Chart for visual acuity screening

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SUMMARY The statistical basis underlying the use of several visual acuity charts is examined. A new chart which offers theoretical and practical advantages for visual acuity screening is described.

The measurement of visual acuity is an essential part of the ophthalmological examination and may be quite time consuming. For busy eye casualty departments, where the majority of patients often have visual acuities of 6/9 or better,¹ a visual acuity chart designed for speed and sensitivity is to be preferred. Visual acuity charts which have up to 10 characters to a line² are time consuming and perhaps not well suited for screening purposes.

The Snellen chart achieves a compromise by having fewer letters for the larger character sizes, but this makes the results obtained for each line no longer comparable. For example, if there are two letters on the 6/36 line and eight on the 6/6 line, then clearly, an incorrect response on the 6/36 line has a different significance from an incorrect response on the 6/6 line. The way the results are interpreted depends on the number of characters on each line.

A problem with the use of visual acuity charts lies in the convention used for recording visual acuity. The commonly used methods for recording visual acuity in the United Kingdom do not take into account incorrect responses on preceding lines. For instance, two patients may both have had their visual acuities recorded as 6/9 even if one patient gave an incorrect response on the 6/18 line and two incorrect responses on the 6/12 line while the other patient made no mistakes. In other words, the end point in such a test is ill defined.

An attempt to circumvent these problems has been to design a chart with five letters to a line read at four metres, allowing the examiner to assign an interpolated score for the logarithm of the minimal angle of resolution.³ Although this improves the monitoring of visual acuity, the chart is large, cumbersome and still time consuming.

A further consideration is that individual letters have different degrees of difficulty.^{4,5} Clues to their

identity are given by the overall shape of the letter. For example, a base down triangle is often read as the letter A, a base up triangle as the letter V. In other words the psychic tasks of recognition may enhance visual acuity beyond the level of pure resolution.⁴ Sloan *et al.*⁵ assigned each letter a difficulty score based on how often that letter is read correctly at the visual acuity threshold (Table 1). Most of the commonly used charts in the United Kingdom take no account of these scores in their design.

Further problems arise when clinicians have different criteria as to what is considered a mistake. Some would pass an N for an H, a C for an O, an M for a W, etc, while others have more rigid criteria. Moreover, a major source of error is that patients often remember the letters of a given chart from previous examinations or when the same chart is used for testing both eyes. This problem can be overcome by having separate charts on a rotating box as is usually the case, or by having computer generated symbols.¹

For screening visual acuity a chart that is easy to use, sensitive, and giving results that are not open to misinterpretation is required. We describe here a

Table 1 *Difficulty scores assigned to letters*

<i>Sloan letter</i>	<i>% Correct at threshold</i>
S	70.6
O	71.0
C	71.4
D	79.5
K	82.1
V	84.6
R	86.3
H	89.3
N	91.6
Z	94.0

The degree of difficulty of the Sloan letters as determined by the percentage correct at threshold is shown.

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visual screening chart using paired Sloan letters and discuss the statistical basis underlying the measurement of visual acuity.

Statistical analysis

Consider the null hypothesis that 'a subject is unable to see the letters on a Snellen chart and guesses the answer.' If one letter is presented the probability of guessing correctly is $1/26$ (0.0385) and the probability of guessing incorrectly is $25/26$ (0.9615). If 2 letters are presented, the probability of 2 correct responses is $(1/26)^2=0.0015$; 2 incorrect responses is $(25/26)^2=0.9246$, and the probability of one correct and one incorrect response is $2 \times (1/26) \times (25/26)=0.0740$. The probability of obtaining 2 correct responses from a line of 6 letters is $15 \times (1/26)^2 \times (25/26)^4=0.0190$, whereas the probability of giving 6 correct responses from the same line is markedly less at $(1/26)^6=0.000000032$.

This stringent demand for accuracy is at odds with other psychophysical tests or forced choice situations, or indeed with most of the clinical evidence on which our medical judgment is based. A more usually accepted scientific level of significance is $p<0.05$ or $p<0.01$, which is approached by using a chart with fewer letters per line.

