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Changes in the clinical measurement of visual acuity

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Abstract. In 1862, Hermann Snellen introduced his letter chart for the clinical measurement of visual acuity. His chart presented letters, or optotypes, arranged in a progressively diminishing size sequence, and the visual acuity was determined by the smallest letters that could read at a specified distance. Numerous modifications of the design of the optotypes, the progression of size and the chart layout were suggested, and in 1976, Bailey and Lovie published a set of design principles that made the visual task the same at all size levels, so that size become the only significant variable. This required the same number of letters at each size level, fixed spacing ratios and a logarithmic progression of size. This facilitates more precise quantification of visual acuity by giving credit for every letter read correctly, and this gives clinicians tighter confidence limits for determining changes or differences in visual acuity. However, optotype choices, and associated spacing arrangements can have significant effects on visual acuity scores as can viewing conditions and testing protocols. Computer based visual acuity tests are becoming more commonplace, there will be more variety in test charts and procedures which will create some problems for making comparisons between tests.

1. Introduction

In 1862, Hermann Snellen introduced his famous “Snellen chart” for the clinical measurement of visual acuity. With it, he introduced the “Snellen fraction” as a measure of angular size. His chart presented a series of serifed letters that varied from large to small. His letters, which he called “optotypes” were designed so that the stroke widths of the letters were 1/5 of the letter height. An individual’s visual acuity was determined by the smallest letters that could be read correctly when the chart was presented at a standard viewing distance. The angular size of the threshold size optotype was specified by the “Snellen fraction” whose denominator is the viewing distance, and the numerator is the distance at which the height of the letters subtends 5 minutes of arc. In the USA, 20 feet is the standard viewing distance, so a visual acuity of 20/40 indicates that the testing distance was 20 feet and the height of smallest letters read would subtend 5 arcmin at 40 feet. Most individuals with good normal vision can achieve a visual acuity of 20/20 or better. Thus, an individual with “good normal vision” can just recognize letters that subtend 5 minutes of arc, and the component strokes and most of spaces within these letters subtend 1 minute of arc. The angular size (in minutes of arc) of the detail within the smallest recognizable optotypes is said to be the “minimum angle of resolution” (MAR). The MAR is equal to the reciprocal of the Snellen fraction. Thus for a visual acuity of 20/20, the MAR = 1 arcmin; for 20/40, the MAR = 2 arcmin; for 20/200, the MAR = 10 arcmin; and so forth.

Following Snellen’s original chart came many alternatives that offered numerous suggested “improvements” and modifications of the design of the optotypes, the progression of size, the range of sizes and the layout. (reviewed by Bennett, 1965). Most of these alternative charts had only one or two optotypes at the largest size, and the number of letters became more numerous as the sizes became smaller. And generally, the ratio between one size and the next became smaller at the smaller sizes. Despite wide variations in the chart designs, they were all said to be “Snellen charts”. The term “Snellen chart” has become a generic descriptor. There is no standardization for Snellen charts.
One of the more important design changes came from Green (1905) who advocated that the progression of size should be logarithmic with a ratio of 0.1 log units (ratio = 1.2589). Sloan (1959) also favored the same logarithmic size progression and she developed a set of 10 non-serifed letters with specified configurations, all of which were based an a 5x5 grid, and these have become the gold standard for letters on the visual acuity charts of today.

The majority of visual acuity charts use Roman letters as their optotypes. But there are many alternative optotypes including numbers and pictures or symbols and some optotypes, notably the Landolt ring and the Tumbling E, are figures whose orientations have to be identified.

The Bailey-Lovie chart design principles
In 1974, at the University of Melbourne, Jan Lovie-Kitchin and I embarked on a project to study vision in macular degeneration. We expected most of our subjects would have poor visual acuity, and we realized that the available visual acuity charts would not be suitable for our purposes. We expected that most our visual acuity business was going to be done at larger sizes where there were too few letters and the ratios between sizes was too large. It was necessary for us to design some new charts so that we could better test subjects with poor visual acuity.

As the optotypes, we chose to use the family of 10 letters recommended by the British Standard Institute in 1968. The letters were non-serifed and their designs were based on a 5x4 grid. First of all, we wanted as many letters as was practical at the largest size, and we decided to use 5 letters. We made the spacing between letters equal to the letter width. Then, we decided that all the subsequent rows should also have 5 letters. We used the logarithmic size progression as first advocated by Green. We realized that if the spacing between on size and the next were made proportional to the adjacent letter sizes, then the visual task would be the same at each size level. That is, as you go from one size level to the next, size becomes the only significant variable.
It had not been the intention, but we now had a chart design, where visual task was the same throughout. An important advantage is that, if the viewing distance is changed, the threshold size simply moves to different size level on the chart in proportion to the change in viewing distance.

