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Measurement of letter acuity in preschool children

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Introduction

Measurement of visual acuity remains the most frequently used technique for the assessment of vision in both adults and children. Visual acuity is usually measured clinically in adults using a Snellen chart. However, this technique demands a level of cognition and literacy which is beyond the majority of young children. The measurement of visual acuity in preschool children presents an additional set of problems but it is important that measures of acuity are made with sufficient precision and accuracy to provide the clinician with valid information.

While visual acuity can be measured in infants and very young children using behavioural and electrophysiological techniques, clinical measurement of letter acuity usually commences when the child is old enough to interact and co-operate with the examiner. By 3 years of age 67% of children will co-operate with visual acuity testing, and by the age of 3.5 years a level of 80% compliance is achieved.

The need to detect and correct visual disorders during childhood has been recognized for many years by eye-care professionals. Although identification of reduced visual function due to ametropia is important, the detection and treatment of amblyopia is essential to allow development of optimal visual function. Amblyopia may be considered as a developmental disorder of spatial vision that is associated with the presence of a 'sensory obstacle' during the child's formative period of development. With a prevalence of 2–3%, amblyopia is the major cause of reduced visual function in the first decade of life[1], and remains 10 times more likely to be the cause of reduced visual function, as opposed to any other ocular disease or trauma, in the first two decades. Although amblyopia is not a life-threatening condition, there remains a valid sociological argument that every child should have the opportunity to achieve good binocular visual function.

Many studies have shown that normal binocular vision can be restored if amblyopia therapy is completed before the age of 2 years[2,3]. This represents the ideal, but unfortunately many children do not present until after this age. Older amblyopic children may not go on to develop normal binocular vision, but significant improvements in monocular acuity can still be achieved. However, it is difficult to obtain an accurate measure of visual acuity in the under-2-years age group. One particular problem is that it can take a considerable amount of time to obtain a measure of acuity, which reduces the likelihood of successfully completing the measurement procedure. In addition, behavioural procedures currently available show low reliability, particularly for the detection of amblyopia[4,5]. For these reasons many amblyopes remain undetected until they are able to perform more reliable letter acuity tests.

In older children (>2.5 years) it is essential that measurement of letter acuity is performed accurately using procedures which are sufficiently sensitive to allow change to be detected. Children with amblyopia are a unique group of patients as they receive active therapy to improve their level of vision. As orthoptic treatment of these children is monitored longitudinally, tests of letter acuity which are accurate and reliable in this age group must be employed.

A vast array of tests exist which have been designed for the evaluation of visual acuity in preschool children. A complete review of all of these tests is beyond the scope of this article, and the interested reader should consult two recent reviews[5,6] for a more detailed treatment.

Picture tests

Visual acuity testing can commence in younger non-literate children using picture or symbol tests. The object of the test is for the child to match or name familiar pictures presented to them on either a chart or in a flip-book. However, picture recognition

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tests suffer from a number of drawbacks. The results are influenced by the child's familiarity with the object, by their vocabulary, and by social and cultural factors, all of which increase the variability of the test and reduce the reliability. Furthermore, the results of the test are difficult to relate, except in an approximate manner, to standard letter acuity measures. Despite these criticisms, picture tests are more successful in obtaining acuity measures in younger children (2–3 years), than letter-based tests. Two picture-matching tests are worthy of note, namely those developed by Kay[7] and Elliott[8]. Both of these tests employ pictures which are constructed on Snellen principles. Two of the test symbols from the chart developed by Kay are shown in *Figure 1*.