An alternative null hypothesis states that 'although a subject is able to respond correctly an incorrect response is intentionally given.' To reject this null hypothesis it is necessary to demonstrate that a series of wrong responses is significant. The probability of an incorrect response when one letter is presented is $25/26=0.9615$, and thus it would require a line of 118 letters, that is $(25/26)^{118}$, before significance is reached. In other words 118 incorrect responses are so unlikely that the patient is probably malingering. A Snellen chart with up to a maximum of 10 letters per line is thus inadequate for deciding if a patient is malingering.

If a similar statistical exercise is applied to the E test, a different picture emerges. In this chart the letter E is presented in one of four possible directions so that the probability of a correct response is $1/4=0.2500$ and an incorrect response $3/4=0.7500$. To achieve significance $p<0.01$ in favour of a patient being able to see, a series of 4 correct responses needs to be given $(1/4)^4$ ($p=0.0039$). Hence a minimum of 4 Es need to be presented. Similarly to prove that a patient can see a line when an incorrect response is given requires 17 consecutive incorrect responses to achieve significance—that is $(3/4)^{17}=0.0075$. The Landolt ring, which is also used in one of four directions, is subject to the same analysis.

In general the more symbols there are to choose from the easier it is to prove and the harder it is

to disprove that a subject can see when correct responses are given.

Although only theoretical, these analyses suggest that the use of alphabets with 26 letters is economical. There are, however, a number of considerations which need to be taken into account when using a Snellen chart. Firstly, not all 26 letters are used. This should not in itself affect the validity of the statistics provided the subject is unaware that certain letters never appear on the chart, so that 26 options remain. Secondly, as previously mentioned, clinicians may count certain incorrect responses as correct, so that the number of possible options falls below 26. Nevertheless, even if it were assumed that the total number of options were as few as 10, then the probability of 2 successive correct responses when 2 letters are presented is still $1/10 \times 1/10$ or 0.01. The statistical considerations given above suggest that 2 letters per character size is sufficient to achieve significance ($p<0.01$) when measuring visual acuity. If a subject reads both letters correctly, there is little point in presenting more letters on that line, because significance has already been reached. It would be more logical to move on to the next character size. If both letters are read incorrectly, again there is little point in testing more letters of the same size, for it would require another 205 wrong responses before one could conclude that the subject can see. It is more likely that the subject will volunteer that he or she cannot see the letters.

Using a chart with two letters for each character size, one would record the lowest Snellen fraction for which both letters are correctly identified. If with the succeeding character size both letters are incorrectly identified, the visual acuity would be recorded as that of the preceding Snellen fraction. This indicates that the probability of having arrived at this result by chance alone is well less than 1:100. If, however, only one of the letters of the succeeding character size is correctly identified, the visual acuity should still be recorded as that of the preceding Snellen fraction. This is because the last response obtained is not significant in that the probability of having identified this last letter by chance alone is approximately 1 in 10. For example, if both letters are correctly identified for the 6/9 character size, the visual acuity is recorded as 6/9. If, however, one letter is incorrectly identified on the 6/9 character size, the visual acuity should be recorded as 6/12.

Design of a new chart

We have used paired Sloan letters for each character size to construct a chart with the letters horizontally disposed in two lines with the following features:

1. *Two letters per character size.* As stated above,

Table 2 Differences in difficulty scores of paired Sloan letters

Snellen fraction	Paired Sloan letters	Difference in their difficulty score (%)
6/60	C S	71.4–70.6=0.8
6/36	V K	84.6–82.1=2.5
6/24	N Z	94.0–91.6=3.4
6/18	D K	82.1–79.5=2.6
6/12	O S	71.0–70.6=0.4
6/9	N H	91.6–89.3=2.3
6/6	V R	86.3–84.6=1.7

The difference in the difficulty scores between the Sloan letters of each pair used in Fig. 1 is shown. This difference does not exceed 3.4%. The likelihood is that either both or neither of the letters comprising a pair will be correctly identified. Similar charts can be constructed based on the difficulty scores determined by Sloan.¹

two letters per character size is sufficient to achieve significance ($p<0.01$) when measuring visual acuity.

