Vision Research 90 (2013) 2–9

Contents lists available at SciVerse ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

# Visual acuity testing. From the laboratory to the clinic ☆

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ARTICLE INFO

*Article history:*
Received 21 January 2013
Received in revised form 17 April 2013
Accepted 1 May 2013
Available online 17 May 2013

*Keywords:*
Visual acuity
Low vision
Clinical research

ABSTRACT

The need for precision in visual acuity assessment for low vision research led to the design of the Bailey–Lovie letter chart. This paper describes the decisions behind the design principles used and how the logarithmic progression of sizes led to the development of the logMAR designation of visual acuity and the improved sensitivity gained from letter-by-letter scoring. While the principles have since been adopted by most major clinical research studies and for use in most low vision clinics, use of charts of this design and application of letter-by-letter scoring are also important for the accurate assessment of visual acuity in any clinical setting. We discuss the test protocols that should be applied to visual acuity testing and the use of other tests for assessing profound low vision when the limits of visual acuity measurement by letter charts are reached.



## 1. Snellen, and a century of visual acuity chart development

In 1974, we began a 2-year study titled "Vision in Senile Macular Degeneration", funded by a grant from Australia's National Health and Medical Research Council (NHMRC) and conducted at the National Vision Research Institute of the Victorian College of Optometry at the University of Melbourne. The plan was to study relationships between visual acuity, contrast sensitivity, reading performance, effects of illumination, and the use of magnifiers in persons with vision loss due to age-related macular degeneration. Visual acuity was to be the principal reference for characterizing levels of vision in our population of partially-sighted research participants. One of the first tasks was to choose a method for measuring visual acuity. There was a multitude of commercially-available "Snellen Charts" that could be considered. Snellen's original chart (Snellen, 1862) had a single large letter at the top and with each successive row, the letters became more numerous and progressively smaller. It covered a 10-fold range in a 7-step sequence (minimum angle of resolution = 10, 5.0, 3.5, 2.5, 2.0, 1.5 and 1.0 min-arc). Snellen's original optotypes were serifed letters designed on a framework that was 5 units high and 5 or 6 units wide, and the thickness of the limbs was mostly equal to one unit. After Snellen, many variations in size sequences, chart layout and designs of the optotypes were made. These had been comprehensively reviewed by Bennett (1965) and there was no broadly accepted "standard" Snellen Chart.

## 2. Making visual acuity charts for low vision research

### 2.1. Choosing the optotypes

Expecting that most of our macular degeneration subjects would have very poor visual acuity, we quickly concluded that none of the available so-called "Snellen Charts" were satisfactory, mainly because they had too few letters at the larger sizes. Instead, we planned to make a set of new charts. We wanted to prepare a set of letter charts that could be presented with a 35 mm slide projector, and in order to reduce problems from subjects memorizing letter sequences, there were to be several versions with different letter sequences.

The British Standards Institute (British Standard, 1968) had recently recommended that visual acuity charts use a family of 10 non-serif letters (DEFHNPRUVZ) drawn on a framework that was 5-units high and 4-units wide with the limb-widths being 1-unit wide. These letters had been shown to have similar legibilities. The 1968 BSI letters are very similar in appearance to letters in Arial bold or Helvetica bold typefaces, and they have a more natural or familiar look than do the 5 × 5 letters most commonly used in "Snellen" charts. Their narrower 4-unit profile meant that charts did not need to be so wide. If the largest letters on a standard 35-mm projector display were to be 50 min-arc high (logMAR = 1.0, 6/6 or 20/200), the display would be able to accommodate 5 British Standard letters in the largest row. Anticipating that the viewing distance would need to be reduced for some research subjects with very poor visual acuity, we decided that we should use 5 letters on

☆ This paper was presented in a Mini Symposium "Testing Vision – From Lab Psychophysical Tests to Clinical Evaluations", on May 9, 2012 at the annual meeting of ARVO, Fort Lauderdale.

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http://dx.doi.org/10.1016/j.visres.2013.05.004

all the rows, because then the visual task would not change whenever different viewing distances were used.

Measures of relative difficulty for the 10 British letters had been published by Bennett (1965), and these values guided the composition of our 5-letter rows so that there was little variation in the average difficulty between rows. Ten 5-letter rows were arranged with letter sequences within the rows strategically scrambled, with care being taken that the letter sequences did not spell out words or common acronyms. In order to control, but not eliminate, contour interaction (Flom, Weymouth, & Kahneman, 1963) and crowding effects (Flom, 1991), each row was laid out so the space between adjacent letters was equal to the width of a letter.

