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LogMAR-based visual acuity measurements: limits of normality

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Abstract

***Aim*: To review critically the literature on the use of logMAR visual acuity tests. This includes visual acuity norms for a range of different ages and tests, and repeatability values.**
***Method*: A literature review was conducted of data on validity, age norms and repeatability of currently available logMAR tests.**
***Results*: All the methodological discrepancies concerning the Snellen-based tests have been accounted for in the design of logMAR-based tests. Tests available for paediatric use include the crowded and uncrowded logMAR test, Kay's linear logMAR crowded picture test, HOTV acuity test and the Lea Symbols chart. Normative acuity data have been reported for logMAR tests for children from 3 to 11 years of age and young adults. The data show that with increasing age the mean acuity improves and the range attributed to normal narrows. The repeatability and reliability of the ETDRS and crowded logMAR tests have been determined and values reported for the detection of change.**
***Conclusions*: Research to date remains sparse on visual acuity norms as a function of age for log-based tests and data tend to be on one test for a limited age group. There is a need for comparative age-specific normative data for acuity scores for logMAR tests, which could only be achieved by undertaking a large cohort study evaluating multiple tests on the same children in the age range 3 to 7 years.**

Key words: Crowded logMAR, ETDRS, Kay's linear, LogMAR visual acuity, Repeatability, Single logMAR

Introduction

An assessment of visual acuity is attempted in the evaluation of every patient attending an eye clinic, vision screening programme or high street optometrist, to assess the integrity of the central visual pathway, monitor change and guide the clinician to an area for further assessment. Given that visual acuity assessment forms such an integral part of the evaluation by all eye care professionals, tests that provide an accurate (valid and repeatable) measure of visual status are required. The deficiencies in the design of Snellen-based tests and the advantages of log-based tests are well documented. This has led to a gradual increase in the use of logMAR-based visual acuity tests over the last 10 years.[1–4] At this time when logMAR tests are being introduced into different clinical situations[5] it is important that an evidence-based approach is adopted in their implementation.

This review aims to highlight the advantages of using logMAR-based tests and considers the literature on the validity, reliability and sensitivity of the tests as a function of age in order to provide some guidance for their use.

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Test design: Snellen versus logMAR

The Snellen chart has many methodological deficiencies, which have an impact on the accuracy of the measurement (Fig. 1*a*). All these methodological issues have been accounted for in the design of logMAR chart (Fig. 1*b*). The logMAR chart allows measurements to be made with the same precision at all levels of acuity, which is particularly important when attempting to monitor patients with reduced visual acuity. In addition, the chart allows interpolated scoring of acuity, which contributes to the improved sensitivity of repeatability scores for the test. Factors in the design of letter test charts have been summarised in Table 1. Comparison of visual acuity scores between the Snellen chart and logMAR charts has revealed a high degree of variability[9,10] (in the region of ± 0.18) compared with that (± 0.07) between different logMAR tests. Calculations of the repeatability of each test have revealed that detecting a real change in visual acuity with certainty requires at least 3 lines difference for the Snellen chart compared with 1.5 lines for log-based tests.[9–11] LogMAR-based tests have been widely accepted as providing an accurate and efficient measure of visual acuity[4] and are now established as the 'gold standard' for acuity measurement of children and adults.

LogMAR tests available

The ETDRS (Early Treatment of Diabetic Retinopathy Study) chart shown in Fig. 1 and derivations of this chart are the gold standard test for adults and children 6 years and above. For children younger than this there is a wide range of tests available, which use either letter or picture optotypes. These tests include the crowded and uncrowded logMAR tests (manufactured by Keeler), Kay's linear logMAR crowded picture test, the crowded HOTV acuity test and the Lea Symbols chart (picture symbols arranged similarly to the ETDRS chart).