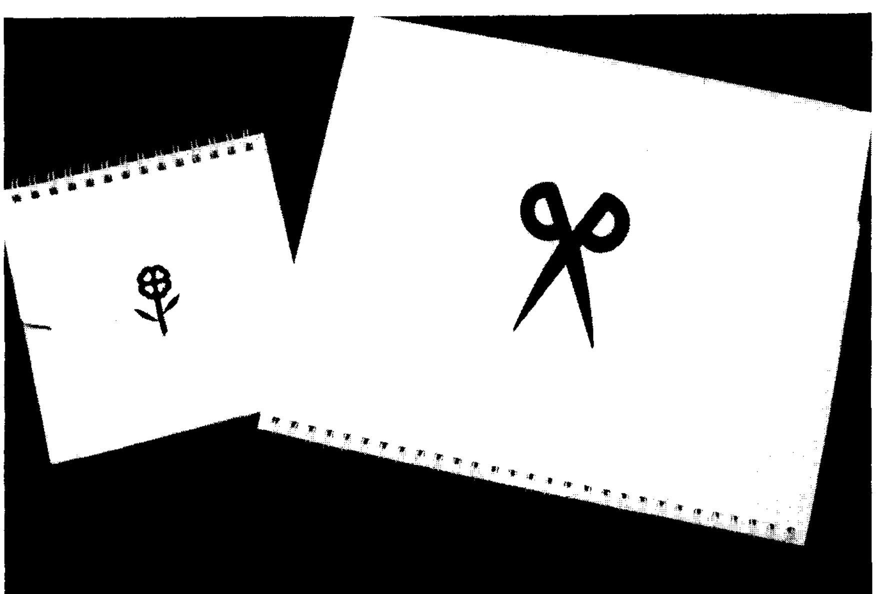

Figure 1. Examples of two of the symbols which are used in Kay's picture-matching test.

Letter acuity tests

Although the Snellen chart is used widely in clinical practice it has been shown to be inappropriately designed for accurate and repeatable measures of visual acuity, especially in patients with reduced vision. Several factors contribute to the shortcomings of Snellen charts:

- Irregular progression of letter sizes on the chart and the tradition of scoring by line do not allow interpolation of scores between lines, which restricts the sensitivity of the test.
- Variation in the number of letters on each line presents the subject with a task of increasing difficulty, rather than providing an approximately equivalent task at all acuity levels.
- At higher acuity levels the scale is truncated, which prevents the use of parametric statistics.
- The legibility of test letters is variable, which means that nominally equally incremental steps on the chart are not equally discriminable. This is particularly important at low acuity levels where only one or two letters are presented.
- Perhaps the major problem with Snellen acuity is the use of a coarse scale, coupled with the lack of a standardized and accurate scoring system. Individual letter scores cannot be incorporated into the final acuity score if standard Snellen charts are used.

Test developments

The above problems have led to the development of alternative charts[9,10] for the measurement of visual acuity. The most notable innovations in the design of new test charts are the use of a logarithmic progression in letter size[9,10], and the introduction of an equivalent test task for all acuity levels, ensuring that the only variable parameter is the change in angular size of letter[9,10]. These charts have been shown to provide accurate and reliable measures of visual acuity[11] and have been used extensively in research.

Until recently, developments in chart design for the measurement of letter acuity in preschool children had not paralleled those used in the production of adult test charts[6]. Commercially available letter charts in the UK for measuring acuity in preschool children between 3 and 5 years of age tend to use single optotypes[12] or are derivatives of the Snellen format[13], and consequently incorporate the inherent drawbacks of this technique.

The performance of any letter charts for use with preschool children will be determined by a number of factors, including the design of the chart. Several design features which require consideration are discussed below.

Test design considerations

Letter size progression

Accurate and reliable measures of visual acuity can be achieved by utilization of a regular geometric progression of letter size, whose ratio is equal to $10\sqrt{10}$ (0.1 log unit)[9]. Letters in each row are larger than those in the following smaller row by a factor of approximately 1.26. This progression ratio offers several advantages. It provides approximately equal increments in resolution[14] across the chart, allows parametric statistical analysis of results, and can also be applied to the standard test distance.

A 0.1 log unit reduction in test distance will cause a 0.1 log unit increase in the angular size of the letters. For example, if the test distance is reduced from 6 to 4.76 m (i.e. reduced by a factor of 1.26), the subject will be able to read one line of letters more than they could achieve at 6 m. A schematic comparison of a logarithmic progression in letter size as compared with the standard Snellen progression is shown in *Figure 2*.

Letter legibility

It is widely accepted that children develop vertical laterality earlier than horizontal laterality; therefore, all letters used as acuity targets should ideally be symmetrical about the vertical mid-line to avoid confusion when used with younger children. It is also important that these letters should be of approximately equal legibility so that incremental steps on the acuity scale are equally discriminable.

Letters per line

It is important that the difficulty of the task remains constant at each acuity level. This factor is controlled by employing letters of equal legibility and ensuring that the number of letters presented at each acuity level is constant.

Visual acuity range

Tests should allow assessment of visual acuity over a large range to avoid truncation effects at each end of the measurement scale.