### *2.2. Choosing the size progression*

Logarithmic size progressions had been recommended and used by many, the most notable advocates being Green (1868, 1905) and Sloan (1959). Green had proposed a logarithmic progression with a ratio of $\sqrt[3]{2}$ ($2^{1/3} = 1.2599$) and Sloan advocated a virtually identical ratio of $\sqrt[10]{10}$ ($10^{0.1} = 1.2589$). Such a systematic progression ratio would give relatively small but practical increments of size and thereby provide reasonably sensitive scaling over the anticipated range of visual acuity measurements. Sloan's recommended 0.1 log-unit sequence seemed to be mathematically more convenient. In experiments with peripheral visual acuity, Westheimer (1979) later showed that, across a wide range of acuity scores, the variance of the measurements is virtually constant if the scaling is logarithmic. In other words, just-noticeable-differences are about the same when a logarithmic scale is used. We chose to make the spacing between successive rows equal to the width of the letters in the larger of the two rows, and for the $5 \times 4$ British letters, this is practically the same as the height of the letters in the smaller of the two rows.

The combination of a constant ratio progression of size, having the same number of optotypes on each row, and making the spacings proportional to optotype size, effectively standardizes the visual task so that size is the only significant variable from one size level to the next. (Bailey & Lovie, 1976). This meant that whenever viewing distance was reduced, the patient's threshold size would move to a smaller row down the chart, but the threshold visual task would remain the reading of a 5-letter row within a display that had standardized spacing arrangements and size increments.

### *2.3. Making the charts*

Ten charts were prepared, all with five letters per row and proportional spacing.

At that time, chart construction required hand drawing of the optotypes, photographing the individual letters and arranging them in rows which, in turn, were photographed, enlarged to the required sizes and assembled. We made 10 different 5-letter rows and enlarged each of these to 10 different sizes. These were pasted up to make 10 unique charts in a center-justified format.

Thus, we constructed 10 alternative charts in the form of 35 mm slides for presentation with a standard projector. When the projector screen was 6 m from the subject, the size range extended from 6/60 to 6/7.5 (20/200 to 20/25) with an 0.1 log unit (1.26x) size progression ratio.

### *2.4. Designation of visual acuity*

For visual acuities poorer than 20/200 (6/60), closer viewing distances were to be used. Snellen fractions with different numerators for different distances seemed awkward and we looked for a simpler and more direct measure of angular size. The decimal notation for designating visual acuity was not attractive because, in the poor visual acuity region, the scale becomes compacted and the scores are in small numbers.

"Visual Angle" and "Minimum Angle of Resolution" are similar terms and both express the angular size of the critical detail in minutes of arc (min-arc). Visual Angle expresses the angular size of detail within the optotype, while Minimum Angle of Resolution (MAR) expresses the angular size of detail within the optotype at threshold. For most optotypes, size of the critical detail is taken to be one fifth of the letter height, and this is commonly the thickness of the strokes or the spacing between them. For a 6/6 (or 20/20) visual acuity task, the angular size of the critical detail is 1 min-arc, and for a 6/60 (20/200) visual acuity task the critical detail is 10 min-arc. For visual acuities poorer than 6/60 (20/200), MAR > 10, the scale expands rapidly and then it is common for the MAR values to be expressed in large whole numbers.

#### *2.4.1. Recording visual acuity scores as logMAR*

Expecting that our data would cover a very wide range of visual acuities, we anticipated that the presentation of our results would require graphs with a logarithmic scale.

Consequently, we decided to record our visual acuity research data in terms of the logarithm of the Minimum Angle of Resolution or logMAR. This gave a convenient system in which there was a constant 0.10 log unit difference between each successive row on the chart. On the logMAR scale, a value of 0.0 corresponds to MAR = 1.0 (6/6, 20/200) and for better visual acuities (MAR < 1.0), logMAR values become negative. LogMAR = 1.0 when MAR = 10 (6/60, 20/20). For our original set of 10 research charts, the range of logMAR values for the viewing distance of 6 m was 1.00 for the largest row to 0.10 for the smallest. We quickly realized that halving the viewing distance to 3 m required a simple adjustment of the scores by almost exactly 0.3 log units, so that the acuity range became logMAR = 1.30–0.40 at 3 m. For a viewing distance of 1.5 m, a 0.60 log unit adjustment was required and this shifted the measurement range to logMAR = 1.60–0.70. Since the visual acuity level for each row was 0.10 log units different from the neighboring rows, and because there was the same number of letters (5) with approximately the same legibility in each row, each letter could be assigned an equal value of 0.02 log units. This enabled a simple method of giving extra credit for every extra letter read. For example, if the subject read the logMAR = 0.70 row (6/30 or 20/100) and could just read two more letters in the next smaller row (logMAR = 0.60), giving 0.02 log units credit for each of the two extra letters causes the visual acuity score to become logMAR = 0.66 (equivalent to 6/27 or 20/91). Scoring letter-by-letter provides a more precise measure of visual acuity (Bailey et al., 1991).

