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Visual acuity testing. From the laboratory to the clinic ☆

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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

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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 5×4 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