Control of contour interaction

The effects of adjacent contours on spatial resolution vary with the separation between target and flanking contour[15]. Letter resolution remains undiminished until an adjacent contour is placed at a distance equivalent to the width (or diameter) of the target letter, and is maximally impaired when adjacent contours are placed 0.4 letter diameters away[15]. This phenomenon has been described using a number of terms, such as: contour interaction, visual crowding, separation difficulty or lateral masking. The superior performance achieved by children when tested with single optotypes compared to line acuity is well documented[16] and has been shown to be due in part to the effects of contour interaction. The effects of contour interaction have been shown to be greatest in childhood, and gradually reduce during the preschool years as part of normal visual development[17]. Changes in the extent of contour interaction with visual maturation negate the application of a simple correction factor to single optotype acuity to account for natural crowding effects.

Therefore, it is necessary to control for such effects when testing the spatial resolving capacity of preschool children. This has been recognized by several workers who have attempted

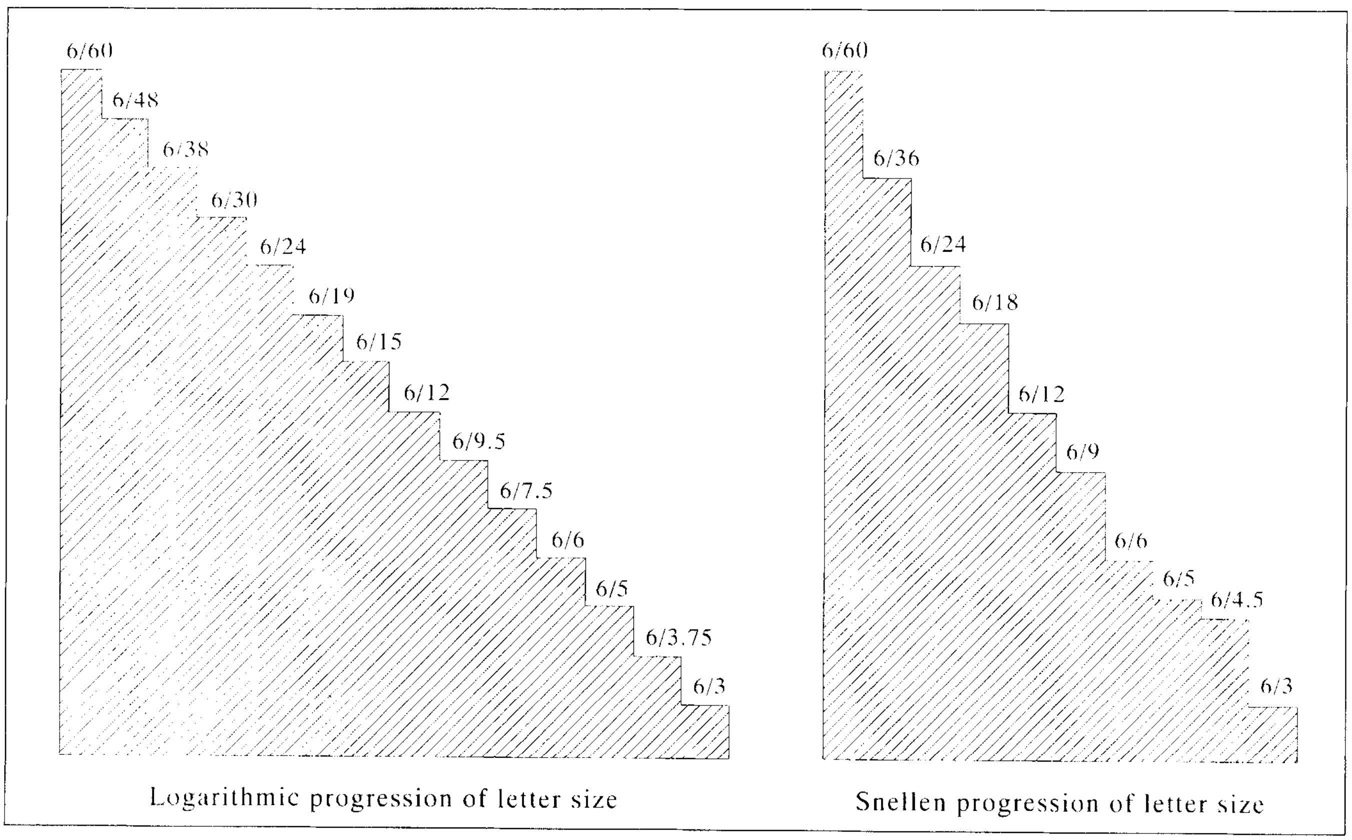

Figure 2. Comparison of a regular geometric change in letter size with the traditional Snellen scale. Scale increments are particularly coarse on the Snellen scale at lower acuity levels.

to include spatially interacting contours into visual acuity tests designed for use in this age group[13,18–21].