## 3. Design principles for standardizing the visual acuity task

A few months after we began using these 35 mm projection charts to measure visual acuity in our research population of visually impaired subjects, we decided that there should be a printed version of the chart for use outside of the laboratory. Also we had come to recognize that, for consistency, the normally-sighted elderly subjects who were to serve as controls should have their visual acuities measured in exactly the same manner. The size range needed to be extended so that very good visual acuity could be measured on the same chart. Four smaller rows were added to the chart. These additional rows covered the size range logMAR = 0.00 to −0.30 (6/6 to 6/3 or 20/20 to 20/10) for the standard 6 m testing distance.

Only then did we realize that the chart design principles that had been developed for the research project had a universal application for the clinical measurement of visual acuity. On a visual acuity test, size should be the only significant variable from one level to the next. Standardization of the task on a visual acuity test chart requires the same number of optotypes in each row, a constant ratio of size progression, and the spacing between optotypes within rows and between rows must be proportional to optotype size. When there are variations in the relative difficulty of the optotypes within a given set, care should be taken to achieve approximately the same average difficulty for each row. These design principles, the logMAR method of designating visual acuity and the Bailey–Lovie chart were first described in 1976 (Bailey and Lovie). Fig. 1 shows a Bailey–Lovie chart.

### *3.1. National Academy of Science/National Research Council Working Group 39*

At about that time, a team of experts, called Working Group 39, was formed by the National Academy of Science/National Research Council to prepare a report on recommended standard procedures for the measurement and specification of visual acuity. The NAS/NRC report (1980) recommended that 4 m be used as the standard testing distance and that the Landolt ring should be the standard optotype against which alternative optotypes should be calibrated following a specific procedure. The 10-letter family of Sloan letters (5 × 5 non-serif letters) was expressly exempted from this recommended calibration requirement as it was accepted as being sufficiently equivalent to the Landolt ring. Working Group 39 recommended that the progression of optotype sizes be in a specific sequence using steps that were roughly in 0.10 log unit increments. However, for one-third of their specified steps, the increments were 0.12 log units, and for another third, the increments were 0.08 log units. For only one third of the steps, the size increments were not significantly different from 0.10 log units. They also specified allowable ranges of spacing ratios between adjacent letters and between adjacent rows, but there was no requirement that these spacing ratios be uniform throughout the chart. The acceptable spacing between letters was from 1.0 to 2.0 widths of the optotypes in that row. The spacing between rows could be from one to two times the height of the larger of the two rows of optotypes.

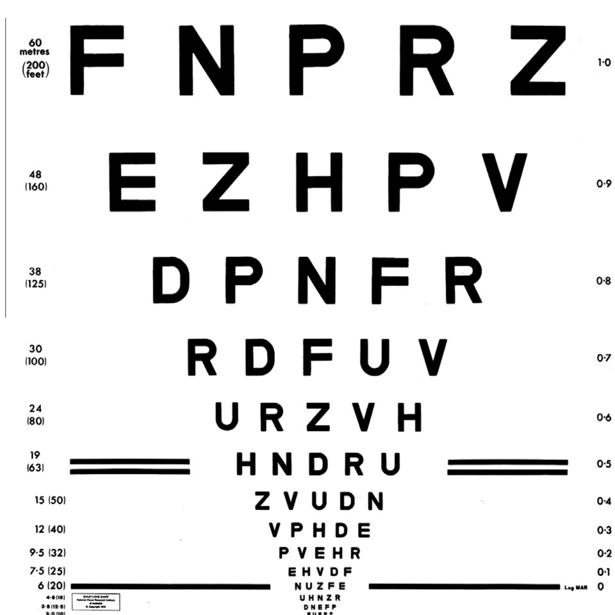


**Fig. 1.** A Bailey–Lovie chart. A logMAR chart with British Standard 5 × 4 letters for a standard testing distance of 6°m.

The NAS/NRC Working Group 39 recommended that there be 10 optotypes at each size level. They recommended that there be two rows of 5 letters at the larger sizes. For smaller sizes, 10 letters could be presented on the same row, but it was suggested that they be separated into two groups of 5. At very large sizes, the number of optotypes could be reduced to 8. The recommended primary criterion for determining the visual acuity score was to specify the smallest size at which at least 7 of 10 letters could be read. However, it was acknowledged that more precision could be gained by recording scores such as $4/8^{-2}$, or $4/8^{+3}$ to indicate numbers of letters missed or extra letters read. They also pointed out that precision of visual acuity measurement could be enhanced by fitting psychometric functions in order to determine the size of the optotype that would give a 70% probability of seeing. The Working Group 39 report made no reference to the design principles that we had proposed for the standardization of the test task within visual acuity tests.

### *3.2. Early Treatment of Diabetic Retinopathy Study (ETDRS) chart*

The Bailey–Lovie chart design principles have become the "gold standard" for visual acuity chart design, regardless of the optotype families or the testing distance. Such charts are commonly called "logMAR charts". The best known logMAR chart is the ETDRS chart which, throughout the world, is used for most major research studies that have visual acuity as an outcome variable.

