INTRODUCTION TO VISUAL ACUITY MEASUREMENT

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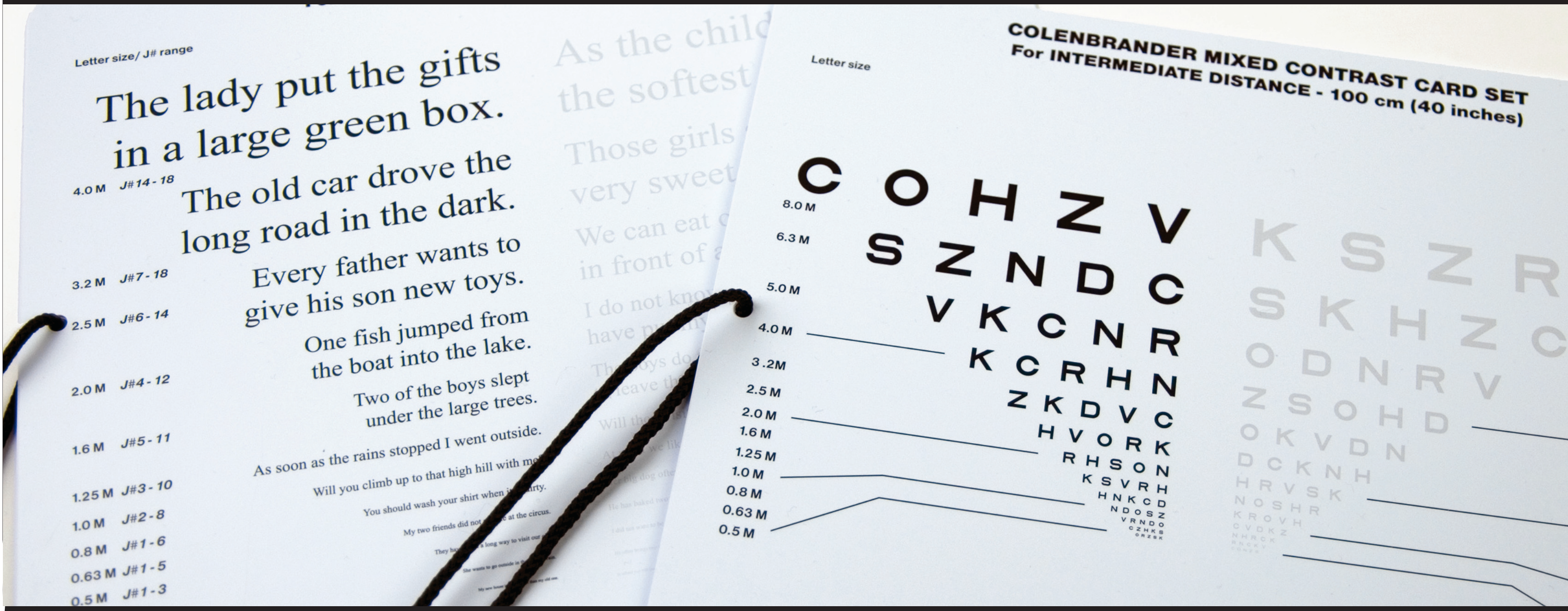


Precision Vision®

Contents

Since the 1970's Precision Vision has built a reputation of producing the most accurate and most durable vision testing tools available. In the 1980's they printed the first ETDRS cards and produced the standard ETDRS illuminator cabinet. Since the 1990's they have carried a variety of Low Vision and pediatric testing tools.

This introduction is meant to provide some guidance in selecting from the vast array of charts and devices available. It is divided into several sections:

A – Visual acuity
B – Letter chart measurements
C – Near Vision and Reading
D – Contrast Sensitivity
E – Low Vision tests
F – Pediatric tests

A more detailed discussion is available in: Measuring Vision and Vision Loss, A. Colenbrander, in: Duane's Clinical Ophthalmology, Vol 5, Ch. 51, ed. 2001 and later.

Updated January, 2020

A – Visual Acuity

Frequently Asked Questions:
> What is visual acuity? What are its limitations?
> What are visual acuity tests used for?
> How is visual acuity defined and recorded?
> What is the reference standard?
> What should be the measurement steps?
> What is the Preferred Numbers series?
> How can I convert between different notations?
> How can I compare and average the functional consequences?

What is visual acuity? What are its limitations?

Visual acuity describes the acuteness or “sharpness” of vision; that is the ability to perceive small details. The primary measurement tool is the letter chart introduced in 1862 by Donders and Snellen at the Eye Infirmary at Utrecht in the Netherlands.

Visual acuity measurement is so common that visual acuity measurement is often mistaken as a unique indicator for vision in general. This is a misconception. Visual acuity loss can detect many disorders, but not all. A primary example is glaucoma, which can do extensive and irreversible visual field damage before visual acuity is affected. Letter chart acuity tells us something about the very small retinal area onto which the letter seen is projected. When the image of that letter is blurred due to optical factors (opacities, refractive error) the surrounding image will be equally blurred. But when visual acuity loss is due to retinal factors, letter chart acuity tells us nothing about how the surrounding retina functions.

Visual acuity can predict many consequences of vision loss, but not all. It is usually measured with black letters on an evenly white background. This condition resembles the reading task, but most other activities of daily living (ADL) involve objects that are much larger, have less contrast and are presented against a busier background. Low contrast tests, discussed later, offer important additional information that high contrast acuity alone cannot give us. Testing under standard illumination also is insufficient for conditions that require extra high or extra low illumination.

What are visual acuity tests used for?

Visual acuity measurement is a good **screening tool** because normal visual acuity requires that all levels of the visual system function properly. The optical system of the eye must project a sharp image of the outside world onto the retina. The retina must then be able to translate this image into neural impulses. Finally, the neural impulses must travel to the brain, where they are analyzed and recognized. Therefore, a wide array of different visual disorders (but not all) can affect visual acuity.

Because visual acuity is so easily measured, it is often used as a primary **eligibility criterion,** such as 20/20 for a pilot’s license, 20/40 for a driver’s license, 20/200 for certain disability benefits. However, the ability to perform various tasks depends on many more factors than visual acuity alone.

For those disorders that affect visual acuity, it also is a good **follow-up tool** to document whether a condition is worsening or recovering or to record the effect of various interventions.

For all of these purposes it is desirable that the measurement methods are well standardized and the same from office to office. This was the primary incentive for producing a standardized test (see below) for the Early Treatment Diabetic Retinopathy Study (ETDRS).

Finally, letter charts are often used as an aid in **subjective refraction**. This is the least demanding application, since the question “Which lens is better, A or B?” is more important than the question “Which line can you read?”

How is visual acuity defined and recorded?

Most people are familiar with the notation of visual acuity (V or VA) as a fraction, but few understand what these fractions mean. Yet, the explanation is simple. If a subject needs letters that are twice as large or twice as close as those needed by a standard eye, that person’s visual acuity is said to be 1/2. If the letters needed are five times larger, the acuity is 1/5, if ten times larger: 1/10, etc. The value of those fractions can be expressed in several different ways. E.g. 1/2 = 20/40 = 6/12 = 0.5 or 1/5 = 20/100 = 6/30 = 0.2. The **MA**gnification **R**equirement is also known as MAR, so that MAR = 1/V and V = 1/MAR. (see Table 1)

Snellen expressed this in the well known Snellen fraction (here in its metric version):

$$\mathrm{VA} = \frac{\mathrm{m}}{\mathrm{M}} = \frac{\textbf{viewing distance } \textit{(in meters)}}{\textbf{letter size } \textit{(in M-units)}}$$

Snellen insisted that the numerator of these fractions should indicate the testing distance; e.g. 20/… for 20 ft, 5/… for 5 meters, 6/… for 6 meters. Today, this convention is rarely followed. Instead, equivalent notations are used, indicating what the Snellen fraction would have been, had the patient been tested at the standard distance. In the US the 20/… notation is routinely used, even if the testing distance is not 20 ft. In Europe the decimal notation is common; in Britain (and former British dominions) the 6/… notation is common. Table 1 compares a variety of Snellen fractions with the equivalent values used in different parts of the world. The last column lists MAR, the MAgnification Requirement, which is the number that is actually measured and upon which the visual acuity value is based. (MAR = 1/V and V = 1/MAR).

In the section on low vision reading tests we will discuss a Modified Snellen Formula, which is easier to use for near vision.

According to the Visual Acuity Measurement Standard (1984) of the International Council of Ophthalmology (ICO) a line is considered read if "more than half" of the characters are identified correctly. For an ETDRS chart with 5 letters per line, this means 3 or more correct.

What is the reference standard?

Since the value of the visual acuity fraction compares a subject's performance to the performance of a standard eye, that standard needs to be defined. Snellen chose to define it as the ability to recognize one of his letters when it subtends a visual angle of 5 min of arc. Louise Sloan later coined the name M-unit to describe this measurement unit. One M-unit subtends a visual angle of 5 min of arc at 1 meter. Simple geometry tells us that the same visual angle applies for 2 M-units at 2 meters, 3 M-units at 3 meters, etc. 1 M-unit also happens to be the size of average newsprint, but that is not the basis of its definition.

Visual acuity notations of 1/1, 4/4, 6/6, 20/20, 1.0 all refer to this reference standard. It is a common mistake to equate 20/20 with normal (i.e. average) or even with perfect vision. Snellen choose his standard for being "easy to recognize". Healthy young adults always exceed the standard; if he had used "average" acuity as the reference standard, by definition half of the population would have failed it.

Clinical tip:

"Normal" visual acuity for healthy eyes is one or two lines better than 20/20. In population samples the average acuity does not drop to the 20/20 level until age 60 or 70. Always remember that the 20/20 reference standard does not refer to the average acuity of American eyes, just as the US standard foot is defined independently of the "normal" length of American feet.

What should be the measurement steps?

Since letter charts contain only discreet letter sizes, the measurement accuracy depends on the step size between lines. Most traditional US charts have an irregular sequence of letter sizes (as did Snellen's original chart). From 20/15 to 20/20 is a 33% increase, from 20/20 to 20/25 is 25%, from 20/60 to 20/70 is 17%, but from 20/100 to 20/200 is a 100% increase. It was soon recognized that equal step sizes would be desirable. The first chart with such a sequence was proposed in 1868 by John Green of St. Louis, who had spent time working with Snellen while touring Europe after his ophthalmology training. He proposed a geometric (logarithmic) sequence:

1.0 1.25 1.6 2.0 2.5 3.2 4.0 5.0 6.3 8.0 10

This sequence later became known as the "Preferred Numbers" series. Unfortunately, Green was far ahead of his time; his proposal was forgotten and it would take a century until this same sequence became generally accepted for visual acuity measurement.

What is the Preferred Numbers series?