Test distance

A 3 m test distance reduces test times[22] and increases patient co-operation, particularly in poorly motivated children[22]. It has been suggested that some children perform slightly better at this reduced distance for psychological reasons. No significant difference exists between the effects of contour interaction, single letter acuity and line acuity when viewed at 3 or 6 m[13].

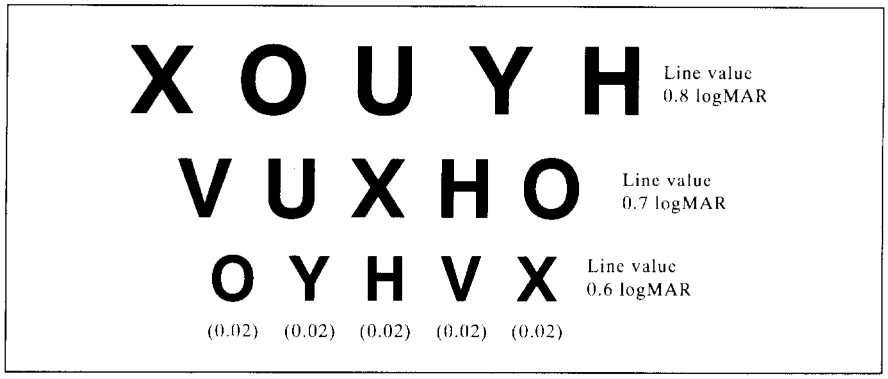

Figure 3. The letter sizes on the chart progress in 0.1 steps. Since there are five letters on each row, each letter is assigned a value of 0.02 log units. Therefore, a patient who reads all the letters on the 0.8 log MAR row and then reads two extra letters on the 0.7 log MAR row would be given a score of 0.76 log MAR units. The same score would be achieved if one letter was missed on the 0.8 log MAR line and three additional letters were identified on the 0.7 log MAR row.

Clinical grading and scoring systems

Several recent reports[23–25] have shown that selection of appropriate grading scales can improve clinical measurement of letter acuity, and allow differences in grades to be determined with increased confidence.

There are a number of options available for scoring a log-based acuity system. The most commonly used method is based on the logarithm of the minimum angle of resolution (log MAR). For example, a 6/6 letter limb width subtends 1 min arc at a distance of 6 m. As the log of 1 is 0, 6/6 is given the equivalent log MAR score of 0. Similarly, since a 6/60 letter limb width subtends 10 min arc, the log MAR score equivalent to 6/60 is 1. As the letters change in size by a constant amount (0.1 log unit) from one line to the next, provided each line has an equal number of letters and these letters are of approximately equal legibility, individual letter scoring can be adopted, which allows interpolation of acuity scores between lines on the chart.

For example, if the change in letter size between lines is 0.1 log unit and there are five letters on every line, each letter correctly identified or missed can be allocated a score of 0.02 log unit (*Figure 3*). Similarly, if the chart had four letters per line, each letter could be assigned a value of 0.025 log unit. Extra letters read or matched by the subject are added to the final score, while letters which are missed or called incorrectly are subtracted.

This log-based method of scoring offers several advantages. It affords discrimination between children with similar Snellen acuity, and allows accurate measurement of low letter acuity. The major advantage to be gained by using this scoring technique is that by scoring each letter the clinical grading scale is effectively made five times finer (for a chart with five letters per line) than a scoring by row technique[23], which consequently improves the clinicians' ability to detect change[23].

General factors

Many young children may be incapable of providing adequate verbal responses to allow a measure of letter acuity. For this reason, a matching response, via a keycard has been suggested as the most appropriate response method for measuring letter acuity in preschool children.

Clearly, preschool children will be unable or unwilling to match a large number of letters to allow an accurate measure of threshold visual acuity to be determined. To overcome this problem, the clinician often has to implement a screening approach, where one letter is shown at each acuity level until the child makes a mistake. The clinician then goes back to the previous level and asks the child to match the remaining letters. This procedure is repeated until the majority of letters at a particular acuity level are not correctly identified. An alternative approach is to incorporate a set of screening cards, which allow the clinician to quickly identify a starting point for the measurement of letter acuity.

