The role of contrast sensitivity charts and contrast letter charts in clinical practice

Russell L Woods PhD MBCO FAAO and Joanne M Wood PhD MBCO FAAO
School of Optometry, Queensland University of Technology

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Visual acuity for many years has been the mainstay of vision assessment in optometric practice. Visual acuity is a measure of the recognition of small (high spatial frequency), high-contrast letters. Hence, visual acuity is a measure of the resolution limit of the visual system and therefore is a sensitive measure of changes in refractive error. High frequency acuity charts as described by Medina and Howland are even more sensitive to refractive blur. Unfortunately, conventional letter acuity is limited because, despite proper refractive correction, some patients will complain of a visual problem but no visual anomalies can be demonstrated with conventional letter charts. This is common with early cataract and contact lens patients. These subtle visual problems can be distressing to the patient and confusing to the practitioner.

Because the ‘real world’ is composed of objects of varying sizes (spatial frequencies) and contrasts, visual acuity is too simplistic an assessment of visual performance for everyday visual tasks. Contrast sensitivity measures, which allow a more complete investigation of visual function, may be used to detect visual problems at an earlier stage, to understand the patient’s problem and to help manage that problem (for example, by advising a patient of increased risks if driving in low contrast conditions).

Though the importance of vision in many daily tasks seems obvious, conventional visual acuity tests are rarely related to functions such as mobility, face recognition, sports or driving. The relative success of measures such as contrast sensitivity in predicting ‘real world’ visual performance suggests that more advanced tests will become more commonly used in vision assessment, for example, to predict driving ability or to investigate differences between children who are ‘good’ readers and those who are ‘disabled’ readers.

It is difficult to introduce these tests into clinical practice when there is only limited information about them and often this information is in journals which are not readily available to practitioners. We begin by briefly reviewing contrast sensitivity as there are many good reviews. Then, we introduce contrast sensitivity charts and contrast letter charts with an emphasis on those which are commercially available to practitioners in Australia, discuss the application of each test, consider clinical studies of the usefulness of the tests, examine their sensitivity and reliability and consider their limitations.
Contrast sensitivity

The contrast sensitivity function (CSF) is a measure of contrast thresholds for a range of object sizes and is conventionally measured by finding the threshold contrast of sine wave gratings of varying spatial frequencies (sizes). The spatial frequency of a grating is the number of cycles (one dark and one light band) per degree of visual angle. The finer the grating, the more cycles per degree (c.p.d.), the higher the spatial frequency. In Figure 1 three sine waves are shown, A and B have the same spatial frequency, while C has a higher spatial frequency. Contrast is a measure of the difference between the luminance of the object and the luminance of its surround. For grating-based tests, where there are equal areas of light and dark, contrast \( C_{\text{grating}} \) may be defined as:

\[
C_{\text{grating}} = \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}} + L_{\text{min}}}
\]

\( L_{\text{max}} \) and \( L_{\text{min}} \) are the maximum and minimum luminances in the grating respectively. In Figure 1, B and C have the same contrast, while A has a higher contrast. The contrast of A = \((35.5)/\sqrt{(35.5+5)} = 0.75\), while the contrast of B and C = \((22.5)/\sqrt{(22.5+17.5)} = 0.125\). Contrast is often expressed as a percentage, hence these become 75 per cent and 12.5 per cent respectively. If A and C represented gratings at threshold, the contrast sensitivity would be \(1/0.75 = 1.3\) and \(1/0.125 = 8\). At medium spatial frequencies (two to five c.p.d.) contrast sensitivity may be as high as 500, and hence a grating with a contrast of \(1/500 = 0.002\) is at threshold.

For measurement of contrast sensitivity, typically the contrast of a grating at a given spatial frequency is varied and this is repeated over the range of spatial frequencies of interest. This is then plotted, as shown in Figure 2, with contrast sensitivity versus spatial frequency. For higher spatial frequencies (greater than 10 c.p.d.), the CSF is approximately limited by the optical performance of the eye, the neural aspects of the visual system being as good as, or better than the optical.

Figure 1. Three sine waves. A and B have the same spatial frequency, while C has a higher spatial frequency. B and C have the same contrast (Equation 1), while A has a higher contrast.