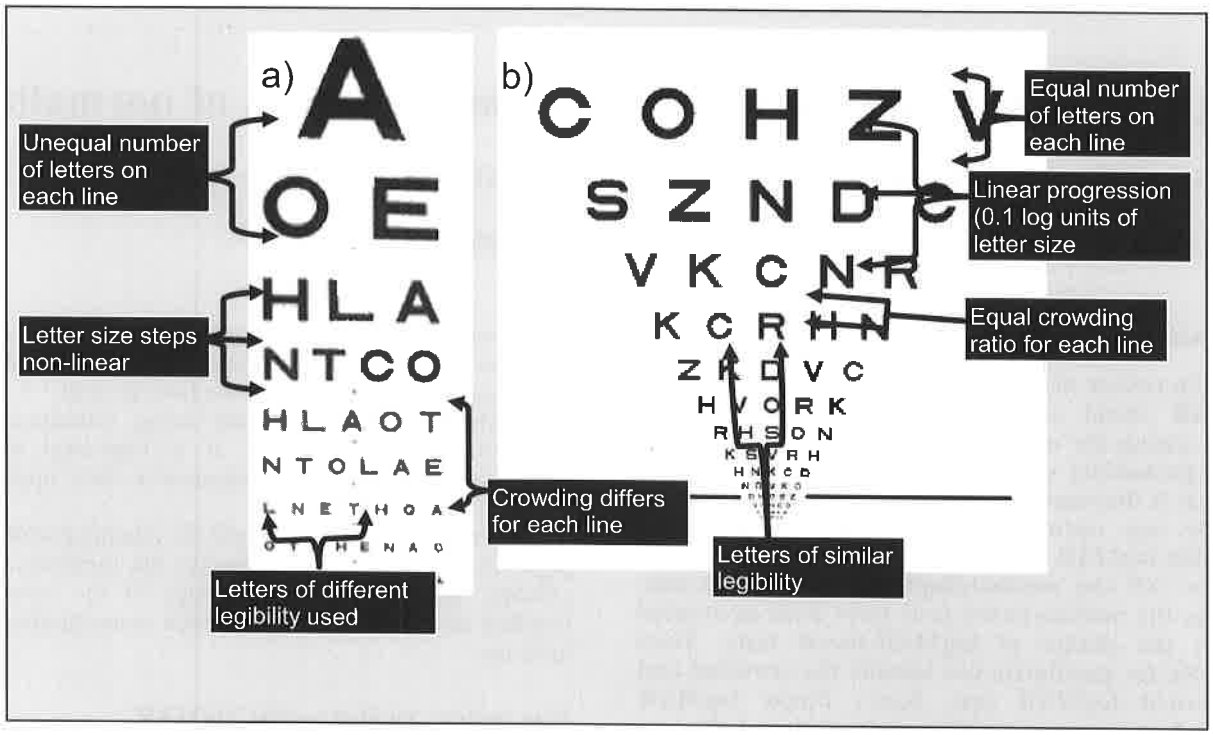

Fig. 1. (*a*) Snellen chart highlighted with methodological discrepancies. (*b*) LogMAR chart (ETDRS) highlighted with methodological improvements.

The crowded logMAR test (part of the Keeler logMAR package) is well recognised as providing equivalent measures of letter acuity to the ETDRS.[9] It was designed for use with the 3½ to 5 year age group and is performed at 3 metres. There are four letters on each line and crowding bars surround each four-letter row. Each letter is given a score of 0.025, so that acuity can be recorded to the nearest letter seen. Six letters are used (X V O H U Y), of which four have been randomly selected for each line. The normal mean acuity for this test is dependent on the age of the child,[10,11] but is in the region of 0.00 to 0.200 logMAR (6/6 to 6/9.5 Snellen equivalent). The uncrowded version of this test (part of the Keeler logMAR package) is a useful easy letter test for children aged 2½ to 3½ years. However, the incorporation of crowding contours into acuity tests has been shown to improve the detection rate for amblyopia.[12,13] For this reason many professionals prefer to use a linear picture test until the child is able to do a linear letter test.

The Kay's logMAR crowded picture test is of similar design to the crowded Keeler logMAR test. It is performed at 3 metres with picture spacing of 0.5 picture diameter and crowding bars that surround the row of four pictures. The test depicts eight familiar pictures (duck, house, clock, van, fish, apple, boot, cup) of which four have been randomly selected for each line. However, the optotypes are 1.5 times bigger than the

Table 1. Factors in the design of visual acuity tests: comparisons between Snellen and log-based tests