In 1978, the Early Treatment of Diabetic Retinopathy Study group was planning a new multi-center research study of the efficacy of early treatment for diabetic retinopathy, and they had identified a need to improve the precision of visual acuity measurement in the range of poorer visual acuities. They had become aware of the recommendations that were being developed by the NAS/NRC Working Group 39 and they knew of the Bailey–Lovie chart and its design principles. The ETDRS group developed a chart (Ferris et al., 1982; Kassoff et al., 1979) that adopted some of the Working Group 39 recommendations and fully followed the design principles of Bailey and Lovie.

The ETDRS chart used 4 m as the standard testing distance and the Sloan family of 5 × 5 letters as the optotypes, and these were both recommendations of Working Group 39.

There were several of the NAS/NRC Working Group 39 recommendations that the ETDRS charts did not adopt. Rather than using 10 letters at each size, they chose to use 5. The ETDRS chart has a size progression in steps of exactly 0.10 log unit rather than the less regular sequence specified by Working Group 39. On the ETDRS chart, the spacing between rows was made equal to the height of the letters in the smaller row and this makes the rows closer together than the limits that were considered acceptable by Working Group 39.

The ETDRS chart complied with the design principles and followed most of design details used in the original Bailey–Lovie chart. Both the original Bailey–Lovie chart and the ETDRS charts chose 5 letters at each size, a size progression in steps of exactly 0.10 log units, a spacing of one letter width between letters and, for both charts, the spacing between rows was made equal to the height of the letters in the smaller of the two rows. The ETDRS chart included logMAR labels for each letter size and the ETDRS group adopted the protocol of specifying visual acuity in terms of logMAR and giving equal credit (0.02 logMAR units) for each extra letter read correctly.

The differences between the Bailey–Lovie chart and the EDTRS chart were the standard testing distance (6 m versus 4 m), and the choice of letter families (1968 British Standard letters versus Sloan letters). The choice of letters meant the ETDRS chart had wider spacing (5 units versus 4 units) between adjacent letters within rows. At the recommended testing distances, the range of acuity values on both charts covered the same range from logMAR = 1.00 to logMAR = −0.30 (6/60 to 6/3 and 4/40 to 4/2).

### 3.3. LogMAR charts with different optotypes

In the 1980s, the Bailey–Lovie chart and the ETDRS chart began to be widely used in clinical research studies and this drew attention to the new chart design principles and the method of scoring visual acuity in terms of logMAR. Numerous new charts that followed Bailey and Lovie's design principles and used logMAR size labels were developed with alternative optotypes. These included established optotypes such as Tumbling E's and Landolt rings, and other optotypes such as various numbers, pictorial symbols and letters and characters from other alphabets. These alternative logMAR charts typically use 5 optotypes per row, a size progression of 0.10 log units, proportional spacing arrangements, and a center-justified layout.

Despite their *prima facie* similarities, it cannot be assumed that these various charts with differing optotypes will give identical scores to the ETDRS chart. Fig. 2 shows rows of optotypes taken from 10 different readily available charts. For this figure, each row of optotypes has been scaled so the size is proportional to the visual acuity size labels on the charts from which they were copied. Thus, nominally, each row of optotypes should present the same visual acuity demand. Within these 10 different families of optotypes, two of the letter families have 10 alternative letters available; for the three families of numbers, there are 8, 5 or 4 alternative numbers available; and there are 4 alternative optotypes or orientations for the Tumbling E's, the Landolt rings, the HOTV series and the two sets of pictorial symbols. For three of the optotype sets, the optotypes are substantially taller than the others. Compared to the spacing between the Sloan letters on the ETDRS charts, spacing between optotypes is narrower for two families and wider for three others. For two of the optotype families, the width of a limb is a substantially smaller proportion of the letter height.

According to their manufacturer's labels, these 10 sets of optotypes, as illustrated, could be expected to have the same visual demand when presented at the same distance. Even if "validation studies" had shown that, on average, results using these charts with large and diverse populations were in good agreement with scores from the ETDRS chart, it should not necessarily be expected that scores would be equivalent for all subject groups. For instance, in patients with amblyopia or macular degeneration, visually acuity can be especially affected by closer spacing so that charts with wider spacing between optotypes would be relatively easier. The design of the visual acuity chart can affect the scores obtained. (Kitchin & Bailey, 1981; Levi, Hariharan, & Klein, 2002; Levi, Song, & Pelli, 2007). When monitoring visual acuity for clinical research or for continuing patient care, the visual task presented by the visual acuity charts and the testing procedures should be kept consistent if subsequent measures are to be compared. Reports of visual acuity findings should identify the charts used. Test chart luminance is another factor that can influence acuity scores (Ferris & Bailey, 1996; Sheedy, Bailey, & Raasch, 1984) and should be reported or be within an accepted range for normal testing.