Many different geometric progressions (progressions with a constant ratio between adjacent terms) are possible. The progression used in the ETDRS protocol and on all professional Precision Vision charts is known as the Preferred Numbers series. This series is defined in standard #3 of the International Standards Organization and is used in a wide variety of industrial standards, because:
(a) The preferred numbers series fits well with the decimal system, since each step represents the same 10√10 ($10^{0.1}$) ratio. Thus, 10 steps equal exactly 10x, and after 10 steps the same digits reappear with only a shift in the decimal position. (b) Preferred numbers are convenient because, with only slight rounding, the series contains mostly whole numbers. Each step represents a 4:5 ratio (rounding error = +0.7%), 3 steps equal a factor 2x (rounding error = -0.2%). The same ratios are used to calculate decibels; 3 decibels = 2x.
(c) Being anchored at 1.0 (10, 100, 1000, etc.) the series is well suited for visual acuity, since the reciprocal of a preferred number and the product or quotient of two preferred numbers is again a preferred number. Thus, if the letter sizes (the denominator of the Snellen fraction) and the

viewing distances (the numerator of the Snellen fraction) both follow this series, so will the resulting visual acuity values. As shown in Table 1, this works well for the 20/… and decimal notations and for Snellen fractions for 1m, 2m, 4m, 5m, 20 ft, 10 ft, 5 ft; in countries that use the 6/… notation, strict adherence to the series would require a test distance of 6.3 m instead of 6 m (6.3 and 3.2 are preferred numbers, 6 and 3 are not). Since the difference between 6 and 6.3 is only 5% (1/5 of a line, 1 ETDRS letter), this difference can be ignored for ordinary clinical measurements, where the measurement accuracy is in the order of one line. For research studies where multiple acuity measurements are averaged for greater accuracy, the difference may be significant.

All professional letter charts prepared by Precision Vision follow this sequence.

How can I convert between different notations?

In the US the 20/… notation is commonly used as an equivalent notation, meaning that the same notation is used regardless of the testing distance. In Europe, the decimal notation of visual acuity is prominent, while in Britain (and former dominions) the 6/... notation prevails. Others may want to use a true Snellen fraction, where the numerator specifies the test distance. The center part of Table 1 shows conversions between these different notations.

In addition, the left part of the table shows the ranges of vision loss defined in ICD-9-CM. Note again that the range of normal vision extends beyond 20/20.

Table 1 – Snellen Fractions and Equivalent Notations

RANGES (ICD-9-CM)		**TRUE SNELLEN FRACTIONS** (numerator indicates actual testing distance)									**EQUIVALENTS** (value = 1/MAR)			**MAR** (MAgn. Requ.)
		6.3m	6m	5m	4m	3.2m	3m	2m	1m	10ft	6/…	dec.	20/…	
(Near-) Normal Vision	Range of Normal Vision	6.3/4	6/3.8	5/3.2	4/2.5	3.2/2	3/1.9	2/1.25	1/0.63	10/6.3	6/3.8	1.6	20/12.5	0.63
		6.3/5	6/4.8	5/4	4/3	3.2/2.5	3/2.4	2/1.6	1/0.8	10/8	6/4.8	1.25	20/16	0.8
		6.3/6.3	**6/6**	**5/5**	**4/4**	**3.2/3.2**	**3/3**	**2/2**	**1/1**	10/10	**6/6**	**1.0**	**20/20**	**1.0**
		6.3/8	6/7.5	5/6.3	4/5	3.2/4	3/3.8	2/2.5	1/1.25	10/12.5	6/7.5	0.8	20/25	1.25
	Mild Vision Loss	6.3/10	6/9.5	5/8	4/6.3	3.2/5	3/4.8	2/3.2	1/1.6	10/16	6/9.5	0.63	20/32	1.6
		6.3/12.5	6/12	5/10	4/8	3.2/6.3	3/6	2/4	1/2	10/20	6/12	0.5	20/40	2.0
		6.3/16	6/15	5/12.5	4/10	3.2/8	3/7.5	2/5	1/2.5	10/25	6/15	0.4	20/50	2.5
		6.3/20	6/19	5/16	4/12.5	3.2/10	3/9.5	2/6.3	1/3.2	10/32	6/19	0.32	20/63	3.2
Low Vision	Moderate Vision Loss	6.3/25	6/24	5/20	4/16	3.2/12.5	3/12	2/8	1/4	10/40	6/24	0.25	20/80	4
		6.3/32	6/30	5/25	4/20	3.2/16	3/15	2/10	1/5	10/50	6/30	0.20	20/100	5
		6.3/40	6/38	5/32	4/25	3.2/20	3/19	2/12.5	1/6.3	10/63	6/38	0.16	20/125	6.3
		6.3/50	6/48	5/40	4/32	3.2/25	3/24	2/16	1/8	10/80	6/48	0.125	20/160	8
	Severe Vision Loss	**6.3/63**	**6/60**	**5/50**	**4/40**	**3.2/32**	**3/30**	**2/20**	**1/10**	10/100	**6/60**	**0.10**	**20/200**	**10**
		6.3/80	6/75	5/63	4/50	3.2/40	3/38	2/25	/12.5	10/125	6/75	0.08	20/250	12.5
		6.3/100	6/95	5/80	4/63	3.2/50	3/48	2/32	1/16	10/160	6/95	0.063	20/320	16
		6.3/125	6/120	5/100	4/80	3.2/63	3/60	2/40	1/20	10/200	6/120	0.05	20/400	20
	Profound Vision Loss	6.3/160	6/150	5/125	4/100	3.2/80	3/75	2/50	1/25	10/250	6/150	0.04	20/500	25
		6.3/200	6/190	5/160	4/125	3.2/100	3/95	2/63	1/32	10/320	6/190	0.03	20/630	32
		6.3/250	6/240	5/200	4/160	3.2/125	3/120	2/80	1/40	10/400	6/240	0.025	20/800	40
		6.3/320	6/300	5/250	4/200	3.2/160	3/150	2/100	1/50	10/500	6/300	0.02	20/1000	50
(Near-) Blindness	**Near-Blindness**	6.3/400	6/380	5/320	4/250	3.2/200	3/190	2/125	1/63	10/630	6/380	0.016	20/1250	63
		6.3/500	6/480	5/400	4/320	3.2/250	3/240	2/160	1/80	10/800	6/480	0.0125	20/1600	80
		6.3/630	**6/600**	**5/500**	**4/400**	**3.2/320**	**3/300**	**2/200**	**1/100**	**10/1000**	**6/600**	**0.01**	**20/2000**	**100**
		---	---	---	---	---	---	---	---	---	---	---	---	---
		No Light Perception (NLP)									NLP			

How can I compare and average the functional consequences?

Traditional visual acuity values are well suited for calculations about letter size, magnification and viewing distance. If the visual acuity is 20/100 (1/5), the letter size has to be increased by 5x to achieve the equivalent of 20/20 (1/1) performance. Alternatively, one has to use a 5x magnifier or a 5x telescope, or bring the object 5x closer. This is commonly referred to as Kestenbaum's rule.

For calculations and comparisons of the functional effects of different visual acuity levels, however, this geometric sequence cannot be used; we need a linear scale with constant increments. Clinicians have long used the expression that visual acuity has changed by a certain "number of lines". This expression is only valid, if the steps between lines are equal. Equal steps imply a geometric (logarithmic) progression. Taking the logarithm of each value converts the geometric progression of letter sizes to a linear scale of functioning. The change from a geometric to a linear progression is demonstrated in Table 3 in the Low Vision Section.

Two linear scales are available. One is the **logMAR scale**, which uses the logarithm directly; it is often found in scientific papers. LogMAR = $\log_{10}$(MAR). In the context of physiological optics, MAR is interpreted as **M**inimum **A**ngle of **R**esolution; in a functional context the interpretation as **MA**gnification **R**equirement is more intuitive. As we have seen earlier, MAR is the basis for the definition of visual acuity: VA = 1/MAR or MAR = 1/VA.

Although logMAR is often presented as a measure of visual acuity, it actually is a measure of visual acuity *loss*. A logMAR value of 0 indicates "no loss", i.e. visual acuity equal to the reference standard (20/20), while normal visual acuity (better than 20/20) is represented by negative logMAR values. Every increment of 0.1 logMAR indicates one line of loss.

The other scale is the **Visual Acuity Score** (VAS); it is an inversion of the logMAR scale, based on the formula VAS = 100 – 50x logMAR. It serves the same purpose, but is more intuitive since higher values indicate better acuity and since it avoids decimal values. For ETDRS-like charts with 5 letters on each line, the VAS increases by 1 point for every letter read correctly (5 points for every line). Similar letter count scores are used in many population studies and surveys (including the ETDRS). VAS values are identified by square brackets; the scale is anchored at **[100] = 20/20**, which means that **[50] = 20/200** and **[0] = 20/2000**.

Clinical tip:

The Visual Acuity Score is well suited for applications with a functional emphasis. It is used as an estimate of visual functioning ability in the 5th and 6th edition of the AMA Guides for the Evaluation of Permanent Impairment. The traditional Snellen values (or the modified Snellen formula discussed in the Low Vision section) are better suited for clinical applications such as calculating the need for changes in magnification or of working distance.

Precision Vision cards on which acuity differences are important (such as the Mixed Contrast cards) also carry VAS values.

Summary

Thus far we have discussed mainly distance visual acuity as measured with letters or symbols. We have seen that

> Visual acuity is defined as the reciprocal of the MAgnification Requirement (MAR) of a subject compared to a reference standard. Snellen chose the 20/20 reference standard to represent easily recognized letters; 20/20 is less than average, let alone than perfect vision.
>
> Although visual acuity is the most often measured parameter of vision, it considers only one aspect of vision (the MAgnification Requirement). Other aspects, such as visual field and contrast sensitivity are equally important in defining the functional capabilities of the subject.

B – Letter Chart Measurements

A variety of factors needs to be considered for accurate measurement of letter chart acuity. This outline discusses the most important ones.

Frequently Asked Questions:
> What is the preferred chart layout?
> What should the viewing distance be?
> What should the illumination be?
> What symbols should be used?
> What display method should be used?

Snellen's Chart (1862)

Part of John Green's Chart (1868)

ETDRS chart (1982)

What is the preferred chart layout?
Beyond the step sizes discussed earlier, another factor that affects the measurement accuracy of letter charts is the number of letters on each line. Traditional charts have a rectangular format. This allows many small letters, but only one or two big letters on a line. In 1976 Bailey and Lovie (then in Melbourne) proposed a new layout, combining the logarithmic progression with 5 letters on every line and spacing equal to the letter size. Their design provides the same task at all levels, but produced a much wider chart with a triangular array of letters that did not fit traditional letter chart boxes or projector charts.

With 5 letters per line the common criterion of counting a line as read when "more than half" of the line is read correctly, becomes 3/5 or 60% correct, about halfway between guessing and 100% correct.

In 1982 the National Eye Institute (NEI) needed new charts to assure standardized measurements for its multi-center Early Treatment Diabetic Retinopathy Study (ETDRS). The NEI chose to implement the geometric progression (Green, 1868) with the Bailey-Lovie layout (1976) and combined it with the letter set designed by Louise Sloan in 1959. These charts became known as ETDRS charts. They have since become a world-wide accepted, de-facto standard.

