AC, Sterling S. Arch. Ophth. 54:443-461, (Sept.) 1925.

[51] *Report of the Committee on Compensation for Eye Injuries*, J AMA 85(2): 113-115, (July) 1925.

[52] *Guides to the Evaluation of Permanent Impairment - Committee report*. JAMA 168 (4): 475-485, 1958.

[53] *Grid for Scoring Visual Fields. I – Tangent Screen,* Esterman B. Arch. Ophth. 77:780-786, 1967.

Grid for Scoring Visual Fields. II – Perimeter, Esterman B. Arch. Ophth. 79:400-406, 1968.

III – Functional Scoring of the Binocular Field, Esterman B. Ophthalmology, 89(11): 1226-1234, (Nov.) 1982.

[54] *Preliminary Implementation of the Functional Vision Score on the Humphrey Field Analyzer,* Colenbrander A, Lieberman, MF, Schainholz DC. Proceedings of the International Perimetric Society, Kyoto, 1992.

[55] *Classification of Visual Impairment and Disability,* Hyvärinen L. Bull. Soc. Belge Ophtal., 215, 1-16, 1985.

[56] *Separating Visual Perception and Non-verbal Intelligence in Children with Early Brain Injury,* Stiers A, De Cock P, Vandenbussche E. Brain & Development 21 (1999): 397-406

[57] *Psychometric Properties of the National Eye Institute Visual Function Questionnaire (NEI-VFQ),* Mangione CM et al. Arch. Ophthalmol. 116:1496-1504 (1998).