**LogMAR. A new unit for designating visual acuity.**

On these new charts, we labeled the size the different optotypes by the common logarithms of the minimum angle of resolution (logMAR), assuming the letters were being viewed from the standard distance of 6 meters (or 20 feet). Thus, for 20/20 vision the MAR = 1 arcmin, so log_{10}MAR = 0; at 20/200, the MAR = 10, so log_{10}MAR = 1.0; at 20/40, the MAR = 2 so the logMAR = 0.30. The visual acuity range on these charts extended from 20/200 to 20/10; that is from logMAR = 1.0 to logMAR = -0.3.

When vision is so poor that the subject is unable to read the largest letters on the chart at the standard distance (6 m or 20 ft), the chart could be moved closer, with an appropriate adjustment being to the logMAR score. For example, if the subject was unable to read the letters in the top row, the chart could be moved closer, and let us say to 1.5 meter (5 ft.). Then, a logMAR score correction of 0.6 needs be made to account for the 4-fold reduction in viewing distance (because log_{10}(4) = 0.6). For the second largest letters on the chart at the standard 6-meter distance, the logMAR label is 0.9. If this is the smallest letter size that can be read at 1.5 meters, then the logMAR score for this subject is 0.9 + 0.6 = 1.5.

**VAR . Visual Acuity Rating**

An alternative method for designating visual acuity is the Visual Acuity Rating (VAR) which is an arbitrary scale for where VAR = 100 – 50 x logMAR. This is easier to use than the logMAR scale. On the VAR scale, useful benchmarks are VAR = 100 when VA = 20/20 (commonly considered as normal vision), VAR = 50 when VA = 20/200 (s commonly used as a border for classifying “legal blindness” and VAR = 0 when VA = 20/2000 (which is about the limit for measuring visual acuity with optotypes). For charts complying with the Bailey-Lovie design principles using a size progression in steps of 0.1 log units and with 5 letter at each size, then each extra letter read correctly increases the VAR score by 1 point. For visual acuities better than 20/20, the VAR is greater than 100. For each extra row carries a VAR value of 5 points. On the VAR scale, 15 points represents a visual acuity change by a factor of 2-fold (0.3 log units). For both the logMAR and VAR scales, the labels on the chart must specify the viewing distance for which the chart has been calibrated. Many charts today use 4 meters as the standard viewing distances, but viewing distances of 20 ft, and 6 meters are still widely used. If the charts are used at non-standard distances, an adjustment should be made to the logMAR or VAR score. The correction factors are log_{10}(standard distance/new distance) added to the logMAR score and 50 x log(new distance/standard distance) added to the VAR score. Halving the viewing distance requires a 0.30 addition to the logMAR score and a 15 point subtraction from the VAR score.

**Letter-by-letter scoring**

This logMAR scale also facilitates giving visual acuity score that give credit for every letter read. Because there are 5 letters per row, and the size increment between rows is 0.10 then each letter can be assigned a value of 0.02. To give an example, consider a subject who correctly reads all the letters at the size where logMAR = 0.3 (this is equivalent to 20/40). Should this person attempt the next smallest row and get one letter correct, the visual acuity score would become 0.28. Had two extra letters been read in that next smaller row, the score would have become logMAR = 0.26.

Giving credit for every letter read correctly provides more precise measurement of visual acuity, and this gives substantial improvement in the sensitivity to detect changes or differences. Unfortunately, it is still common practice for clinicians to assign visual acuity scores on a row-by-row basis. The
assigned visual acuity score corresponds to the size the smallest letters at which a certain percentage (usually 50% or more) of letters are read correctly. Comparing test and retest measurements of normally sighted subjects, when visual acuity scores are assigned on a row-by-row basis, it is found that there is perfect test-retest concordance about 60% of the time. For 20% of the time, the second score is 1-row better, and 20% of the time, one-row worse. The 95% confidence limits for identifying change become 2 rows (i.e., 2 size levels) on the chart. When scoring visual acuity of a letter-by-letter basis, as expected for a finer scale, the rate perfect concordance between test and retest is reduced and it is about 20%. The distribution of test/retest discrepancies has a standard deviation of about 0.04 log units, so the 95% confidence limits for change become 1.00 and this corresponds to 5 letters. If visual acuity scores are assigned on a row-by-row basis, the confidence limits for change are ±2 rows on the chart. But when the scores are assigned giving credit for every extra letter read, the confidence limits become about ±5 letters.

![Test/Retest agreement for row-by-row scoring](image1)

![Test/Retest agreement for letter-by-letter scoring](image2)

**Figure 2.** Histograms of test/retest discrepancies when assigning visual acuity scores using the row-by-row method and the letter-by-letter method.