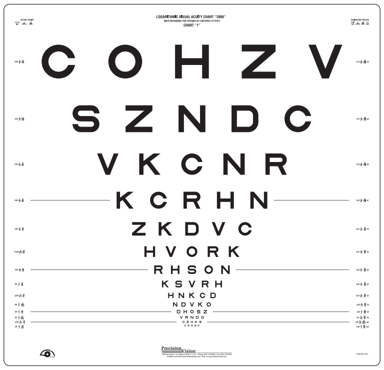
Because of the larger chart size, the NEI protocol reduced the standard viewing distance to 4 meters. Even at that distance, full ETDRS charts require a larger cabinet.

Since the letter spacing, the number of letters per line and the steps between lines are all standardized, the letter size is the only variable on ETDRS and similar charts.

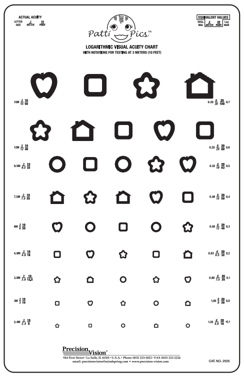
Precision Vision was called upon to develop the first commercially viable trans-illumination cabinets and charts for this study. Today these products are still considered the world standard used in research, education and clinical settings everywhere.

Most Precision Vision charts follow the triangular ETDRS layout; a few charts still offer the traditional rectangular format, mainly for use in the smaller, traditional cabinets for school testing. All professional Precision Vision charts follow the logarithmic progression.

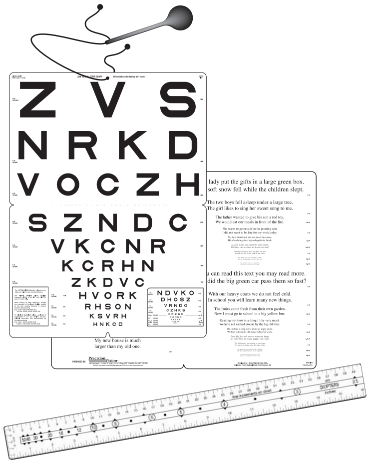
The **MassVat** layout and the effects of crowding will be discussed in the pediatric section.



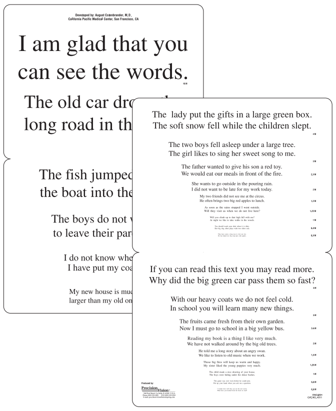
ETDRS – 4m for large cabinet



Patti Pics – 3m for small cabinet



1 meter chart



Large Reading card

What should the viewing distance be?
Since visual acuity is defined by the angle under which letters are viewed, its measurement can be done at any distance, provided that the scale is adjusted for the distance used.

When a letter chart is used as a target for subjective refraction, the viewing distance is important, because the longer the viewing distance, the more accommodation will be relaxed. Snellen's original charts were calibrated for a viewing distance of **20 Parisian feet** (in 1862 more than 20 different feet were in use across Europe). As soon as the Treaty of the Meter was signed (1875) he converted to metric distances and made charts for **5 meter** (more convenient with the decimal system) and **6 meter** (closer to 20 feet). These distances have the advantage that they relax accommodation and that small forward movements of the patient have a negligible influence.

The ETDRS protocol reduced the viewing distance to **4 meters** to have a more manageable chart size. For refractive measurements, one must be aware that this distance is 1/4 (0.25) D from infinity and adjust the prescription accordingly.

For testing of children a **3 meter** distance (10 ft) is often used, since it is easier to keep their attention at that distance. For refractive use, this distance is not recommended.

For smaller areas, Precision Vision also produces charts for 2.5 meter and 2 meter. These charts are well suited for visual acuity measurement, but not for refractive use.

For testing of Low Vision patients a **1 meter** distance is advantageous, since it can cover a much wider range of visual acuity values. The Colenbrander 1-meter chart covers visual acuities from 20/1000 to 20/20. It requires 1 D over the distance correction.

Precision Vision offers the Colenbrander 1-meter chart, which folds for easy transportation and has a cord attached to accurately maintain the viewing distance.

For testing of reading acuity, various distances have been used. The distance of **40 cm** is a commonly recommended standard.

Most Precision Vision charts for use at 1 meter or less have a cord attached to facilitate maintaining the accurate viewing distance.

What should the illumination be?
Visibility of objects is determined by their size, their illumination and their contrast. In visual acuity measurement we want to determine a size threshold. We therefore have to make sure that illumination and contrast are at levels where a ceiling effect is reached, so that small variations in illumination and contrast do not influence the measurement. This leaves a fairly broad range of acceptable values.

Clinical tip:
For routine clinical use of front illuminated charts, a rule of thumb can be that contrast should be maximal and that the charts should be illuminated well enough so that extra illumination will not improve the visual acuity readings.

All Precision Vision charts are printed on plastic formulated to resist yellowing and with inks that will maintain their blackness.

For the Precision Vision trans-illumination cabinets the surface illumination is set at about 170 cd/m^2, which is consistent with the ETDRS protocol and is in the middle of the 85 to 300 cd/m^2 range, recommended in the 1984 Visual Acuity Measurement Standard of the International Council of Ophthalmology (ICO).

What symbols should be used?
Before Snellen vision was usually assessed with existing printer's fonts, which could vary enormously in recognizability. Snellen's innovation was to design specific characters to be used only for the measurement of visual acuity. He called these characters optotypes and designed them all on a 5x5 grid.

Although Snellen also experimented with other symbols, he chose letters for his chart since they have most face validity for patients, whose main desire is to be able to read. As explained above for contrast and illumination, we also need to make sure that letter recognition and letter naming are tasks of trivial difficulty that do not confound the size recognition task. If this is not the case, as for young children and illiterate adults, other symbols should be used.

Letters are the obvious first choice for adults. Many different letter sets have been used. Since the establishment of the ETDRS protocol, Sloan letters have become the preferred choice. They are designed on the same 5x5 grid on which Snellen designed his letters.

Numbers are the second choice for adults. Even illiterate adults can often recognize numbers. Deaf/non-speaking adults can indicate the number seen with simple finger signs.

PV numbers are designed on a Snellen's 5x5 grid and have been calibrated against Sloan letters.

Tumbling Es can be used for young children. They are the optotype of choice for many studies in the developing world.

Landolt Cs are often used in research studies, but have found limited application in clinical practice in the US. Tumbling Es and Landolt Cs offer four alternative directions; a prerequisite is that the subject can duplicate this direction, which may be a problem for children with a young developmental age.

Children who are too shy to respond verbally, can be asked to match the letter or optotype to one of four flash cards in front of them. For some this is easier than indicating a direction.

HOTV charts also offer only four choices. The four letters H, O, T and V have been chosen because they are R/L symmetrical.

Numerous **picture cards** have been designed. A problem is that not all children are equally familiar with all pictures and that many picture sets have uneven difficulty. Most pictures cannot be designed on a 5x5 grid.

Patti Pics are stylized pictures designed by Precision Vision on the basis of the 5x5 Snellen grid and calibrated for equal recognizability against Sloan letters. Visual acuity readings should not change appreciably when children are advanced from Patti Pics to a regular letter chart.

Precision Vision offers charts with all of the above optotypes: Sloan letters, PV numbers, tumbling E's, Landolt C's, HOTV and Patti Pics.

What display method should be used?
The opaque printed chart is the oldest format. It has the advantage of easy transportability. It is the preferred format in offices where visual acuity is only measured occasionally or for school screenings where the venue often changes. For each setup, care must be taken that the viewing distance conforms to the distance for which the card has been labeled.

Sloan Letters

PV Numbers

Tumbling E

Landolt C’s

HOTV

Patti Pics™

Translucent charts need a special illuminator cabinet. When that cabinet is available, they have the advantage of a standardized light level that is largely independent of the room illumination.

Precision Vision provides a small cabinet that is easily moved from one location to the next and a large cabinet that accommodates the full ETDRS chart format. The large cabinet has a rolling stand to move it to different distances from the patient, but it is less easily moved from office to office.

Projector charts are the choice of most eye care professionals for permanent installation in the office. Since most rooms are smaller than they were in Snellen’s days, the fixed installation usually involves a mirror to increase the viewing distance. Since the projector lenses are adjustable, care must be taken that the letter size on the screen is adjusted for the actual viewing distance (patient to mirror + mirror to screen). Since most examination rooms are only semi-dark, care must also be taken that there is no stray light reaching the screen, since this could seriously reduce the contrast.

In recent years **computer displays** have replaced many projectors. Such displays have several advantages: Optotypes and a wide variety of display modes can be changed with the click of a button on a remote control. The screen is less sensitive to stray light. Presentations can be switched from a fixed letter sequence (easy for the doctor, who knows it by heart) to a random sequence for patients who have been tested quite often. As with projector charts, the letter size on the screen must be coordinated with the actual viewing distance.

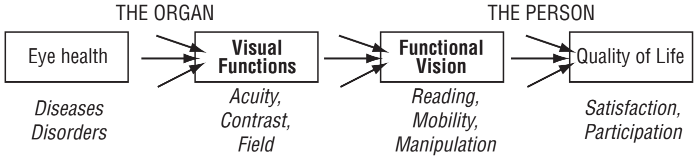
Precision Vision provides the PVVAT™ computer displays with its full range of test characters.

C – Near Vision and Reading

Frequently Asked Questions:
> Visual Functions and Functional Vision
> Why should I use a reading test?
> How can I judge the imaging range of various presbyopia corrections?
> What is the best print size notation for Reading tests?
> What is the best layout for Reading tests?

Visual Functions and Functional Vision

At this point we need to make a distinction between **Visual Functions** and **Functional Vision**. Visual functions refer to how the eye functions; functional vision refers to how the person functions. Visual functions are measured one parameter at a time in an artificial environment; functional vision refers to actual functioning in a real life environment where multiple parameters can change and interact. Although the two aspects are closely related, they should not be confused. Letter chart testing at 20 ft is an artificial task, where we are interested in one parameter: the smallest detail seen. Reading tests are closer to regular activities of daily living (ADL). The following schematic diagram places these concepts in a broader frame work.



The oblique arrows indicate that there is not just a simple cause and effect relationship between the different boxes, but that each link can be influenced by additional factors and interventions. The ultimate goal of all interventions is to optimize not just specific activities, but the ultimate Quality of Life of the subject.

It is important to realize how assessing parameters of visual functions differs from the assessment of visual abilities and functional vision. When assessing parameters of Visual Function, we create an artificial environment where we vary only one parameter at a time. When we vary the letter size on a letter chart, we test visual acuity. When we vary the contrast, we test contrast sensitivity; when we vary the illumination, we test dark adaptation. To test all three parameters, we need to do three different tests. Each test provides us with a threshold value.