### 3.4. Testing protocols

Whether visual acuity measurements are being taken for research or clinical purposes, there needs to be standard testing procedures. The researcher or clinician should have rules about how and when the patient can be encouraged to guess when the optotype sizes are close to threshold, whether or not the patient is allowed to correct some responses, whether some errors can be forgiven (e.g., confusing an O with a C, or a P with an F), and

| Optotypes *n* | Height *Minarc* | Width *Minarc* | Row (5) *Minarc* | Spacing *Minarc* | Height/ Stroke | Size and Spacing Dimensions for 10 different optotypes |
|---|---|---|---|---|---|---|
| 10 | 5.0 | 5.0 | 45 | 5 | 5 | Sloan Letters |
| 4 | 5.0 | 5.0 | 45 | 5 | 5 | Landolt Rings |
| 4 | 5.0 | 5.0 | 45 | 5 | 5 | Tumbling E |
| 4 | 5.0 | 5.0 | 45 | 5 | 5 | HOTV |
| 8 | 5.0 | 5.0 | 45 | 5 | 5 | LVRC Numbers |
| 10 | 5.0 | 4.0 | 36 | 4 | 5 | 1968 British |
| 5 | 5.7 | 5.7 | 51 | 5.6 | 5 | PV Numbers |
| 4 | 6.4 | 4.3 | 40 | 4.6 | 7.5 | Lea Numbers |
| 4 | 5.0 | 5.0 | 51 | 6.5 | 5 | Patti Pics |
| 4 | 6.0 | 6.0 | 56 | 6.5 | 7 | Lea Symbols |


**Fig. 2.** Rows of optotypes from 10 different "logMAR" charts with a table giving size and spacing information for each.

whether the clinician may help the patient locate the rows or individual optotypes by pointing or covering nearby rows or letters. The protocols (AREDS 2, 2009) for the Age Related Eye Disease (AREDS) and AREDS 2 studies required no pointing or no going back to correct an earlier response. Guessing was encouraged but testing was stopped when it became evident that no further readings could be made. Carkeet (2001) modeled visual acuity scoring and the effect of forced choice guessing and stopping rules and he recommended that testing be stopped when four mistakes are made in one row. Many clinicians stop testing when less than half of the row is read correctly. A record should be made of refractive corrections being worn for the visual acuity test. Clinicians measuring visual acuity should have consistent procedures and test conditions. Researchers need to follow rigorous protocols that should be reported when their visual acuity data are presented.

## 4. Scoring visual acuity in logMAR units

Scoring visual acuity in a manner that gives credit for every additional letter read significantly enhances sensitivity for identifying changes or differences. It has long been the common clinical practice to assign the visual acuity score on a row-by-row basis, giving credit for the row when the patient correctly reads a specific proportion of the optotypes at that size. Perhaps the most common criterion is that credit for reading a particular row is given if more than 50% of the letters are correctly identified. The NAS/NRC Committee on Vision recommended that the criterion be 70% correct.

With "LogMAR charts", the standardization of the test task and the logMAR scale allow 0.02 log units credit to be given for every letter read. Compared to row-by-row scoring, letter-by-letter scoring provides much better precision and sensitivity to change. For normally sighted subjects being tested and retested on logMAR charts, row-by-row scoring gives perfect concordance between test and retest scores for about 60% of the comparisons (Bailey et al., 1991). This means that about 40% of the time, the difference between test and retest score is 0.10 log units and occasionally more. Consequently, at least two rows (or 0.20 log units) of difference or change is required for the clinician to be confident (at a 95% level) that there is a real difference between the two measurements. Conversely, letter-by-letter scoring gives perfect concordance between test and retest scores only about 20% of the time. However, for more than 95% of the comparisons, the test–retest discrepancies do not exceed 0.08 log units (4 letters). This allows the 95% confidence limits for a significant difference to become 0.10 log units or 5 letters. (Arditi & Cagenello, 1993; Bailey et al., 1991; Beck et al., 2007; Brown & Lovie-Kitchin, 1993; Carkeet et al., 2001; Raasch, Bailey & Bullimore, 1998). Hazel and Elliott (2002) compared letter-by-letter scoring methods with fitting psychometric functions and found that while the latter method gives slightly higher scores, there is no improvement in test–retest reliability.

### *4.1. Visual Acuity Rating (VAR) scale*

The Visual Acuity Rating (VAR) scale (Bailey, 1988) is an alternative way of designating visual acuity that is simpler and more intuitive than the logMAR scale The VAR is a simple transform of the logMAR scale: VAR = 100 − 50(logMAR).