Artefacts introduced through memorization and inter-session variability are also an important consideration. If letter acuity is to be used to assess the efficacy of amblyopia therapy, or any other treatment modality, then training effects must be controlled or minimized. This is best achieved by having a number of versions of the same test, each of which presents different letters or presents the letters in a different sequence at the same acuity level. Therefore, different charts can be used if frequent retesting of acuity is indicated or if an acuity score requires verification on the same visit.

Children's letter acuity tests

Sheridan–Gardiner test

The most widely used tests for assessing visual acuity in preschool children are the single letter acuity tests, many of which are derivatives of the original test devised by Dr Mary Sheridan, such as the Sheridan–Gardiner test[12] (*Figure 4*). The original version appeared as a nine letter-matching test. While this test was successful in assessing letter acuity in older children, it proved to be too complicated for younger preschool children. The current version of the Sheridan–Gardiner test uses seven vertically symmetrical letters (H U X T A V O), which are presented singly in three flip books which range as follows: 6/60–6/24, 6/18–6/9 and 6/6–6/3 when used at 6 m. Further reductions in the number of test letters to four (H O T V) have been advocated by some authors, in an attempt to facilitate the testing of younger children.

Several shortcomings exist in the design of this test. The seven letters used vary in legibility, and an interpolated scoring system cannot be employed. Perhaps the most important criticism of single letter acuity tests remains the failure to account for the effects of contour interaction. An early attempt to modify a single letter acuity test, by adding interaction or confusion bars, was described by Flom and is reported in an article by Friendly[21]. An example of one of the test cards is shown in *Figure 5*. Unfortunately, this important feature has not been incorporated into the currently available Sheridan–Gardiner test.

Cambridge crowding cards

Recently, Cambridge crowding cards were introduced, and endeavoured to address the problem of contour interaction. In this test the child's task is to identify a central letter which is surrounded by four other letters (*Figure 6*). The central letter is from the set of letters comprising H O V T X, while different letters are used to surround the central letter (L U A C) to avoid confusion. The spacing between the adjacent letters is equivalent to 0.5 letter diameter, which increases the amount of contour interaction to approximately 80% of the maximum effect.

A 3 m single letter acuity chart is also provided with the test to allow the clinician to calculate a crowding ratio, which is simply the unflanked acuity divided by the flanked acuity. If this value is greater than unity then visual crowding or contour interaction is present.

Measured visual acuities range from 3/30 to 3/1.5 (equivalent to 6/60–6/3) allowing parametric statistical analysis of the complete distribution of acuity scores. The set of crowding cards present three test cards at each acuity level from 3/9 to 3/1.5 (equivalent to 6/18–6/3). The standard clinical procedure for scoring is to designate letter acuity as the smallest letter size at which 2 of the 3 central letters were matched correctly. The adoption of a Snellen-based letter size progression, and the provision of different numbers of letters at low acuity levels negates the application of an interpolated scoring system and consequently restricts the clinician's ability to detect changes in acuity using this test.

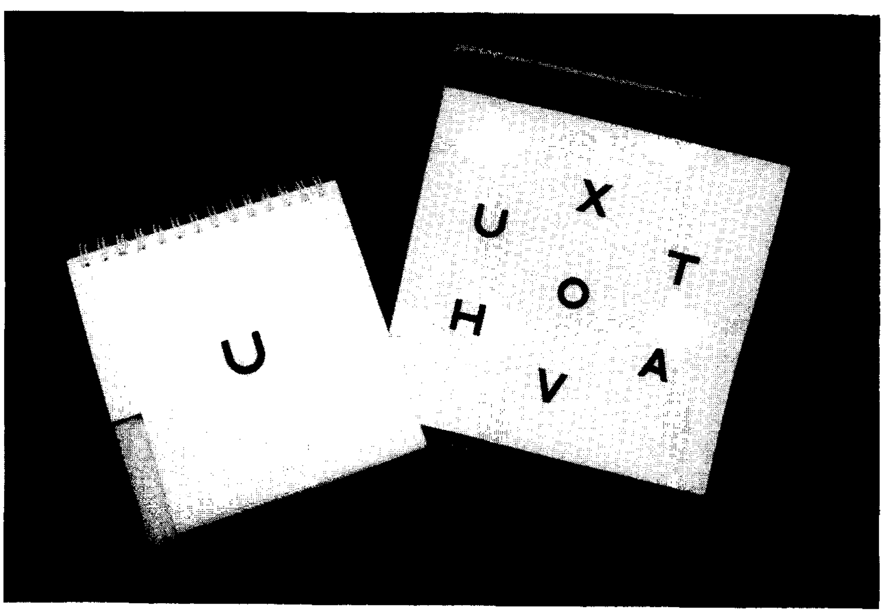

Figure 4. Sheridan–Gardiner single letter acuity test.