When assessing Functional Vision we want an environment that is close to real life. That means that several parameters can vary simultaneously and independently. We also are interested in *sustainable* performance, rather than *threshold* performance. For instance: standard acuity (20/20) allows us to read 1 M letters (average newsprint) at 100 cm; normal visual acuity (20/16) allows us to do that at 125 cm. Yet, most people prefer to read the newspaper at about 40 cm, which is 3x above threshold. This difference between threshold performance and comfortable, sustainable performance is also known as the magnification reserve. The magnitude of the chosen reserve is not the same for all people or for all tasks.

When assessing visual functions, we limit our attention to one strictly visual parameter at a time. When assessing functional vision, on the other hand, we must deal with multiple parameters, including some that are not strictly visual. While visual acuity is an important parameter of reading ability, it certainly is not the only relevant factor. Other visual factors include illumination and contrast. If language skills and letter recognition are not trivially easy, we must resort to pictures, as discussed earlier, and to matching rather than to naming.

When should I use a reading test?

As part of a routine eye exam, near-vision reading tests are primarily used to verify that the prescribed reading correction is appropriate. For this limited goal of checking on an optical correction, almost any test, whether a letter test, a word test or a reading test, can be used.

However, when dealing with patients with low vision (see the next section), the emphasis is not on optics, but on functional performance. Here, accurate measurement of reading performance is important, since it is the basis for the prescription of magnification.

Reading tests involve a much larger retinal area than do letter recognition tests. They thus give us a better assessment of the peri-foveal area. Furthermore, sustainable reading (not just letter recognition) is the function most patients list as their primary objective.

Clinical tip:
Verifying that your prescription, indeed, allows them to read comfortably, will result in more satisfied patients. Remember that presbyopic patients are in an age group that is also at risk for retinal changes.

How can I judge the imaging range of various presbyopia corrections?

Routine reading tests are often performed at 40 cm (16”). However, not all near vision tasks are performed at 40 cm. This is why the array of presbyopia corrections was expanded from bifocals to trifocals to progressive lenses. More recently, the range of accommodation or pseudo-accommodation solutions has been augmented with solutions such as mono vision, multifocal lenses and accommodating IOLs.

To compare these different solutions, it is important to objectively document visual acuity at various distances. Since not all activities of daily living involve high contrast objects, it is also relevant to document the effect on low contrast acuity. Until recently no cards were available to easily document and compare these parameters.

The **Colenbrander Mixed Contrast Card Set** fills that gap. The set has two cards (four surfaces) and allows measurement of both high-contrast and low-contrast (20% Weber, 10% Michelson) acuity at three distances: **40 cm** (16”), **63 cm** (25”) and **100 cm** (40”), which are at 2.5, 1.5 and 1.0 diopter from infinity. These distances were chosen because they are spaced by two line increments on a logarithmic scale. Cords attached to the cards make it easy to maintain the accurate viewing distance for each test. The fourth side provides high and low contrast reading sentences for 40 cm.

Precision Vision produces the Colenbrander Mixed Contrast Card Set, which is also discussed under Mixed Contrast tests.

Multifocal lenses and other presbyopia solutions involve a trade-off between ultimate clarity at one distance vs. reasonable clarity at a variety of distances. These trade-offs may be judged differently by different individuals. This has increased interest into how various interventions affect not just objectively measured visual acuity thresholds, but also the more subjective experience of satisfaction and ultimate quality of life. Assessing the goals and priorities of the patient requires the use of questionnaires, which is beyond the scope of this introduction.

What is the best print size notation for Reading tests?

Reading tests have been used for centuries and have become especially prevalent since Jaeger (1856) and Snellen (1862) each published their print samples.

Variants of Jaeger’s print samples are routinely used in US practice. Jaeger first published his print samples several years before Snellen introduced the concept of visual acuity measurement. To identify his samples Jaeger used the reference numbers of a print catalogue in Vienna in 1856. As others attempted to reproduce Jaeger’s samples with locally available fonts, deviations were bound to occur. This explains the wide variability in current **Jaeger notations** from card to card. Table 2 shows that all current Jaeger samples use larger print than Jaeger’s original and do not even cluster around average values.”

Snellen, on the other hand, recognized the importance of a well-defined standard. His measurement unit, which would later become known as **M-unit**, has a physically defined size that can be reproduced or recalculated anywhere. 1 M-unit subtends 5 min of arc at 1 meter; it measures 1.454 mm or 1/7 cm (error -2%) or almost 1/16 inch (error 10%).

M-units can be applied to the capital letters on letter charts, as well as to the lower case letters in reading samples. They thus allow a comparison between letter acuity and reading acuity.

Note: M-units have a defined value, as do cm or inches. They should not be confused with “em” (as in em-space, em-dash) which defines a typographical unit that varies with the type style and the font size.

Table 2 – Letter Size Measurements on Various Jaeger Cards

Actual Size	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	Actual Size
4M														1	1	2	4M
3.2 M							1					1		2		5	3.2 M
2.5 M						1				2		2	1	4			2.5 M
2 M				1	1		2	1		1	1	7					2 M
1.6 M					2	4	2	1	1	3		1					1.6 M
1.25 M			2	3	4	1	2	4		4							1.25 M
1 M		4	5	3	1	7	6	4									1 M
0.8 M	3	4	4	7	4	3											0.8 M
0.63 M	5	2	8	2	1												0.63 M
0.5 M	5	9	2														0.5 M
0.4 M	4																0.4 M
Range	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11	J12	J13	J14	J15	J16	Range
lines	4	4	5	6	6	6	6	4	2	4	2	4	2	3	2	2	lines
ratio	2x	2x	2.5x	3x	3x	3x	3x	2x	1.25x	2x	1.25x	2x	1.25x	1.5x	1.25x	1.25x	ratio

Table 2 lists the Jaeger numbers that were found when print sizes were measured on 20 current cards. The black cells refer to Jaeger's original print sizes, rounded to the nearest M-unit size on a logarithmic scale. The vertical gray columns indicate how often various letter sizes were found with the same J-designation. It shows that the print sizes labeled as J5, J6, J7 and J8 each varied over a 3x range. 1 M print (average newsprint) was labeled as J2 on four of the 20 cards and as J8 on four others. It is clear that this makes J-numbers unfit to serve as a reference standard.

Sometimes print samples are identified with **printer's points** (N-notation in Britain). This notation originally referred to the slugs on which fonts were mounted. Most people are familiar with this notation, since it is used on computers. Since the relation of letter size to slug size is not constant, the point notation may vary from type font to type font. Computer users may have noticed that 10 pt Arial is about as large as 12 pt Times Roman. As an approximation 8 pt Arial, Verdana or Courier equals about 1 M-unit (average newsprint).

Examples of 20 pt print

abc	abc	abc	abc
Gautami	Times	Arial	Verdana

Furthermore, point notation is not applicable to letter charts and to distance acuity.

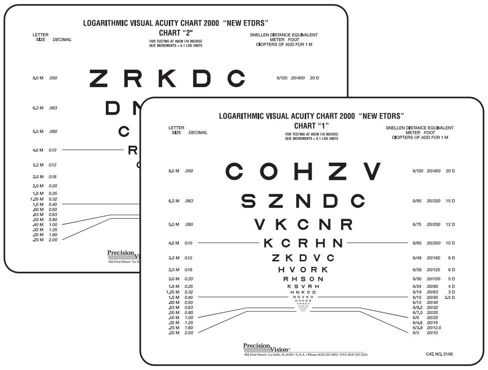
In summary, Jaeger numbers and printer's points do not allow the calculation of a near-vision acuity value, since they do not have a defined numerical value and do not fit into Snellen's acuity formula. The only notation that is standardized, that can be used in calculations and is applicable to distance charts and reading material alike, is the **M-unit** notation, as defined by Snellen. How to use the Modified Snellen Formula to calculate reading acuity using M-units will be discussed in the Low Vision section.

All Precision Vision reading cards carry M-unit notation, as used by Snellen.

What is the best layout for Near-vision tests?

Near vision **letter tests** are appropriate when vision is limited only by optical factors, such as insufficient refractive correction or by opacities. In these cases, retinal function is assumed to be normal and the blur of the area onto which each letter is projected predicts equal blur for surrounding retinal areas.

An increasingly important group of patients are those with retinal disorders, such as AMD. Here, the media are often normal and vision is limited by the retinal condition. Since the condition of the retinal area onto which a letter is projected cannot predict the condition of the surrounding retina, tests that involve a larger retinal area are desirable. For this purpose **reading** tests are better suited than letter tests.



LOGARITHMIC VISUAL ACUITY CHART 2000 "NEW ETDRS"
CHART "1"
FOR TESTING AT 40CM (16 INCHES)
SIZE INCREMENTS = 0.1 LOG UNITS

LETTER SIZE	DECIMAL		SNELLEN DISTANCE EQUIVALENT METER	FOOT	DIOPTERS OF ADD FOR 1 M
8,0 M	.050	C O H Z V	6/120	20/400	20 D
6,3 M	.063	S Z N D C	6/95	20/320	15 D
5,0 M	.080	V K C N R	6/75	20/250	12 D
4,0 M	0.10	K C R H N	6/60	20/200	10 D
3,2 M	0.12	Z K D V C	6/48	20/160	8 D
2,5 M	0.16	H V O R K	6/38	20/125	6 D
2,0 M	0.20	R H S O N	6/30	20/100	5 D
1,6 M	0.25	K S V R H	6/24	20/80	4 D
1,25 M	0.32	H N K C D	6/19	20/63	3 D
1,0 M	0.40	N D V K O	6/15	20/50	2,5 D
,80 M	0.50	D H O S Z	6/12	20/40	
,63 M	0.63		6/9,5	20/32	
,50 M	0.80		6/7,5	20/25	
,40 M	1.00		6/6	20/20	
,32 M	1.25		6/4,8	20/16	
,25 M	1.60		6/3,8	20/12.5	
,20 M	2.00		6/3	20/10	

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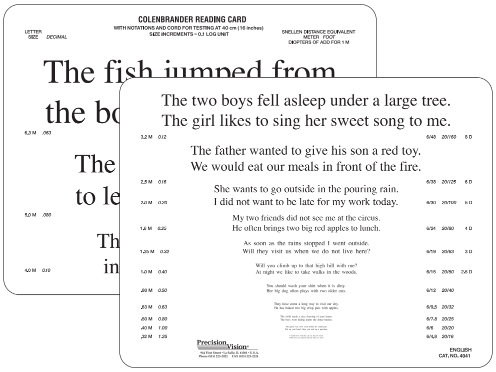
CAT. NO. 2106

Near LETTER card



COLENBRANDER READING CARD
WITH NOTATIONS AND CORD FOR TESTING AT 40 cm (16 inches)
SIZE INCREMENTS = 0.1 LOG UNIT
SNELLEN DISTANCE EQUIVALENT
METER FOOT
DIOPTERS OF ADD FOR 1 M