On the VAR scale, 100 corresponds to logMAR = 0.0 (6/6, 20/20), VAR = 50 corresponds to logMAR = 1.0 (6/60, 20/200) and VAR = 0 corresponds to logMAR = 2.0 (6/600, 20/2000). VAR values only have a negative sign when MAR > 100 (poorer than 6/600, 20/2000). On charts with 5 letters per row and size increments of 0.10 log units, each letter has a value of 1 on the VAR scale, and each row is 5 points. Thus, with a little practice, it becomes a matter of simply counting the letters read correctly (or incorrectly). Changing to a non-standard viewing distance requires that the logMAR score be adjusted by 50 x log (new distance/standard distance). This VAR scale facilitates and simplifies the scoring of visual acuity when giving credit for every letter, the statistical analysis of visual data and the graphical presentation of results.

## 5. Reading charts

Reading typeset print presents a task that is distinctly different from reading relatively widely spaced letters on visual acuity charts. Reading charts with typeset sentences or paragraphs or sets of unrelated words have long been used by clinicians to measure vision at close viewing distances, and such charts are routinely used in the process of prescribing reading glasses.

The design principles that we introduced to standardize the test task for the letter chart test of visual acuity have also been applied to reading charts. We designed a word-reading chart that used a logarithmic size progression, a standard font, and a standardized task with two 4-, 7- and 10-letter words at each size level (Bailey & Lovie, 1980). Legge et al. (1989) developed the MNREAD chart that introduced standardized sentences and it used a logarithmic size progression, a standard font and a standard layout. The sentences in the MNREAD charts all have 60 characters, arranged in three rows of approximately equal length. The sentences were designed to be very simple and easily read by most primary school children. Originally prepared in English, versions of the MNREAD test have been made in many other languages. A further increment towards standardizing of the test task in reading charts was advanced by Radner et al. (1998) who used more rigorous methods of standardizing the linguistic content or the text within their reading charts, and this has been done for many different languages. Standardization of the task within reading charts has facilitated research into reading speed and efficiency as a function of print size. They have become widely used by low vision clinicians for the assessment of reading performance and the prescribing of optical aids for reading.

## 6. Moving towards computerized testing of visual acuity

Research needs drove the development and adoption of chart design principles that standardized the visual acuity test task. There are now numerous visual acuity and reading test charts that comply with these principles. Amongst the many visual acuity test charts there are variations in the optotypes used, the standard testing distances, spacing ratios, and the inclusion of flanking bars and boxes to change contour interaction effects. There is an inevitable trend to use more computer-based displays for the measurement of visual acuity and, in part, this is being driven by the research advantages that come from computer control of visual displays for measuring visual acuity. Computer displays can provide selectable options of stimulus parameters such as choices of optotypes, spacing arrangements, luminance, contrast, color, exposure time, presentation sequences and psychophysical methods for determining thresholds. Computerization also enables the automatic recording of all responses, response times, running estimates of acuity scores and individual estimates of test reliability.

The E-ETDRS chart (Beck et al., 2003) is an example of a computerized visual acuity test developed for research. Instead of using a chart format, the E-EDTRS test presents single Sloan letters with 4 flanking bars as the visual acuity task. The sequencing of the presentation of the letters is strategically designed to efficiently estimate the visual acuity and to present 5 targets at each size close to threshold. This provides a precision of measurement that is equivalent to that obtained with ETDRS charts. For a large diverse clinical population, the E-ETDRS test has been shown to provide results that are in good agreement with results from ETDRS charts (Beck et al., 2003). Because recognizing isolated letters with flanking bars is a different task from reading across rows of letters embedded within a chart, it might be expected that there will be poorer agreement between the scores from the E-ETDRS and ETDRS charts in some visual disorders (such as macular degeneration and amblyopia) where target crowding has a more pronounced impact on visual acuity performance.

There are limitations of current display-screen technology that prevent typical logMAR charts from being presented on an electronic display screens. For the smallest letters, a pixel density of about 10 pixels per letter height is required to achieve reasonable fidelity of the letter shapes. At the other end of the scale, if the largest row is to have five letters that are 20 times larger than the smallest letters, it becomes necessary to have more than 2000 pixels across the display. To have an entire chart visible at the one time, there also needs to be 2000 pixels in the vertical dimension. A screen would require at least 4 megapixels in order to display logMAR charts with 5 letters per row and covering a 20:1 size range. If the chart were to be presented at 4 m, the screen would need to be about 65 cm wide. It seems reasonable to expect that large area screens with 4 or more megapixels will become available in the not too distant future. However, with computer controlled displays, it seems likely that visual acuity measurement with single optotypes could become the common practice because this allows a wider a range of sizes to be presented on the one screen, and also the visual task is simpler so testing is probably a little quicker.