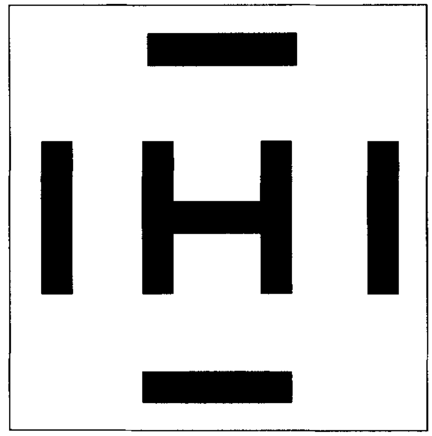

Figure 5. Single letter acuity target with confusion bars positioned at half a letter diameter. The flanking contours are designed to control for natural crowding effects.

Sonksen–Silver acuity cards

The Sonksen–Silver acuity cards present optotypes in a linear format. Six test letters are used (H O V T X U), and are displayed on a key card in a curved line. For acuity levels from 6/36 to 6/3 there are five letters on each line. The spacing between the letters is equal to one letter diameter, the position at which the effects of contour interaction are just detectable. Unfortunately, only the three central letters are crowded on both sides and no vertical crowding is present.

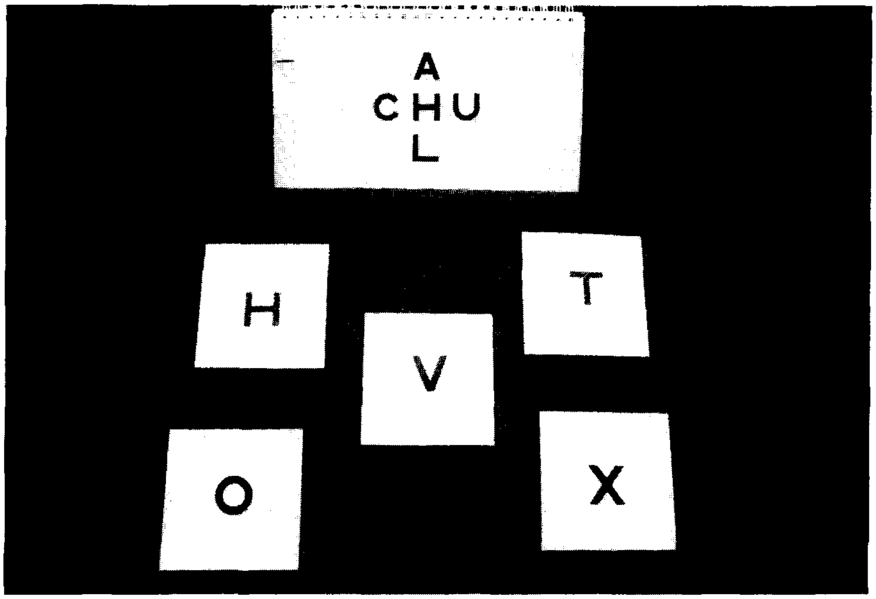

Figure 6. Cambridge crowding cards. The child's task is to identify the central letter in the five letter array using a letter-matching response. Contour interaction is controlled by the use of appropriate interletter spacing.

Glasgow acuity cards

This test was designed specifically to overcome the shortcomings of currently available letter acuity tests for preschool children (*Figure 7*). The key design features of the test are as follows:

- A 3 m test distance.
- An equal number of letters per line (four).
- Letters of approximately equal legibility (O U V X Y H) which are symmetrical about the vertical mid-line.
- Acuity scale ranges from 3/19 to 3/1.5 (equivalent to 6/38–6/3).
- A regular geometric progression of letter size (0.1 log unit).
- Screening cards are used to identify a starting point for the measurement of line acuity (*Figure 7*). Each letter on the screening cards corresponds to a specified acuity level within the chart system. All screening cards control crowding effects and each of the six letters used appear an equal number of times in the screening series. Once a starting point is identified a maximum of three cards are exposed to obtain a threshold measure.
- Control of contour interaction. The interletter spacing is the same as the Cambridge crowding cards (0.5 letter diameter). Standardization of the crowding effect at each acuity level is controlled by using a crowding bar to surround the four letter array, the width of which is equal to the stroke width of a letter (*Figure 7*).