Design factor	Snellen-based tests	Log-based test
Progression of letter sizes	• Irregular progression of letter sizes • Sensitivity restricted, particularly around normal vision cut-off (6/9–6/6 region)	• Linear progression of letter size equal to $10\sqrt{10}$ (0.1 log units) • Sensitivity the same throughout the chart
Number of letters per line	• Different number of letters on each line • Scoring to the nearest letter not possible • Different visual task at each level	• Equal number of letters per line • Interpolated scoring system (score by letter) • As a criticism, scoring to the nearest letter approximates the size of letter seen (for example a score of 0.04 refers to 0.1 line plus 3 letters of 0.0 line, not a letter 0.04 in size)[6]
Crowding	• Unequal crowding throughout the test • Crowding ratio dependent on the level of vision (for example 6/24 ≅ ½ letter width spacing between letters, 6/5 ≅ 2 letter widths)	• Crowding equal throughout the test (1 letter width: logMAR chart, Lea test; 0.5 letter width: Keeler crowded test, Kay's linear logMAR test) • Optimum crowding 0.4 to 1.0 letter width[7]
Legibility of letters used	• Irregular legibility (0.53 to 1.36)	• Sloan letters used • Similar legibility (0.58 to 1.0)[8]
Grading scale	• Coarse in parts (line differences range from 0.08 (6/5 to 6/4) to 0.220 (6/60–6/36) log units)	• Fine (0.02 or 0.025 log units)

Table 2. LogMAR visual acuity norms for adults and children

Reference	Age group (years)	Test	Mean visual acuity ± SD (logMAR)	Normal range
Elliott *et al.*, 1995[14]	18–24	ETDRS	−0.130 ± 0.06	−0.200 to 0.000
Manny *et al.*, 2003[15]	6–11	ETDRS	0.010 ± 0.08	−0.160 to 0.140
Jones *et al.*, 2003[16]	3–5	Crowded Keeler logMAR	0.04	−0.125 to 0.3
		Kay's linear logMAR	−0.04	−0.100 to 0.225
Stewart, 2000[11]	4–6	Crowded Keeler logMAR	0.087 ± 0.10	0.000 to 0.400
		Uncrowded (single) Keeler logMAR	−0.010 ± 0.10	−0.100 to 0.300
Shea and Gaccon, 2006[17]	3	Crowded Keeler logMAR	0.200 ± 0.09	0.025 to 0.375
	4	Crowded Keeler logMAR	0.142 ± 0.08	−0.025 to 0.300

logMAR score recorded. This is because each picture represents 7.5 × 7.5 minutes of arc to accommodate 1 minute of arc detail within the picture. This could potentially lead to overestimates of threshold visual acuity.

Age norms

A range of values rather than a single value more appropriately represents normal visual acuity. This is because a variation in repeated measurements for the same individual is expected, as is a variation within a given population. Table 2 shows mean visual acuity and the normal range of acuity values obtained for the ETDRS, crowded Keeler logMAR test, Kay's linear logMAR crowded picture test and the uncrowded (single) Keeler logMAR test. The values presented in the table suggest that a better mean acuity value and a narrower range of normal are obtained with increasing age into adulthood. For example, at 3 years of age the normal range on the crowded Keeler logMAR test is 0.025 to 0.375 with a mean acuity value of 0.200, whereas for adults tested on the ETDRS the range is −0.20 to 0.0 with a mean of −0.13. Therefore a child aged 3 years should not be expected to see 0.00 (6/6 Snellen equivalent). These differences in mean scores and the normal range should be considered when judging whether an individual has 'normal' visual acuity and when determining the referral criteria for a vision screening programme.

Comparison of tests

For younger children aged 2 to 5 years there is a range of vision tests available and the test chosen at a clinical visit may be dependent on the ability of the child on the day. Consequently, it is important to know whether test results using different tests are comparable. The tests of particular interest are the Kay's linear logMAR crowded picture test and the crowded and uncrowded Keeler logMAR tests. Jones *et al.*[16] compared the Kay's linear logMAR crowded picture test and the crowded Keeler logMAR test on a clinical population of 103 children aged between 2.5 and 16 years who attended the hospital with suspected amblyopia. The testability of children aged between 2½ and 5 years was found to be greater for the Kay's linear logMAR than the crowded Keeler logMAR test (70% vs. 60%; see Table 3).[16] The mean ages of children unable to perform the test were 3.13 years and 3.6 years for the Kay's linear logMAR and crowded Keeler logMAR tests, respectively. For the 83 children who were able to perform both tests, vision scores were not clinically significantly different and were found to be highly correlated, indicating a good agreement with the scoring. A 100% testability has been reported for children aged 4.9 years using the crowded and uncrowded (single) Keeler logMAR tests (Table 3).[11]