The histograms of Figure 2 show the frequencies of test/retest agreements and discrepancies when scores were assigned by the row-by-row method and by the letter-by-letter method. Letter-by-letter scoring substantially enhances a clinician’s ability to determine changes of difference in visual acuity.
The clinical research community has adopted the Bailey-Lovie chart design principles that standardize the visual task, the logMAR units and scoring visual acuity by giving credit for every letter read. Most visual acuity charts used in clinical research have 5 optotypes at each size, and a size progression ratio of 0.1 log units (1.26x). The spacings between optotypes and between rows is usually kept proportional to the optotype size. However, there are many different alternative optotypes being used. There are different families of letters, different families of numbers, some have symbols arranged in different orientations and some have sets of symbols or pictures. It is not widely appreciated that these alternative charts do not always give equivalent scores of visual acuity, even though the manufacture’s labeling usually suggests otherwise. Figure 3 shows a row of optotypes from 10 different charts. The sizes of the optotypes are to scale in that the manufacturers’ labels assign the same visual acuity value to each of these.

<table>
<thead>
<tr>
<th>Optotypes</th>
<th>Height a/c min</th>
<th>Width a/c min</th>
<th>Row (5) a/c min</th>
<th>Height/Stroke</th>
<th>Dimensions of 10 sets of Optotypes</th>
<th>Letters different</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sloan Letters</td>
<td>5.0</td>
<td>5.0</td>
<td>45</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landolt Rings</td>
<td>5.0</td>
<td>5.0</td>
<td>45</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tumbling E</td>
<td>5.0</td>
<td>5.0</td>
<td>45</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOTV</td>
<td>5.0</td>
<td>5.0</td>
<td>45</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVRC Numbers</td>
<td>5.0</td>
<td>5.0</td>
<td>45</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968 British</td>
<td>5.0</td>
<td>4.0</td>
<td>36</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PV Numbers</td>
<td>5.7</td>
<td>5.7</td>
<td>51</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lea Numbers</td>
<td>6.4</td>
<td>4.3</td>
<td>40</td>
<td>7.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patti Pics</td>
<td>5.0</td>
<td>5.0</td>
<td>51</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lea Symbols</td>
<td>6.0</td>
<td>6.0</td>
<td>56</td>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3.** Illustration and a list of dimensions for rows of optotypes from 10 different charts

The Sloan letters a family is used in the ETDRS (Early Treatment of Diabetic Retinopathy Study) is generally taken as the standard optotype against which others should be compared. On a group of 20 normally sighted subjects, we measured visual acuity with 10 charts with these various optotypes. The right-hand column of Figure 3 indicates the magnitude of the average differences in the visual acuity scores for each optotype when compared with the Sloan letters. The differences are here expressed as number of letters – a one letter difference correspond to 0.02 log units. The difference between the easiest chart (HOTV) and the most difficult chart (Patti Pics) is substantial. (4.1 letters or 0.082 log units) These differences result from variations in legibility of the different sets of optotypes and also from the variations in sizes and spacing. These results come from normally sighted subjects, but it is well known that for many ocular disorders, spacing and congestion of the optotypes on the chart a can have more pronounced effects of their visual acuity scores.
Need to identify tests and procedures.
Because visual acuity scores can be significantly affected by the choice of visual acuity chart and testing procedures, all reports and records of visual acuity results should include specific information about the test and testing protocols. The chart should be identified. Record should be made of the illumination levels and note should be made about optical correction being worn by the persons being tested. There should be rules about guessing, stopping, correcting and feedback. While there is no universally accepted protocol, it is common for clinicians to encourage but not oblige guessing. A recommended procedure is that if half or more letters on a given row are read correctly, the patient should be asked to try to read any letters in the next row, and explicit permission should be given to guess when not quite sure. Usually, the patient is not told whether responses are correct or not, and the clinician does not point in order to help the patient locate the row or a letter within a row.

Future changes in visual acuity testing
Most measurement of visual acuity in clinical research is using charts printed on trans-illuminated plastic panels or on cards with a width about 65 cm or more designed for a standard viewing distance of 4 meters. The size range extends from logMAR =1.0 to -0.3. (i.e., 20/200 to 20/10) In order for such a chart to be presented on a computer-controlled display, a screen with 4 or more megapixels is required. But both the research and clinical ophthalmic communities are beginning to use computer-controlled tests of visual acuity. Computer-controlled tests enable easy variations to the visual stimulus by allowing choices of different sets of optotypes, and changes of the layout from chart format, to single rows, to isolated letters or to single letters with nearby flanking lines. Stimulus variables such as luminance, contrast, color and presentation times become easily varied. With computerized control, detailed data can be recorded, instant scores and reliability values can be generated and different psychophysical testing strategies and procedures can be implemented. The subjects’ responses could be generated by their own keyboard or button-press responses or by speech. And there can be more sophisticated and potentially useful performance information available from response times or detailed error analysis.

With computerization of visual acuity testing there should be much better control of the testing procedures but there will be much more diversity in the tests being used. It can be expected that, for a given test, better measurements will be obtained, but with an expanded diversity of tests it will become more difficult to compare the results from one test to another. Thus, it will become more important for clinicians and researchers to record and report the details of their visual acuity tests, and for collecting data for research or monitoring individual patients, the test procedures should remain consistent.

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