The two boys fell asleep under a large tree.
The girl likes to sing her sweet song to me.
3.2 M 0.12 — 6/48 20/160 8 D

The father wanted to give his son a red toy.
We would eat our meals in front of the fire.
2.5 M 0.16 — 6/38 20/125 6 D

She wants to go outside in the pouring rain.
I did not want to be late for my work today.
2.0 M 0.20 — 6/30 20/100 5 D

My two friends did not see me at the circus.
He often brings two big red apples to lunch.
1.6 M 0.25 — 6/24 20/80 4 D

As soon as the rains stopped I went outside.
Will they visit us when we do not live here?
1.25 M 0.32 — 6/19 20/63 3 D

Will you climb up to that high hill with me?
At night we like to take walks in the woods.
1.0 M 0.40 — 6/15 20/50 2.5 D

You should wash your shirt when it is dirty.
Her big dog often plays with two older cats.
.80 M 0.50 — 6/12 20/40

They have come a long way to visit our city.
He has baked two big crisp pies with apples.
.63 M 0.63 — 6/9.5 20/32

The child made a nice drawing of your house.
The boys were hiding under the dense bushes.
.50 M 0.80 — 6/7.5 20/25

.40 M 1.00 — 6/6 20/20

.32 M 1.25 — 6/4.8 20/16

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ENGLISH
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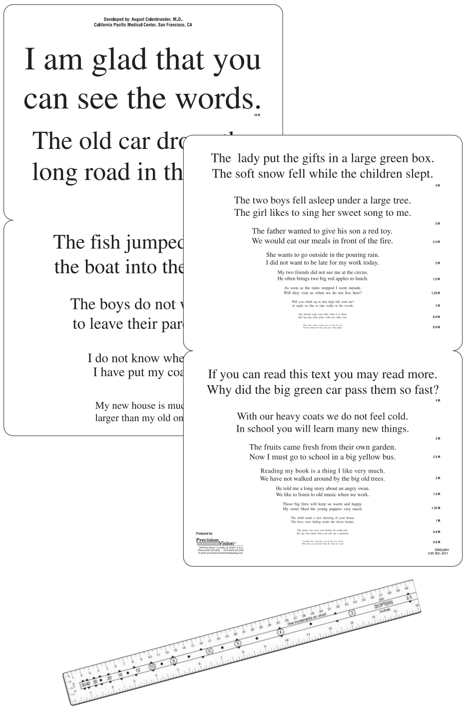
Near READING card with cord for 40 cm



Developed by: August Colenbrander, M.D.,
California Pacific Medical Center, San Francisco, CA

I am glad that you
can see the words.
10 M

The lady put the gifts in a large green box.
The soft snow fell while the children slept.
4 M

The two boys fell asleep under a large tree.
The girl likes to sing her sweet song to me.
3 M

The father wanted to give his son a red toy.
We would eat our meals in front of the fire.
2.5 M

She wants to go outside in the pouring rain.
I did not want to be late for my work today.
2 M

My two friends did not see me at the circus.
He often brings two big red apples to lunch.
1.5 M

As soon as the rains stopped I went outside.
Will they visit us when we do not live here?
1.25 M

Will you climb up to that high hill with me?
At night we like to take walks in the woods.
1 M

You should wash your shirt when it is dirty.
Her big dog often plays with two older cats.
0.8 M

They have come a long way to visit our city.
He has baked two big crisp pies with apples.
0.6 M

If you can read this text you may read more.
Why did the big green car pass them so fast?
4 M

With our heavy coats we do not feel cold.
In school you will learn many new things.
3 M

The fruits came fresh from their own garden.
Now I must go to school in a big yellow bus.
2.5 M

Reading my book is a thing I like very much.
We have not walked around by the big old trees.
2 M

He told me a long story about an angry swan.
We like to listen to old music when we work.
1.5 M

Those big fires will keep us warm and happy.
My sister liked the young puppies very much.
1.25 M

The child made a nice drawing of your house.
The boys were hiding under the dense bushes.
1 M

The game was over even before he could join.
Put up your hand when you ask me a question.
0.8 M

0.6 M

Produced by:
Precision Vision™
ENGLISH
CAT. NO. 4011

Large reading card with ruler for use at any distance

Tests with standardized sentences are preferred, because they allow better evaluation of reading speeds.

Precision vision offers near-vision LETTER charts for use with patients whose retinal function is assumed to be normal.

Precision vision also offers near-vision READING cards for a more comprehensive assessment of reading performance.

These cards are available with standardized sentences in English, Spanish, Portuguese, French, German, Italian, Dutch, Swedish and Finnish

Precision Vision offers the Colenbrander Mixed Contrast Card Set for the assessment of presbyopia corrections at various distances for both high contrast and low contrast.

Calculation of a visual acuity value requires consideration of both print size and reading distance. Note that the visual acuity labels on reading cards are valid only if the card is used at the distance for which it was designed.

Most of the Precision Vision near-vision tests have a cord attached to easily maintain the desired reading distance.

What other near-vision tests are available?
The high-contrast only near vision tests, offer a way to test for optical problems.

In addition, the **Mixed Contrast tests** offer a way to screen for contrast deficits with very little additional effort. These tests are discussed in the section on Contrast Sensitivity.

Special tests with much larger fonts are available for **Low Vision** patients, who may need a shorter reading distance than the traditional 40 cm.

D – Contrast Sensitivity

Frequently Asked Questions:

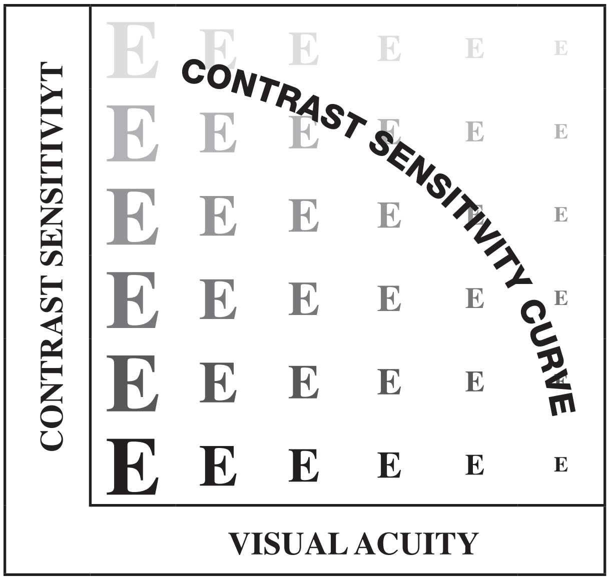
> What is contrast sensitivity, why is it important?
> What is the Contrast Sensitivity Curve?
> What are the Colenbrander Mixed Contrast cards?

What is contrast sensitivity, why is it important?
Visual acuity measures the ability to recognize small objects with high contrast. Often however, the visibility of objects in our environment is limited more by lack of contrast than by their small size. Consider the pedestrian who misses a curb or step, or the driver who did not detect a pedestrian on a dark road. In many surveys, contrast sensitivity is the visual parameter that is most closely related to problems experienced in activities of daily living (ADL).

Like visual acuity, contrast sensitivity loss is not disease specific. Like visual acuity, it can be affected by **optical problems** (refractive error, opacities) that prevent the projection of an adequate image on the retina. It can also be affected by disorders of the **outer retina** (such as macular degeneration), which prevent part of the image from being detected. Several longitudinal studies suggest that it is a good predictor of acuity loss in the next five years. Finally, contrast sensitivity loss can be caused by **neural problems** that interfere with adequate processing of the visual information. Neural problems might occur in the inner retina (glaucoma), the optic nerve (optic neuritis), or in the brain and visual cortex.

Regardless of the cause, the **consequences** of contrast sensitivity loss are significant, since many Activities of Daily Living (ADL) involve objects of less than optimal contrast. Patients with contrast problems often notice that something is wrong, but they cannot pinpoint it. They become frustrated patients when told not to worry because their high-contrast visual acuity is normal. A simple contrast test could have identified the problem. Once warned, the patient can take preventive action, such as avoiding night driving and other low-contrast situations. Warning the patient about steps and curbs may avoid a fall and thus a broken hip. Providing better contrast and better illumination in the home can also improve many tasks.

What is the Contrast Sensitivity Curve?
The relationship between visual acuity and contrast sensitivity (CS) can be depicted on a plot with visual acuity along the X-axis and contrast along the Y-axis.



On this plot, the Contrast Sensitivity Curve defines the limits of visibility. Points under the curve (large size, high contrast) can be seen; points beyond the curve (small size, low contrast) cannot be seen.

For letter recognition the top of the curve is practically flat. It is known as PEAK Contrast Sensitivity. It must be measured with rather large letters to be certain to be on the flat part of the curve.
The bottom of the curve indicates the familiar high-contrast letter chart acuity. The lower part of the curve is practically vertical. Improving contrast from around 50% Weber (33% Michelson) to 100% usually has very little effect on visual acuity.

Measuring visual acuity at lower contrast levels yields increasingly lower visual acuity values.

The next diagram depicts various ways of determining points on the CS curve.

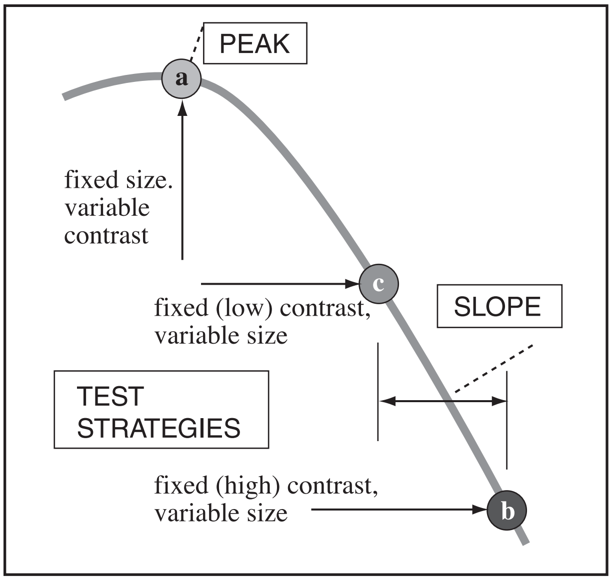
To determine point **“a”**, the PEAK of the CS curve, we use large letters of variable contrast. This can be done on a 1-meter wall chart, the well known Pelli-Robson chart (used in many research studies), or more easily on a handheld chart, the more recent Mars card.

Both charts are available through Precision Vision.

Point **"b"** represents high-contrast letter chart acuity.

To determine point **"c"**, low-contrast letter charts are used.

Precision Vision offers ETDRS charts and other charts at at contrast levels of 1.25%, 2.5%, 5%, 10%, 20% and 40% Weber (0.6%, 1.25%, 2.5%, 5%, 10%, 25% Michelson).



When "b" and "c" are known, the difference defines the SLOPE of the CS curve. When the low-contrast level is set at 20% Weber (11% Michelson), a normal difference will be 1 or 2 lines. This difference is often independent of the visual acuity level. Greater differences point to a contrast deficit. In AMD patients differences of up to 10 lines have been found between high-contrast and low-contrast acuity.