2. *Paired Sloan letters.* Paired Sloan letters are chosen and their difficulty scores are used to construct the chart. Letters having similar difficulty scores are paired so that they are equally difficult (or easy) to recognise (Table 2). The advantage of this is that the subject will most probably identify the letters either both correctly or both incorrectly. This in turn, would minimise the occurrence of results such as 6/9–1 or 6/9+1 etc.

3. *Horizontal weighting.* The letters in the chart are horizontally disposed in two lines. By positioning bigger letters on the same line as some of the smaller, the crowding phenomenon associated with amblyopia may be detected. An additional advantage is that testing time may be further reduced by starting with the second line of smaller characters (that is, 6/18 onwards) since most patients have vision better than 6/18.¹

Use of the chart

The chart in Fig. 1 has seven pairs of Sloan letters proportionately equivalent in size to the Snellen fractions 6/60 to 6/6. The letters of each pair have similar difficulty scores. The subject is asked to read along a line from left to right. Visual acuity is recorded as the equivalent Snellen fraction of the last pair of letters correctly identified.

Discussion

Visual acuity charts are used for many different purposes, such as refraction, screening, and monitoring changes in visual function. No chart serves all these purposes. For screening, sensitivity and speed are of importance, whereas the monitoring of subtle changes in the presence of disease demands a chart of high specificity. A sensitive test yields few false negatives—that is, patients who cannot see the letters and yet give correct responses. A test which is specific has few false positives—that is, patients who can see and yet give incorrect responses. In designing a visual acuity chart the more characters or lines used the greater would be its sensitivity and specificity at visual threshold. For example, if threshold is defined as 50%, the situation is analogous to tossing a coin; the results would approach threshold the greater the number of tests performed (or letters used). Conversely, the fewer the number of letters used (fewer tests performed) the more likely it is that chance will prevail, producing both more false positives and false negatives.

The sensitivity and specificity are therefore also dependent on the defined threshold or the endpoint of the test. If the endpoint is 'stringent', requiring a patient to get all the letters correct on every line, the

Fig. 1 Chart with paired Sloan letters.

number of false positives would increase while the number of false negatives would decrease. In other words, the specificity falls while the sensitivity rises. This is used to our advantage with the proposed chart in that the decreased sensitivity resulting from using only 2 letters per line is compensated for by raising the threshold. In effect this chart uses a supra-threshold endpoint which reduces the ambiguity of the test and the interpretation of the results. The clear advantage of this test is that the testing time is markedly reduced.

CONCLUSION

The proposed chart represents a compromise between sensitivity, specificity, and time. It has been designed with the following features: (1) it has a supra-threshold endpoint; (2) the results obtained are not open to misinterpretation and have a defined

statistical significance; (3) it is easy to use and time saving.

We would recommend that this chart be used for screening purposes.

References

- 1 Wong D, Plumb A. Computer automated visual acuity testing for visual screening. *Trans Ophthalmol Soc UK* 1986; **105**: 498-503.
- 2 NAS-NRC Committee on Vision. Recommended standard procedures for the clinical measurement and specification of visual acuity. *Adv Ophthalmol* 1980; **41**: 103.
- 3 Ferris III FL, Kassoff A, Bresnick GH, Bailey I. New visual acuity charts for clinical research. *Am J Ophthalmol* 1982; **94**: 91-6.
- 4 Newman M. Visual acuity. In: Moss RA, ed. *Adler's physiology of the eye*. St Louis: Mosby, 1975; 6 ed: **18**: 500-28.
- 5 Sloan L, Rowland WM, Altman A. Comparison of three types of test targets for the measurement of visual acuity. *Q Rev Ophthalmol* 1952; **8**: 4.
- 6 Sloan L. Measurement of visual acuity. *Arch Ophthalmol* 1951; **45**: 704.

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