Figure 2. A typical contrast sensitivity function. Higher contrast is required to detect smaller objects (high spatial frequency). Even with 100 per cent contrast (contrast sensitivity = 1) objects finer than about 30 to 60 cycles per degree (c.p.d.) cannot be distinguished. This resolution limit is related to visual acuity. Peak contrast sensitivity of better than one per cent contrast (contrast sensitivity > 100) is found at medium spatial frequencies of about 3 to 5 c.p.d.
Figure 3. A square wave can be produced by the addition of suitable sine waves which include the fundamental frequency and all the odd harmonics each at the appropriate amplitude.

Contrast charts in practice Woods and Wood

Performance. For lower spatial frequencies the CSF is attenuated principally due to neural factors. The shape of the CSF varies with many factors including luminance, temporal characteristics, target size, grating motion, and grating shape (for example, square, sine) and thus can vary between different tests and between different studies. If the same conditions are always used with the same test then the shape of the CSF will remain the same unless there is some visual dysfunction.

Optical degradation can affect contrast sensitivity. Spherical refractive error reduces contrast sensitivity in proportion to the spatial frequency, with a minimal effect on low, a moderate reduction for medium and a greater reduction for higher spatial frequencies. Astigmatic refractive error can produce ‘notch’ defects, where only the medium spatial frequencies are reduced. Monocular diplopia, such as with a bifocal contact lens, can also produce a notch defect.

So what does it all mean?

Theoretically, any object can be ‘decomposed’ into a series of sine waves (Fourier analysis). In other words, with sine waves of just the right size and shape, it is possible to ‘recreate’ the object. As an example, it is possible to produce a square wave using a series of sine waves of suitable amplitude and frequency as shown in Figure 3. The square wave is formed from a combination of the fundamental frequency (the same spatial frequency as the square wave) and the odd harmonics (three, five, or seven times the spatial frequency of the square wave) of appropriate amplitude. These harmonics are important when we consider letter targets which are effectively composed of small square wave elements. Modern image analysis computer programs are able to perform Fourier analysis and can modify images by enhancing or removing different spatial frequencies. It is possible to produce a letter chart using these principles where, unlike a Snellen chart, the letters disappear almost as soon as they are out of focus. This mathematical ‘trickery’ is a fundamental principal of optics and implies that the CSF is a relatively basic aspect of vision. In practical terms, low spatial frequencies (less than 0.5 c.p.d.) are related to the detection of large objects. Low spatial frequency detection helps us to avoid being run down by a bus, although the bus would be unrecognizable from any other large ‘blobs’. Medium spatial frequency (2 to 6 c.p.d.) detection allows recognition of the ‘blob’ as a bus rather than a truck and helps one find the door. Fine detail requires high spatial frequency (greater than 10 c.p.d.) detection, allowing us to read the number of the bus. Most tasks require medium spatial frequencies and, fortunately, medium spatial frequencies are at the peak of the CSF. While letters comprise many spatial frequencies, a 6/60 letter is approximately 3 c.p.d., a 6/12 letter approximately 30 c.p.d, and a 6/3 letter approximately 60 c.p.d.

The patient who experiences a reduction in contrast sensitivity at low and medium spatial frequencies may have a greater functional visual loss and require earlier referral than a patient who only experiences a reduction in high spatial frequency contrast sensitivity (that is, visual acuity). A reduction in contrast sensitivity for low and medium spatial frequencies would reduce the ability to detect large to moderately sized objects under reduced contrast conditions (for example, a rainy day) thereby seriously compromising a patient’s orientation and mobility. Contrast sensitivity reductions and information from other vision tests should be used to assess functional vision. For example, peak contrast sensitivity and visual field extent are correlated with orientation and mobility and reduced contrast letter sensitivity is correlated with reduced driving skills.