Point **"c"** could also be determined by offering small letters of varying contrast (along a vertical line in the diagram, not shown). Since point "c" is on the slope and not on the plateau of the CS curve, it is sensitive to variations in visual acuity as well as to changes in contrast. If point "c" is on a steep part of the CS curve, a small change in visual acuity (X-axis) will be equivalent to a large change in contrast (Y-axis). Thus, the test may be particularly sensitive to follow subtle acuity changes after refractive surgery. It is not a good test to determine peak CS. Such a chart is known as the Small Letter Contrast Sensitivity test developed by Rabin.

Precision Vision offers the Rabin small letter contrast sensitivity test for both the small and the large illuminator cabinet.

Others have advocated the use of sine-wave gratings, rather than letters. Sine-wave tests are preferred for lens quality calculations, but may not appear as relevant to the patient as do letter tests. Letter tests may also be faster to administer with higher test and re-test repeatability.

What are the Colenbrander Mixed Contrast cards?
The diagnostic implications of contrast sensitivity losses are not well understood. One of the reasons is that contrast tests are rarely included in a routine eye exam, because they involve doing two tests and comparing the results. This means that little clinical experience is available, which in turn does not stimulate testing.

The Mixed Contrast cards were developed to remedy this situation. Because the high and low contrast text or symbols are printed side by side, only one card is needed. Because the cards are handheld, no repositioning of the patient (as with a wall chart) is needed. The high contrast part of the test replaces a high-contrast-only test, so the extra time needed is only the time for the patient to look at the low contrast part. Since the two contrast levels are side by side, the illumination and the viewing distance are always the same. The test has a strong demonstration value both for the patient and for family members. If increased illumination improves performance, a strong case has been made for improved illumination at home or at work. It is hoped that this will encourage more clinicians to include contrast tests in their routines, so that more clinical experience can be gained.

Precision Vision offers the Colenbrander Mixed Contrast Card Set for use with presbyopia corrections and the Colenbrander Mixed Contrast Reading cards for use in retinal disorders.

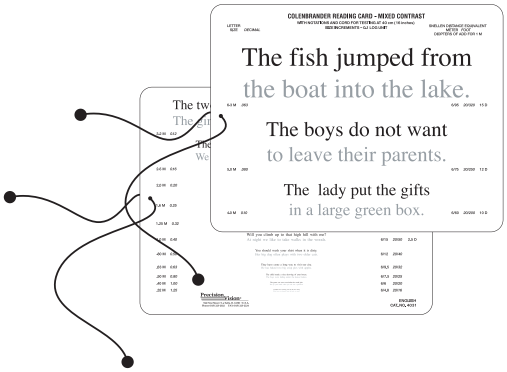
The Mixed Contrast layout is available in several versions. For routine use, the **small Mixed Contrast reading card** is recommended. It is especially recommended for the elderly, where it may help to detect early AMD changes, where contrast losses may be found before visual acuitiy losses are evident. It has a cord for the fixed 40 cm reading distance. The appropriate visual acuity values for that distance are listed on the card. Use of a reading card is recommended over use of a letter chart, since reading involves a larger retinal area than does single letter recognition.

To document the effectiveness of various presbyopia corrections, the **Mixed Contrast card set** is recommended. It is used to compare high- and low contrast acuity at 40 cm, 63 cm and 100 cm. Cords are attached for the various distances. Since this is an optical problem in patients with a normal retina, the use of letter cards is acceptable. No other simple standardized test is available for this purpose. The set can be used to compare simple solutions, such as bifocal, trifocal or progressive lenses or monovision. It can also be used for various multifocal or accommodating lenses.

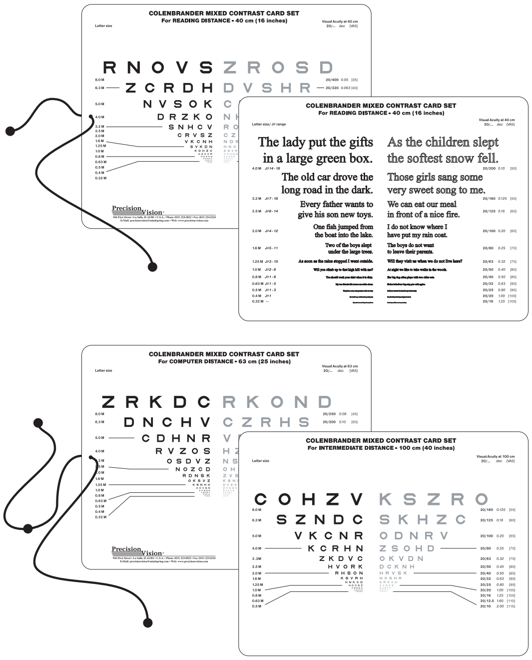
The **large Mixed Contrast reading card** is meant for use with low vision patients, especially those with AMD. It has a wider measurement range than the small card and can be used at any distance, using the included ruler and the modified Snellen formula as discussed in the low vision section.

Also available is a full size **Mixed Contrast letter chart** for the large illuminator cabinet. This chart has acuity scales for 1 m and 2.5 m. For more portable use a **Mixed Contrast flip chart** is available with a similar layout and conversion tables for use from 15 cm to 6 m.

For young children, Mixed Contrast cards are available with **Patti Pics** and other symbols. There also is a reading card for **Beginning Readers.**



Small Mixed Contrast reading card



Mixed contrast card set

Large Mixed Contrast reading card

Contrast Measurement Scales

The contrast on a chart can be labeled in different ways.

"Contrast" identifies the difference between the brightest and the dimmest parts of the target.

"Contrast Sensitivity" (CS) identifies the sensitivity of the visual system. It is the reciprocal of the threshold contrast. Compare: visual acuity is the reciprocal of the threshold magnification requirement.

"Log(CS)" converts the CS values to a linear scale, suitable for comparisons between levels of contrast sensitivity. Compare: MAgnification Requirement (MAR) and logMAR.

When contrast measurements are always done with the same test, it is not important to know how the initial contrast value is calculated. However, when contrast values need to be compared between different tests or with literature data, it is important to know that there are two contrast notations: **Michelson contrast** and **Weber contrast**, with markedly different scales.

Early CS tests considered mainly optical factors and used sine wave gratings, since this is the preferred target for measurements of optical lens quality. The contrast of such repetitive patterns is expressed with Michelson's formula: brightness amplitude / average brightness. Grating tests (sine waves or square waves) always use Michelson contrast. Based on this tradition, early low-contrast charts also adopted this notation, and until recently, Precision Vision charts were also labeled with Michelson contrast.

When Pelli and Robson introduced the Pelli-Robson chart, which uses letters rather than gratings, they chose to use Weber's formula, because it is more appropriate for non-repetitive patterns. Weber's formula calculates: brightness difference / background brightness. Weber contrast is also used for the Mars chart.

Since the Pelli-Robson charts have become the de-facto standard for contrast measurements to which other measurements may be compared, it is appropriate to follow their lead and change from Michelson to Weber notation.

On both scales 0% indicates the absence of contrast and 100% indicates the theoretical maximal contrast. For values in between, however, the two scales differ. In the range from 1% to 10% Michelson, which is the range most used for clinical measurements, the Weber contrast values are about twice the Michelson values, and the log(CS) values differ by 0.3, as indicated in the following table.

Michelson contrast	0.6%	1.25%	2.5%	5%	10%	25%	*Used for gratings*
Weber contrast	1.25%	2.5%	5%	10%	20%	40%	*Used for letters*
Log(CS) *Michelson*	2.2	1.9	1.6	1.3	1.0	0.6	*Used for gratings*
log(CS) *Weber*	1.9	1.6	1.3	1.0	0.7	0.4	*Used for letters*

Precision Vision Low Contrast charts sold in 2007 and before, are labeled with Michelson contrast.

Starting in 2008 all Precision Vision Low Contrast charts will be labeled with both the Michelson and Weber notation.

E – Low Vision Tests

Frequently Asked Questions:

> What is Low Vision?
> How do we categorize Low Vision?
> How do we measure letter chart acuity for low vision patients?
> How do we measure reading acuity for low vision patients?
> How do I use the Modified Snellen Formula for reading tests?

What is Low Vision?

Low vision is not a single condition. When we say that individuals have "Low Vision", the word low indicates that their vision is lower than normal, while the word vision indicates that they are not blind. Vision loss is a continuum, not a black-or-white condition. Unfortunately, the widespread use of the term "legal blindness" has promoted black-or-white thinking and thus the thought that people who cannot make out the big E on the letter chart are as bad off as if they had no vision at all and that "nothing can be done" about it. This common misperception has severely hampered the acceptance of vision rehabilitation. Whatever their level of remaining vision, individuals with low vision can be helped to make maximal use of their remaining vision and thus to improve their quality of life and participation in society through vision rehabilitation.

How do we categorize Low Vision?

Individuals with low vision vary significantly in their capabilities. No single statement can cover all conditions. On a continuum all sharp cut-offs are arbitrary. It may help however to place some markers as points of reference.

The first columns of Table 3 indicate broad ranges recognized in ICD-9-CM, by the WHO and by the International Council of Ophthalmology.

The next columns indicate visual acuity ranges, expressed as equivalent values which were also given in Table 1.

The next block translates the visual acuity measurements (how well the EYE functions) to estimates of performance (how well the PERSON functions). To make this transition we must convert the geometric progression of visual acuity measures to a linear scale, as discussed in the first section. This conversion is consistent with Weber-Fechner's law, which states that proportional increases in the stimulus result in a linear increases in the sensation.

Thus, we progress from the MAgnification Requirement (MAR = 1/VA) to logMAR ($\text{logMAR} = \log_{10}(\text{MAR})$) to the Visual Acuity Score (VAS = 100 – 50 x logMAR).

The last block shows that these scales correspond reasonably well with actual performance. Reading performance was chosen, because it is the activity that most patients list as their goal and since it is most dependent on visual acuity. The first column in this block indicates the distance at which 1M print (average newsprint) should be readable for the measured acuity. The last column describes actual reading performance.

It should be realized that these ranges reflect statistical estimates and that individual performance may be better or worse than the estimate. Also, vision loss is a continuous variable. The dividing lines in the table provide useful reference points along the way; they do not indicate stepwise increments in ability.

The **Range of normal vision** covers 20/12.5 to 20/25. Note that the visual acuity scale is not truncated at 20/20. 20/20 is a reference standard; it is not perfect vision. Snellen chose this standard so that all healthy young adults exceed it. This range allows reading of newsprint (1 M) at 80 to 160 cm. Since normal reading is at about 40 cm, there is a very comfortable reserve.

Part of this reserve is needed to bridge the gap between letter chart acuity, which measures threshold performance and actual reading, which requires supra-threshold, sustainable performance.

The next range of **Mild vision loss** allows reading of newsprint at 32 to 63 cm (13 to 25"). This means that the comfortable reserve is gone, but that the average performance is not seriously compromised.