## 7. Limits on testing with visual acuity charts

There are limits to the range of visual acuity that can be measured with logMAR visual acuity charts. Very large angular sizes require either very large optotypes or very close viewing distances. At the standard testing distance, for most charts the size of the largest available optotypes is logMAR = 1.0 (MAR = 10, 6/60, 4/40, or 20/200). Shortening the viewing distance is commonly used to extend the range. Reducing the viewing distance by a factor of 4 extends the size range to logMAR = 1.6 (MAR = 40, 6/240, 4/160, or 20/800), and for a logMAR chart, the width of the chart subtends an angle of more than 30°. At such close viewing distances, significant eye and head movements are likely to be elicited as the examinee shifts attention from one side of the chart to the other, so the task becomes different. Also, the process can be claustrophobic and intimidating to the patient. To extend the range of acuity measurement beyond logMAR = 1.6, the visual task needs be simplified, and in order to achieve very large angular sizes of test targets, very close viewing distances might become necessary.

### *7.1. New research attention to visual acuity in severe visual impairment*

Recent advances in prosthetic vision devices and biological technologies for sight restoration in some blind or severely visually impaired persons have brought new attention to methods for assessment of very low vision. Quantification of vision changes when vision is severely impaired requires new clinical tests. Bach (1996) developed the computer-based Freiburg Acuity and Contrast Test (FrACT) for measuring visual acuity using an automated protocol for presenting single optotypes. Bach and his colleagues (Bach et al., 2009) created other tests for contrast sensitivity, motion detection, temporal resolution, spatial localization and light detection. These tests are mainly used for measurements of visual outcomes in clinical trials. Bittner, Jeter, and Dagnelie (2011) recently described a new computer screen test of Grating Acuity (GAT) and also a grating test of contrast sensitivity for use in clinical trials involving severe vision loss. These new tests of vision have made the visual task simpler than having to read rows of optotypes. They are ideally suited for research in clinical-laboratory settings but they require computer-controlled displays.

### *7.2. Berkeley Rudimentary Vision Test*

The Berkeley Rudimentary Vision Test (BRVT) is a simpler test for assessment of spatial vision in severely impaired patients (Bailey et al., 2012). It is intended to be easily useable in almost any setting, without requiring access to a power supply or having to move the patient. The BRVT test consists of three card-pairs. Each card-pair has two 25 cm square cards hinged together so that there are 4 panel faces for the test targets (see Fig. 3).

On the first card-pair there is a single Tumbling E target in the center of each of the 4 panels. The panels are hinged so that when the largest and the smallest (100 M and 25 M) Single Tumbling E's are on the outside, the two intermediate sizes (63 M and 40 M) are on the inside. The recommended protocol is to present the Single Tumbling E (STE) acuity test at a viewing distance of 100 cm, where STE acuity range is from logMAR = 2.0–1.4 (equivalent to 6/600 to 6/150, 20/2000 to 20/500) in increments of 0.20 log units. If the orientation of the 100 M Tumbling E cannot be recognized at 100 cm, then the viewing distance is reduced to 25 cm. There should be at least 4 presentations at each size level when close to threshold. At 25 cm, the STE acuity range becomes logMAR 2.6–2.0 (6/2400 to 6/600 or 20/8000 to 20/2000). If the patient is unable to identify the orientation of the 100 M Single Tumbling E, testing with optotypes is abandoned in favor of a yet simpler visual task.

The second card-pair has square-wave gratings as the 4 test targets. The largest grating has two black and two white stripes, each of which is 6 cm wide. Stripes of this width would subtend a visual angle of 1 min-arc at 200 m so, in M units, their size is 200 M. The finest gratings have eight black and eight white stripes, each 1.5 cm wide, and the size in M-units is 50 M. The panels are hinged so that when the largest and the smallest (200 M and 50 M) gratings are on the outside, the two intermediate sizes (125 M and 80 M) are on the inside. By the recommended protocol, this card-pair is only presented at 25 cm and the Grating Acuity range is logMAR 2.90–2.30 (6/4800 to 6/1200, 20/16000 to 20/4000) in steps of 0.20 log units. At size levels close to threshold, there should be at least 6 presentations. If the patient is unable to identify the orientation of the 200 M grating at 25 cm, visual acuity measurement is abandoned and a visual task that is simpler again is used to characterize basic vision abilities.

The third card-pair has two tests, one called "white field projection" (WFP) and the other called "black–white discrimination" (BWD). For the WFP test, one panel has a white quadrant on a black background and its partner panel is divided into a black half and white half. Both panels can be presented in 4 different orientations and the patient's task is to identify the location of the white quad-field or hemi-field. For both panels, there should be a minimum of 4 presentations, with at least one in each the four orientations. The recommended procedure is that this card-pair only be presented at 25 cm. At this distance, the cards subtend an angle of 53°, so that the white quad-field is $26° \times 26°$ and the white hemi-field is $26° \times 53°$. If the patient is unable to consistently identify the location for the white field, the black–white discrimination (BWD) test is administered. For this test, one panel is all white and the other is all black. The two card faces are presented at 25 cm where the angular subtense is 53°, and the patient's task is to identify whether the panel presented is black or white. If the patient cannot reliably tell the black from the white, then testing with the BRVT series of cards is abandoned. Then a test of light perception (LP) is administered. A bright light is held close to the eye, and the patient's task is to tell whether or not the light is present.