Perhaps the most important feature of the Glasgow acuity cards is the use of an interpolated log-based scoring system. A modification of the logMAR scoring system is used. In the Glasgow system 6/6 is designated a score of 1 and 6/60 a score of 0, with visual acuities less than 6/60 carrying a negative sign. Improvements in acuity, therefore, result in an increase in the

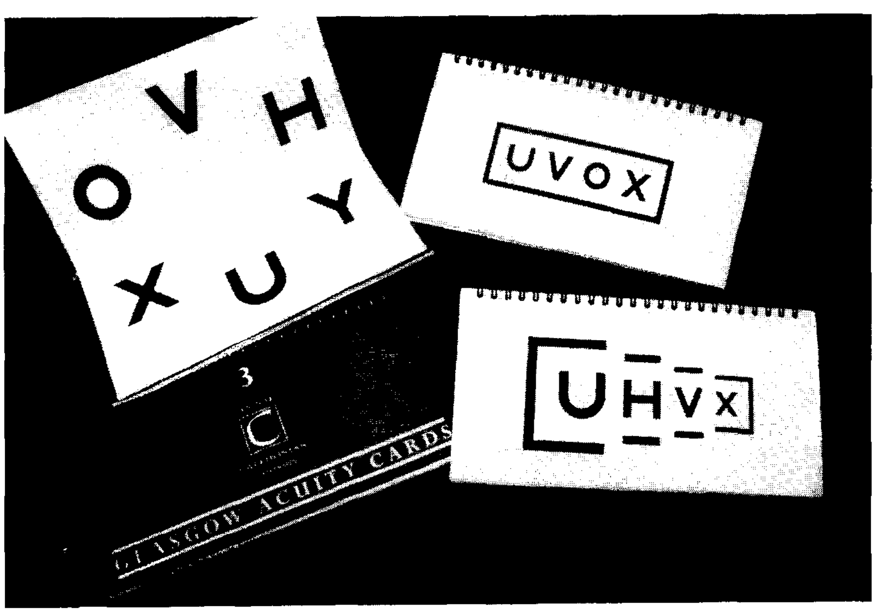

Figure 7. Glasgow acuity cards. An example of a single screening card, and a typical line of letters are shown. Each of the letters on the screening card corresponds to an acuity level in the chart system. The screening cards are used to identify a starting point for the measurement of line acuity. Cards for the measurement of line acuity control contour interaction by appropriate interletter spacing and incorporation of a surrounding crowding bar.

score unlike the logMAR system described previously, where improvements are denoted by a reduction in the score. The Glasgow acuity cards (GAC) score can be calculated from the following:

GAC score = 1 − logMAR

The largest line on the GAC is equivalent to 6/38 Snellen and is assigned a score of 0.2 log units (logMAR 0.8) with each following line changing in size by 0.1 log units to the smallest line which is scored 1.3 log units (logMAR −0.3 or 6/3 Snellen equivalent). As there are four letters per line and the difference between lines is 0.1 log unit, each individual letter correctly identified scores 0.025 log unit. The end-point is reached when the child cannot identify any letters on a particular line, the child being encouraged to guess until this point is reached. The use of this system improves the clinician's sensitivity to detect changes in acuity. This feature is essential for the monitoring of visual therapy such as occlusion for the treatment of amblyopia.

Recommendations

A comprehensive review of preschool visual acuity tests by Fern and Manny[6] made the following constitutional recommendations for a well-designed preschool letter acuity test. The test should consist of:

- high contrast Snellen optotypes without directional components;
- the optotypes should be equivalent to a Landolt C and progress to an acuity level of 6/3 in 0.1 log unit steps;
- a forced choice or matching response should be used at a testing distance of 3 m;
- published norms should be available.

Clinicians should be aware of the limitations of letter acuity tests, and construct performance or confidence limits which will allow change to be detected with increased certitude. Children with amblyopia present the clinician with a unique problem since therapeutic intervention is designed to induce an improvement in acuity. If such improvements are to be detected reliably, and the efficacy of therapy is to be evaluated, it is essential that letter acuity tests are selected which have the necessary level of precision and sensitivity.