Moderate vision loss is said to exist when visual acuity drops below 20/63. This is the level where the WHO classifies persons as having "low vision". The reading distance for 1 M print drops below 25 cm (10"); note that this also is the reference point for the strength of magnifiers.

With strong reading glasses or low power magnifiers, most tasks can still be performed without significant restrictions. Large print books are appreciated.

At 20/200 we enter the range of **Severe vision loss.** In the US individuals at this level are eligible for "legal blindness" benefits. They need stronger magnifiers with a more restricted field of view and perform slower. At a reading distance of less than 10 cm (4") binocular viewing is no longer possible. Viewing with a magnifier must be monocular, but with a videomagnifier the larger image allows a longer viewing distance, so that the image can still be viewed binocularly. Vision substitution (use of senses other than vision) may be helpful. For recreational reading some may prefer talking books.

Below 20/400 we speak of **Profound vision loss**; the WHO and many European countries consider this level (<3/60) as "legal blindness". In this range, vision is still useful for orientation, but reading becomes marginal. There is a shift towards more use of vision substitution skills.

The range below 20/1000 is recognized as **Near-blindness** in ICD-9-CM. In this range vision substitution is dominant, although remaining vision may still be used as an adjunct.

Table 3 – Visual Acuity and Reading Performance

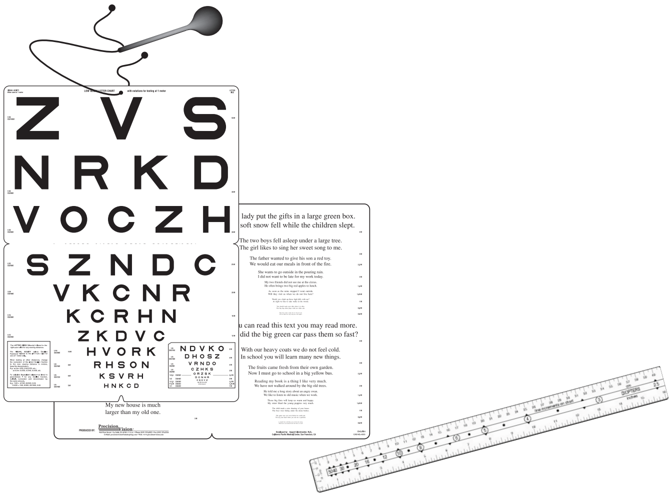
RANGES (ICD-9-CM)		EQUIVALENTS (value = 1/ MAR)			PERFORMANCE SCALES			READING PERFORMANCE	
					Geom.	Linear		1M at … cm	*(statistical estimates, individuals may vary)*
		6/…	Dec.	20/…	MAR	logMAR	VAS		
(Near-) Normal Vision	Range of Normal Vision	6/3.8	1.6	20/12.5	0.63	–0.2	110	160	Since average newsprint is generally read at around 40 cm, this range has an ample reserve.
		6/4.8	1.25	20/16	0.8	–0.1	105	125	
		6/6	**1.0**	**20/20**	**1.0**	**0**	**100**	**100**	
		6/7.5	0.8	20/25	1.25	+0.1	95	80	
	Mild Vision Loss	6/9.5	0.63	20/32	1.6	0.2	90	63	Individuals in this range have lost their reserve, but have no or only minimal vision rehabilitation needs
		6/12	0.5	20/40	2.0	0.3	85	50	
		6/15	0.4	20/50	2.5	0.4	80	40	
		6/19	0.32	20/63	3.2	0.5	75	32	
Low Vision	Moderate Vision Loss	6/24	0.25	20/80	4	0.6	70	25	Reading at 25...12.5 cm (10"...5") requires strong reading glasses or low power magnifiers.
		6/30	0.20	20/100	5	0.7	65	20	
		6/38	0.16	20/125	6.3	0.8	60	16	
		6/48	0.125	20/160	8	0.9	55	12.5	
	Severe Vision Loss	**6/60**	**0.10**	**20/200**	**10**	**+1.0**	**50**	**10**	Strong magnifiers (small field) reduce reading speed. May prefer talking books for prolonged reading.
		6/75	0.08	20/250	12.5	1.1	45	8.0	
		6/95	0.063	20/320	16	1.2	40	6.3	
		6/120	0.05	20/400	20	1.3	35	5.0	
	Profound Vision Loss	6/150	0.04	20/500	25	1.4	30	4.0	Visual reading becomes marginal. Shift to vision substitution aids. Vision still useful for orientation.
		6/190	0.03	20/630	32	1.5	25	3.0	
		6/240	0.025	20/800	40	1.6	20	2.5	
		6/300	0.02	20/1000	50	1.7	15	2.0	
(Near-) Blindness	**Near-Blindness**	6/380	0.016	20/1250	63	1.8	10	1.6	These groups must rely entirely on vision substitution skills. Any residual vision is at best an adjunct to the use of blind skills.
		6/480	0.0125	20/1600	80	1.9	5	1.25	
		6/600	**0.01**	**20/2000**	**100**	**+2.0**	**0**	**1.0**	
		---	---	---	---	---	---	---	
	Blindness	**No Light Perception (NLP)**							

Note: This table describes average adult performance. It does not apply directly to children. For instance: where adults use magnifiers, young children may use their strong accommodative power to observe objects up close.

How do we measure letter chart acuity for low vision patients?

Letter chart acuity represents only one aspect of vision. Yet it is important, (a) because it is so widely used, and (b) because it provides a direct measure of the MAgnification Requirement (MAR = 1/V) of the patient. Traditional letter charts were primarily designed for the normal and near-normal range. At the 20/100 level most have only two letters. Snellen knew this and recommended to use a reduced testing distance for lower visual acuity levels. The ETDRS charts extend measurement to 20/200, but this still does not address the ranges of severe and profound vision loss in Table 3.

The Colenbrander 1-m chart addresses this problem. The chart is designed for use at 1 meter and thus has a six times wider measurement range than charts designed for 6 meters (20 ft). The chart comes with a 1 m cord and occluder attached, so that the 1 m testing distance can be accurately maintained. Letter sizes range from 1 M to 50 M, so that visual acuities from 1/1 (20/20) to 1/50 (20/1000) can be measured accurately. The layout follows the ETDRS layout with five Sloan letters per line (except for the two largest lines). The chart folds for easy transportation in an attaché case or for storage in a desk drawer. The back of the chart has the same reading segments as the large, Low Vision reading card and comes with a ruler, so that it can be used at any distance.



Precision vision also has variants with Patti Pics and with PV numbers.

With this chart the use of vague guesstimates, such as "count fingers" or "hand motions" can be a thing of the past. Its use is not limited to vision rehabilitation settings, but is indicated for any clinician who wants to accurately follow the progress of patients with visual acuity of 20/100 or worse.

Testing at 1 meter has an important psychological effect for patients who previously "could not see anything" on a traditional letter chart and now realize that their vision may be limited, but that they are not blind.

Clinical tip:

When testing for ***optical problems*** *(refractive error, opacities) there usually is a fairly sharp cut-off from lines that are read to lines that are not recognized. Thus it is acceptable to test only the lines around that cut-off value.*

When testing for ***retinal problems*** *(like AMD), on the other hand, the topography of the vision loss is important. Additional information can be gained by having the patient read the entire chart. Patients who miss the first (last) letters on several lines, may have a scotoma to the left (right) of fixation. Patients who read the first large lines slowly and then speed up may have a small remaining island that is not large enough for the largest letters.*

Do not point to letters or isolate letters. We are more interested in how well patients can perform with their own fixation ability, than in the smallest detail they can see in an isolated symbol.

How do we measure reading acuity for low vision patients?

Reading is the most important ability persons with visual complaints want to regain. Reading performance has two aspects. The first is the visual function aspect (how the EYE functions); the second is the functional vision aspect (how the PERSON functions).

Under the visual function aspect we are primarily interested in reading acuity – what is the smallest print that can be read at a given distance. We may also consider reading speed.

Under the functional vision aspect, we are interested in other aspects, such as reading fluency, reading endurance and reading comprehension. The latter aspects are rarely considered in a routine eye exam, but are very important in the context of vision rehabilitation, where specific training regimens have been developed to help patients with low vision regain their reading skills.

If the focus is only on strictly optical problems (as for presbyopia), the use of near-vision letter charts is appropriate. For a more comprehensive evaluation of patients who may also have retinal problems (as in AMD), reading tests are more appropriate, because reading fluency involves a larger retinal area than does letter recognition, in part because of the need to recognize whole words, in part because of the need to guide scanning eye movements to the next word.

Reading tests come in various formats.

A **continuing story** is most useful for testing reading speed and reading endurance. However, reading a continuing story is considered too time-consuming for use in the average office. It may be part of a homework assignment in vision rehabilitation training. The availability of contextual cues lowers the error rate.

Unrelated sentences offer contextual cues within each sentence, but not from line to line. Traditional cards often have short sentences with large print and longer sentences with smaller print. This makes it difficult to compare reading speeds. Cards with standardized sentences with a fixed number of spaces and characters are preferred.

Precision Vision offers the Colenbrander reading cards with standardized unrelated sentences in many languages.

Unrelated words offer no contextual cues at all. However, the total absence of such cues disrupts the usual reading pattern. Such cards are best suited for conditions where reading is done word-by-word anyhow, such as for low vision patients who require high magnification. The absence of contextual cues also increases the error rate. This feature can be useful to get an idea about the presence of scotomata around the point of fixation. The SKread cards were developed especially for this purpose.

Clinical tip:

Remember that the goal of a reading test is to find a magnification level that will allow a sustainable reading performance. For this purpose the concept of critical print size is important. The critical print size is the smallest print size for which a reasonable reading speed can be maintained; this is one or more lines larger than the threshold print size. Best performance will be obtained if normal print is magnified to the ***critical print size****, not just to the threshold print size as suggested by Kestenbaum's rule.*

The standardized sentences on the Colenbrander reading cards allow the assessment of reading speed and critical print size.

How do I use the Modified Snellen Formula for reading tests?

The statement is sometimes heard that near visual acuity and distance visual acuity are poorly related. This is a misconception, largely based on inaccurate measurement. Traditionally, US practitioners have used Jaeger numbers, which, as we have seen, are only labels, without a numeric value. Additionally, measuring reading distances in inches (non-metric) and reading corrections in diopters (a metric measure) does not facilitate calculations.

When reading acuity is measured accurately, reading acuity and letter chart acuity are closely related. However, two factors have to be considered. (1) reading comfort and endurance generally require several lines more magnification than does threshold performance on a letter chart. (2) For patients with normal or near-normal vision a standard reading distance can be used, but for low vision patients a shorter reading distance with a stronger reading add is often needed.

Cards for a standard reading distance can have a cord (usually 40 cm) attached and have visual acuity values for that distance listed on the card. For use at different distances (as for low vision) the actual viewing distance must be measured and the visual acuity value must be calculated, using that distance.