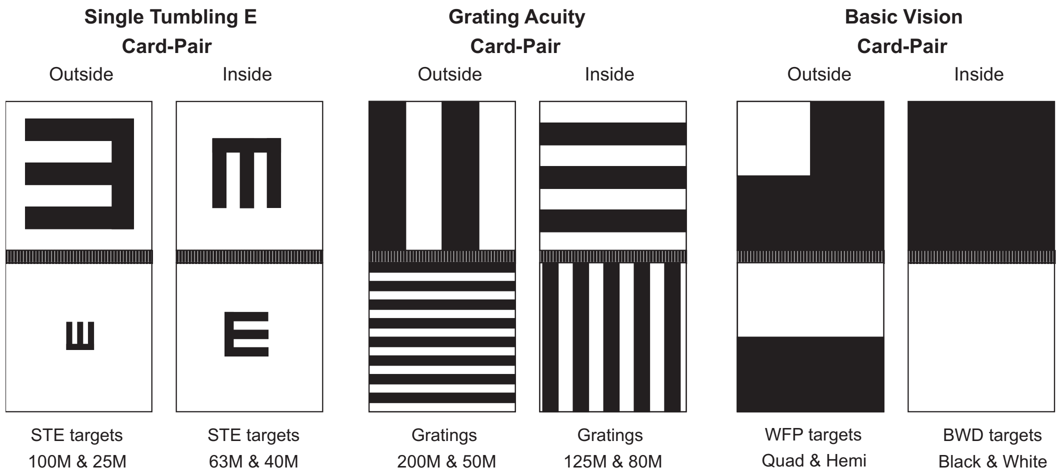


**Fig. 3.** Berkeley Rudimentary Vision Test for testing visual acuity in severe visual impairment. There are three 25 cm square hinged card-pairs.

The BRVT is intended for testing vision beyond the limit of testing with a letter chart when clinicians have traditionally resorted to coarse qualitative tests of "Counting Fingers" (CF) and "Hand Motion" (HM). The BRVT includes a series of tests that have progressively simpler task complexity (single optotypes, gratings and a basic vision function test). The BRVT provides 7 steps of STE acuity, 4 steps of Grating Acuity and two additional qualitative categorizations of basic vision function. Compared to using only CF and HM for measurements within this acuity range, it allows more precise measurement and categorization of spatial vision in persons with severe visual impairment, but the precision is less than that available from the computer-based FrACT and GAT tests.

## 8. Summary

Many important improvements to clinical visual acuity measurement have resulted from problems being addressed or solved in the research laboratory. The logMAR chart design emerged from a research need for a test that improved the precision of visual acuity measurement in persons with low vision. This led, somewhat naturally, to the identification of the combination of chart design characteristics that are required to make the visual task virtually the same at each size level. Having the same task on each row meant that extra letters read, or letters missed carried the same meaning regardless of the row on the chart. Then, if visual acuity is scored as a logMAR value, each individual letter could be assigned the same value. For a chart with 5 optotypes per row and a size progression ratio of 0.10 log units, each letter can be assigned a value of 0.02 log units. This facilitates the giving of credit for every extra letter read. Such letter-by-letter scoring substantially enhances the precision of visual acuity measurement and narrows the confidence limits for identifying differences in acuity scores, and this is an important benefit to both the researcher and the clinician.

Detecting changes in an individual patient's visual acuity is a broadly recognized responsibility of ophthalmologists and optometrists. Assigning visual acuity scores on a row-by-row basis is imprecise to such an extent that it could be considered professionally negligent. For a clinician to be confident that visual acuity has changed at all, row-by-row scoring requires that there be at least two rows of difference between the acuity measurements. Sensitivity to change can be enhanced by about a factor of two if the clinician scores visual acuity more precisely, simply by giving extra credit for every extra letter read.

New reading test charts emerged from research into relationships between print size and reading performance. As had been done for letter charts, the visual task was made to be the same at each size level. Nowadays, such reading charts and some of the research methods for assessing and characterizing reading skills have become quite widely used in clinical practice.

Recently new computer tests for measuring visual acuity in severe visual impairment have been developed to meet research needs. New technological and biological interventions have brought new possibilities for restoring vision to some blind eyes, or enhancing vision in eyes with severe vision impairment. There emerged a need for better methods to assess visual abilities in persons with profound vision loss. To better assess visual acuity in such populations, the FrACT and the GAT tests were developed, mainly for research purposes although these computerized tests can easily be used by clinicians in order to obtain more precise acuity measurements. The BRVT is designed to test the same population groups and to be a more convenient test that is more easily administered in diverse clinical settings. But the gains in simplicity and efficiency are accompanied by a reduction in the rigor of the psychophysical methods and a reduction in precision should be expected.

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