Measurement of a full CSF can be very time-consuming. While the CSF is conventionally measured at a range of spatial frequencies and many early studies measured such a range, it would appear that often this is unnecessary. It has been suggested that the measurement of two or three well-chosen spatial frequencies will adequately describe the CSE. In conjunction with conventional visual acuity a measure at or near the peak of the CSF appears to be a good clinical compromise. The new clinical charts allow a measurement of medium spatial frequency sensitivity to be taken quickly.
Contrast sensitivity in clinical practice

Contrast sensitivity measurement in practice has been suggested for:
1. screening for ocular disorders,
2. diagnosis of ocular disease,
3. monitoring visual function,
4. assessment of visual function,
5. prediction of vision-related ability.

Contrast sensitivity is affected by many ocular diseases and conditions. Of most interest are reports that contrast sensitivity for low or medium spatial frequencies may be reduced when visual acuity is normal in conditions such as amblyopia, astigmatic error, cataract, diabetes, glaucoma, keratoconus, multiple sclerosis, ocular hypertension, optic neuritis and papilloedema. However, the ability of contrast sensitivity tests to effectively screen for ocular disease appears to be limited. For example, Elliott and Whitaker reported an evaluation of a range of contrast charts on 535 selected patients in optometric practice. As shown in Table 1, of the 89 patients with ocular or visual dysfunction, 16 had a reduction with a contrast sensitivity chart or a contrast letter chart measure despite normal visual acuity. These 16 included patients with diabetes, glaucoma, multiple sclerosis and those who were at risk from glaucoma. Similarly, Maugdal and colleagues using a contrast sensitivity chart, noted that there was a medium spatial frequency sensitivity reduction with normal high spatial frequency sensitivity in 22 of 211 patients who had a range of ocular diseases. However, not all patients with the same disease exhibit the same changes in contrast sensitivity. Differences in contrast sensitivity reduction between patients with the same ocular disease have been used to suggest that there are subtypes of amblyopia, glaucoma and optic neuritis; although the clinical significance is not clear. Also, as the contrast sensitivity changes in many ocular diseases are similar, there is a limited ability to distinguish between ocular diseases. For example, contrast sensitivity tests cannot distinguish between patients with diabetic retinopathy and patients with cataract. Since many diseases cause changes which are detected routinely with conventional tests, the usefulness of contrast sensitivity as a screening device has been questioned. The exceptions are patients with optic neurinopathies who may otherwise be undetected. Though the incidence of ocular disease is low, the new clinical charts allow quick, easy screening of patients, particularly when performed by appropriately trained staff. Given the reduced reliability of contrast sensitivity and low contrast charts in patients with ocular disease or degraded vision the ability to monitor changes in vision is limited. Conversely, the usefulness of contrast sensitivity for assessment of visual function and in the prediction of skills such as mobility and driving is becoming more apparent.

Psychometric method

It is very important to separate visual function (sensitivity) from the willingness of an observer to report a weak visual sensation (decision criterion). A test which has a poor measurement technique (psychometric method) may measure changes or differences in the decision criterion rather than changes in sensitivity. As an example, there may be differences in the decision criterion between a timid young patient and a confident older person. Though their ‘true’ visual acuity (sensitivity) may be the same, the timid patient will probably give up two lines early in case a mistake is made, while the confident person will probably attempt the line beyond, even though there is little chance of reading it. Thus, even in the measurement of visual acuity, it is important to use a good psychometric method. In this example, the ‘true’ visual acuity is found by encouraging the recalcitrant patient to continue to try (‘guessing’) until a complete line is read correctly. Having the patient read until no correct responses are made is a forced choice psychometric method and is the recommended scoring technique for logMAR charts.

In a recent study, Woods and Thomson repeating a previous study found an apparent improvement in contrast sensitivity after exercise. Contrast sensitivity was measured using the method of limits (similar to the method used with the Arden gratings). When the contrast sensitivity of the same patients was measured after exercise using a two-alternative forced-choice presentation, a psychometric method free of decision criterion effects, there was no change in contrast sensitivity. Hence, the apparent improvement in contrast sensitivity after the period of exercise was due to changes in the decision criterion (for example, mood or motivation). Good psychometric techniques avoid such problems and improve the reliability of a test. Poor psychometric methods explain why some of the commercially available charts do not meet expectations. Unfortunately the better psychometric methods usually take longer to perform.