Snellen expressed the relation between letter size, viewing distance and visual acuity in the familiar Snellen fraction

$$V = m / M$$

(in which V = visual acuity, m = viewing distance in meters and M = letter size in M-units).

This traditional Snellen notation is convenient for distance tests, where m is a whole number. The formula is awkward for near vision, since the numerator (m) becomes a fraction-within-a-fraction. This can be avoided by inverting the formula and substituting D = diopters for the reciprocal of the metric viewing distance.

$$\mathbf{1/V} = M / m = M \times 1/m = \mathbf{MxD} \quad \text{or:} \quad \mathbf{V} = 1 / \mathbf{MxD}$$

(where D = viewing distance in Diopters = 1/ viewing distance in meters).

(D can be measured directly with the ruler provided with the large reading card)

This modified Snellen formula is convenient for reading vision, since a multiplication is much easier to calculate than a fraction and also because all components have direct clinical value: **1/V** indicates the **MA**gnification **R**equirement (see definition of visual acuity) and **M-units** indicate the print size read. The viewing distance measured in **diopters** relates directly to the required reading add (or accommodation in younger people). The formula does not require a pre-defined or standardized viewing distance.

Precision Vision offers small reading cards with a 40 cm cord attached. These cards require no calculations, since the visual acuity values for use at 40 cm (16") are printed on the card. They are appropriate for the vast majority of patients who have normal or near normal visual acuity and for whom a "one size fits all" reading distance is adequate.

Precision Vision also offers a large reading card for use in Low Vision services, where other reading distances may be needed. That card can be used at any distance; a ruler calibrated in diopters is supplied to facilitate the use of the modified Snellen formula.

F – Pediatric & Fixation Tests

Frequently Asked Questions:
> What symbols should be used?
> What is the effect of “crowding”?
> What is the preferred distance?
> Behavioral tests (Preferential Looking)

What symbols should be used?

Recognition of **letters** and **numbers** is not trivially easy for young children. Using these symbols may underestimate their acuity by measuring a combination of acuity and cognitive development.

A simplified chart with only the letters **H, O, T** and **V** may overcome this problem. These letters were chosen because they are symmetrical, so they will not pose a problem for young children who still have problems with Right/Left laterality. If children cannot name the letter, they may be given large flash cards to which they may match them.

Another solution is the use of **directional symbols**, such as **tumbling E’s** and **Landolt C’s**. Here the child does not need to name the symbol, but merely indicates its direction. These symbols have a different problem, however, in that some children with a cognitive delay may see the symbol, but may have difficulty copying the direction.

Pictures are a third option. Many picture cards exist. The problem with most charts is that not all children are equally familiar with all pictures and may have had varying practice at home with naming pictures. Some older cards use items, such as an old rotary phone, that may not be familiar to today’s youth.

Precision Vision has developed the **Patti Pics** symbols. This is a series of five stylized pictures, designed on Snellen’s 5x5 grid and calibrated for equal recognizability with Sloan letters. For children that are shy in naming the symbols, matching to flash cards can again be used.

Sloan Letters

PV Numbers™

HOTV


Tumbling ”E”


Landolt ”C”

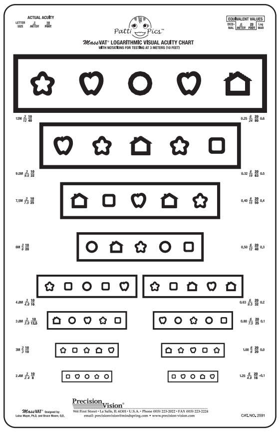

Patti Pics™

What is the effect of “crowding”?
The legibility of letters can be affected by “contour interaction” or “crowding” when letters are too close together. Thus, recognition of single letters or of widely spaced letters is an easier task than recognition of closely spaced letters and will therefore result in a better visual acuity. To standardize this effect, the ETDRS format uses

proportional spacing. The horizontal spacing is equal to the letter width on the line; the vertical spacing is equal to the letter height of the line below.

Sensitivity to crowding is especially pronounced in children with amblyopia or recovering from amblyopia. Here a dilemma exists. Getting the attention of young children on a specific symbol on a crowded chart is often difficult; testing them with single symbols may overestimate their actual acuity and miss low grade amblyopia.

To overcome this difference, characters that are presented singly, are often surrounded by "crowding bars" to simulate the effect of adjacent letters on a chart.



The **MassVAT®** format extends this principle to a line of characters. Each line of symbols is presented within a rectangular frame to simulate the contour interaction of adjacent lines.

Precision Vision offers charts with various optotypes using the MassVAT® format to isolate a letter or a line at a time.

What is the preferred distance?

Since it is difficult to keep a child's attention on a chart at 20 ft (6 m), children are often tested at 10 ft (3 m).

Shorter distances can be used also. At shorter distances exact visual acuity measurement is often unreliable. However, often the most important piece of information is whether there is a difference between the eyes, since this could point to amblyopia or to a monocular disorder. Detecting such a difference is often possible even in infants by observing their reaction to occlusion of one eye or the other. For a more quantifiable observation one may present stimuli with varying detail or contrast.

For children who cannot see the largest symbol at 10 ft (3m), the chart may have to be brought even closer. To get an accurate impression of the visual acuity threshold, the chart should be close enough so that the child can identify some of the symbols. When a child cannot name any symbols, it might be that the symbols are not large enough; it might also be that there is a cognitive problem.

When an exact numerical acuity value is desired at a distance not listed on the chart, some conversion is needed. This can be tricky, since the 20/… notation is based on feet and visual acuity calculations are based on metric measurements. The best way to do this conversion is in two steps. First, convert the Snellen fraction to a 1/… fraction; then convert this fraction to the desired notation. Notice that the denominator of the 1/… fraction equals MAR, the MAgnification Requirement.

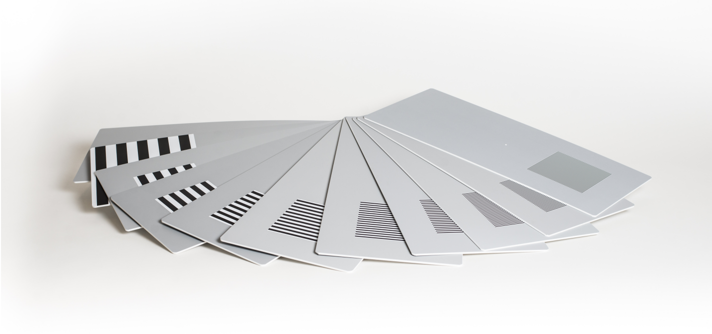
If the chart for 10 ft is labeled with 20/… notation, the numerators do not indicate the actual letter size. We must do an additional conversion: 20/100 = 1/5 = 10/50 (see Table 1). The 1/5 notation is easiest, since it indicates the Snellen fraction for 1 meter.

If the distance is less than one meter, the Modified Snellen formula is easier. Recognizing a 5 M symbol at 2.5 D (40 cm) yields: MAR = 5 x 2.5 = 12.5. and VA = 1/12.5 = 20/250.

Sometimes visual acuity values are used to indicate letter sizes (as in a "20/100 letter"). This is a mistake; any letter size can represent any acuity value by simply changing the viewing distance. Calculating (metric) letter sizes from the (feet-based) 20/… notation is awkward.

All Precision Vision charts list the actual letter size in M-units directly on the chart.

Teller Acuity Cards® being administered



Teller Acuity Cards®

Behavioral tests (Preferential looking)

Assessment of vision in infants and pre-verbal children requires unique strategies. A widely-used strategy for measuring visual acuity in infants and young children, called Preferential Looking Testing, takes advantage of infants' and children's natural preference for looking at a bold pattern rather than a blank, homogeneous area. The Teller Acuity Card® procedure combines the high-quality grating stimuli used in formal laboratory testing with the observer's subjective judgment concerning qualitative aspects of the child's response to those stimuli. The procedure is easy to use and requires only uncomplicated equipment. Note: these cards are not restricted to infants; they have also been used successfully with Alzheimer patients.

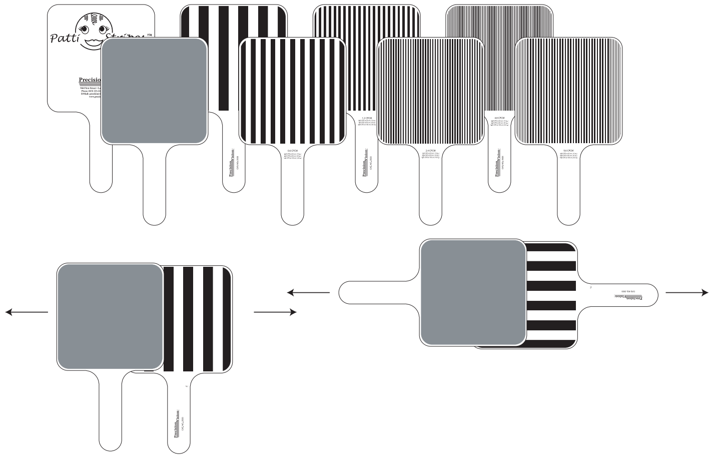
Mathematically 30 cpd equals about 20/20, 3 cpd = 20/200. However, grating detection is an easier task than symbol recognition, so this is not a psychophysical equivalence. Generally, grating detection acuity is better than object recognition acuity.

In lieu of the Teller Acuity Cards®, one can also use the Patti Stripes™ Grating Paddles to get an impression of the visual acuity and the Peek-a Boo Patti™ cards to get an impression of contrast vision.

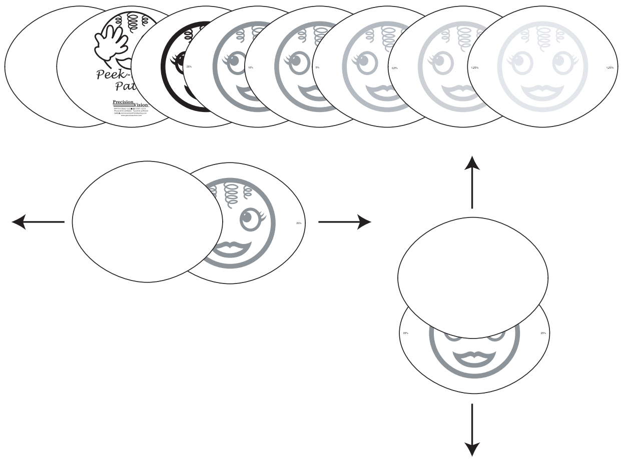
In most instances it is more important to detect a difference between the eyes than to obtain an absolute measurement.

Precision Vision offers Square Wave grating paddles at 0.3, 0.6, 1.2, 2.4, 4.8, and 9.6 cycles/cm with conversion to cycles/degree notations for use at 25 cm, 50 cm and 100cm.

Precision Vision also offers cards with "Peek-a-Boo Patti"™ faces with full contrast and low contrast at 40%, 20%, 10%, 5%, 2.5% Weber (25%, 10%, 5%, 2.5%, 1.25% Michelson).



Patti Stripes™ Square Wave Grating Paddles



Peek-a-Boo Patti™

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Precision Vision®

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