References

1 von-Noorden, G. K. In: *Burian-von Noorden's Binocular Vision and Ocular Motility*, 3rd edn, C. V. Mosby, St Louis, USA, p. 212 (1985)
2 Banks, M. S. and Aslin, R. N. Sensitive period for the development of human binocular vision. *Science* **190**, 675–677 (1975)
3 Beller, R., Hoyt, C. S., Marg, E. and Odom, J. V. Good visual function after neonatal surgery for congenital monocular cataract. *Am. J. Ophthalmol.* **91**, 559–565 (1981)
4 Horwood, A. M. The Cardiff Acuity Test in amblyopic children. *Br. Orthopt. J.* **51**, 19–22 (1994)
5 McDonald, M. A. Assessment of visual acuity in toddlers. *Surv. Ophthalmol.* **31**, 189–210 (1986)
6 Fern, K. D. and Manny, R. E. Visual acuity of the pre-school child: A review. *Am. J. Optom. Physiol. Opt.* **63**, 319–345 (1986)
7 Kay, H. New method for assessing visual acuity with pictures. *Br. J. Ophthalmol.* **67**, 131–133 (1983)
8 Elliott, R. A new linear picture vision test. *Br. Orthopt. J.* **42**, 54–57 (1985)
9 Bailey, I. L. and Lovie, J. E. New design principles for visual acuity letter charts. *Am. J. Optom. Physiol. Opt.* **53**, 740–745 (1976)
10 Ferris, F. L., Kassoff, A., Bresnick, G. H. and Bailey, I. L. New visual acuity charts for clinical research. *Am. J. Ophthalmol.* **94**, 91–96 (1982)
11 Lovie-Kitchin, J. E. Validity and reliability of visual acuity measurements. *Ophthal. Physiol. Opt.* **8**, 363–370 (1988)
12 Sheridan, M. D. Diagnosis of visual defect in early childhood. *Br. Orthopt. J.* **20**, 29–36 (1963)
13 Atkinson, J., Anker, S., Evans, C., Hall, R. and Pimm-Smith, E. Visual acuity testing of young children with the Cambridge Crowding Cards at 3 m and 6 m. *Acta Ophthalmol.* **66**, 505–508 (1988)
14 Westheimer, G. Scaling of visual acuity measurements. *Arch. Ophthalmol.* **97**, 327–330 (1979)
15 Flom, M. C., Heath, G. and Takahaski, E. Contour interaction and visual resolution: contralateral effects. *Science* **142**, 979–980 (1963)
16 Fern, K. D., Manny, R. E., Davis, J. R. and Gibson, R. R. Contour interaction in the pre-school child. *Am. J. Optom. Physiol. Opt.* **63**, 313–318 (1986)
17 Atkinson, J., Pimm-Smith, E., Evans, C., Harding, G. and Braddick, O. Visual crowding in young children. In: Detection and measurement of visual impairment on pre-verbal children. London, *Doc. Ophthalmol. Proc. Ser.* **45**, 201–215 (1985)
18 McGraw, P. V. and Winn, B. Glasgow Acuity cards: A new test for the measurement of letter acuity in children. *Ophthal. Physiol. Opt.* **13**, 400–404 (1993)
19 Flom, M. C. New concepts in visual acuity. *Optom. Weekly* **57**, 63–68 (1966)
20 Davidson, D. W. and Eskridge, J. B. Reliability of visual acuity measures of amblyopic eyes. *Am. J. Optom. Physiol. Opt.* **54**, 756–766 (1977)
21 Friendly, D. S. Pre-school visual acuity screening tests. *Trans. Am. Acad. Ophthalmol.* **76**, 383–480 (1980)
22 Pickert, S. M. and Wachs, H. Stimulus and communication demands of visual acuity tests. *Am. J. Optom. Physiol. Opt.* **57**, 875–880 (1980)
23 Bailey, I., Bullimore, M. A., Raasch, T. and Taylor, H. R. Clinical grading and the effects of scaling. *Invest. Ophthalmol. Visual Sci.* **32**, 422–432 (1991)
24 Reeves, B. C., Hill, A. R. and Aspinall, P. A. The clinical significance of change. *Ophthal. Physiol. Opt.* **8**, 441–446 (1987)
25 Lloyd, M. Lies, statistics and clinical significance. *J. Br. Contact Lens Assoc.* **15**, 67–70 (1992)