Reliability of logMAR tests

A clinician needs to determine whether a patient's visual acuity is stable ('unchanged') or whether it has changed. The detection of change is important clinically as it is likely to influence the management strategy. To define the difference between changes that occur due to normal test–retest variability and a real change it is necessary to know how 'reliable' or 'repeatable' a test is, i.e. the level of agreement between replicate measurements in an interval where no change was expected. From test–retest scores confidence intervals can be established to define what degree of change in the measurement constitutes a real change. Small confidence limits will allow changes in visual function to be detected with increased

Table 3. Comparison of the crowded Keeler logMAR, uncrowded (single) Keeler logMAR and Kay's linear logMAR tests

Reference	Age (years)	Tests compared	Mean difference (log units)	Significance	Testability
Stewart, 2000[11]	4.9 ± 0.3	Crowded Keeler logMAR vs. uncrowded (single) Keeler logMAR	0.125	<0.001 (singles higher)	100% vs. 100%
Jones *et al.*, 2003[16]	4.3 ± 1.0	Crowded Keeler logMAR vs. Kay's linear logMAR	0.080	<0.001 (Kay's higher)	60% vs. 70%

Table 4. Repeatability of the crowded Keeler logMAR and ETDRS tests for children

Reference	Age (years)	Test	Corrected?	Repeatability	Detection of change
McGraw *et al.*, 2000[10]	5.3 ± 1.2	Crowded Keeler logMAR	Yes	±0.100	±0.125
Stewart, 2000[11]	4.9 ± 0.3	Crowded Keeler logMAR	No	±0.200	±0.225
Manny *et al.*, 2003[15]	6–11	ETDRS	Yes	±0.130	±0.150

sensitivity. The finer the grading scale, i.e. the smallest increment change possible on the test, the more repeatable the test is likely to be and therefore the greater the sensitivity with which change can be detected.[18]

A logMAR chart allows measurements to be attained with the same precision at all levels of acuity and provides highly repeatable measurements of visual acuity;[18–20] it therefore detects change with increased precision compared with Snellen-based charts.

Data for the repeatability of the ETDRS and crowded Keeler logMAR test are shown in Table 4. The repeatability values shown represent the normal test–retest variation (±1.96 standard deviations of differences between test and retest results) of acuity. A significant change in acuity score is calculated by taking the repeatability value for the test and adding one scale increment of the test, i.e. one letter value, which is 0.02 for the ETDRS and 0.025 for the crowded Keeler logMAR test. Reported values for the detection of change for the ETDRS and crowded logMAR tests have ranged from ±0.125 to 0.25 log units.[4,11,12,15,19,20] Repeatability values tend to be larger, i.e. measures are more variable, when the tests is administered to children with refractive error uncorrected compared with corrected (Table 4).

Screening issues: significant inter-ocular difference

Reduced visual acuity is the widely accepted clinical indicator of amblyopia and is frequently used for the detection of the condition in visual screening programmes. It is not the intention of this paper to consider screening referral criteria, which have been discussed elsewhere,[21] but to consider the issues with regard to normative data for the test used. The pertinent issues are: the level of vision considered abnormal and the level of inter-ocular difference considered abnormal for the given age group and test used.

When considering the first issue it is essential to take into account the normal variation for age to ensure the screening programme is highly sensitive (i.e. it detects all those with the disease) and specific (i.e. it does not detect any of those without the disease). In addition the criterion for a significant difference in acuity between the eyes is needed to ensure the detection of unilateral disease such as unilateral amblyopia – that is, the level of inter-ocular difference that represents a genuine abnormality in one eye above that gained from inter-ocular variability resulting from, for example, fatigue by the time the second eye is tested. An abnormal acuity is one scale increment, i.e. one letter/picture value, or more above the upper limit of the normal range of inter-ocular difference.

Snellen-based charts are still commonly used in screening programmes. However, due to their coarse grading scales, large confidence limits are required to be certain of abnormal vision, which prevent them from being useful stand-alone tests for vision screening.

Summary

It is clear from research aimed at investigating the validity, repeatability and precision of logMAR visual acuity charts that these tests are superior to Snellen-based tests. Research remains sparse on normal visual acuity values as a function of age for logMAR-based tests. Existing data tend to be on one test for a limited age group. There is a need for comparative age-specific normative data for acuity scores for the logMAR tests. This could only be achieved by undertaking a large cohort study evaluating multiple tests on the same children in the age range 3 to 7 years. This would contribute to the widespread implementation of these tests and the provision of appropriate guidelines.

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