**Contrast Sensitivity Charts**

Traditionally, contrast sensitivity has been measured using electronically generated targets which are expensive, difficult to set up and calibrate, and often use time-
Contrast charts in practice

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...are unsuited to clinical practice. Over the last decade, a number of rapid and relatively inexpensive chart-based tests have been introduced with the aim of making contrast sensitivity a clinically viable technique. While some of these tests have been promoted as screening tests, their principal use is probably as supplementary tests. If used for screening the test should be quick, reliable and able to detect potential visual problems.

Some of these tests may also have a role in testing during domiciliary visits. A domiciliary test should be portable, robust in construction and robust in its lighting and distance requirements. Details of lighting requirements, test distances, spatial frequencies and contrast levels tested are listed in Table 2, while details of suppliers and the purchase costs are listed in Table 3.

**Arden grating (AO contrast sensitivity test plates)**

The Arden grating test, the first attempt to develop a simple and inexpensive contrast sensitivity technique, was marketed by American Optical (AO). Photographic plates of seven spatial frequencies (0.2 to 6.4 c.p.d. at 57 cm) are presented to the patient. Each plate contains a single spatial frequency with the sine wave grating oriented vertically. The contrast of the grating varies from high at the bottom to low at the top. One plate at a time is placed in a neutral grey holder and then slowly drawn upwards, out of the holder, until the patient reports that the grating is visible. The score on all seven plates is then summed. There is a small effect of age on scores. The lighting requirement is specified as 100 ft candles (1076 lux) or 'a 60 watt bulb 14 inches (36 cm) above the plates'. This simple lighting specification and the size of the charts make them easily portable and suitable for domiciliary visits.

The Arden grating scores have been reported to be reduced in diseases such as ARM, cataract and glaucoma. The test has a reasonable ability to screen for ocular disease. The Arden grating test has been criticised for the use of a poor psychometric method (method of limits) which is subject to large variations in the patient's decision criteria (that is where the patient decides to say 'yes'). The clinicians must establish 'normal' values for their practices as the 'normal' values provided with the test may not be correct in different clinical settings. Results may vary between operators, mainly due to differences in the speed of exposure of the plates and due to differences in the interpretation of the instructions.

Despite their initial popularity and a
<table>
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<th>Test</th>
<th>Supplier</th>
<th>Telephone / fax</th>
<th>Cost</th>
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<td>British Optical Co</td>
<td>02 557 2666 (008 80 4331) /</td>
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<td>Reichert, USA)</td>
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<td>02 550 5201</td>
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<td>NSW 2294</td>
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<tr>
<td></td>
<td>18 Cox Road, Windsor, QLD 4030</td>
<td>07 357 9677 / 07 357 5649</td>
<td></td>
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<td>High contrast Bailey-Lovie charts</td>
<td>National Vision Research Institute</td>
<td>03 347 4066 / 03 349 7498</td>
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<td>of Australia (NVRI)</td>
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<td>High and Low contrast</td>
<td>Australian Vision Charts</td>
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<td>Bailey-Lovie charts</td>
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<td>Medmont (computer generated) $2,550 to $5,400</td>
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<tr>
<td></td>
<td>Private Bag 1250, Artamon, NSW 2044</td>
<td>02 438 0836</td>
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<td></td>
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<tr>
<td></td>
<td>431 Logan Road, Stones Corner, QLD 4120</td>
<td>07 394 8204 / 07 394 4080</td>
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<td>LSV Acuity Test (Richard Lenne, VIC)</td>
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<td>Medmont AT-20 Acuity Tester (Medmont, VIC)</td>
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<td></td>
<td>Private Bag 1250, Artamon, NSW 2044</td>
<td>02 436 0836</td>
<td>computer $5,400</td>
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<tr>
<td></td>
<td>431 Logan Road, Stones Corner, QLD 4120</td>
<td>07 394 8204 / 07 394 4080</td>
<td>controller, software and interface</td>
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<td></td>
<td></td>
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<td>card (for computer with minimum</td>
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<td></td>
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<td>configuration requirements) $2,550</td>
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<td>Australian Vision Charts</td>
<td>03 878 9862 / 03 870 2394</td>
<td>2 charts $550</td>
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<td>VIC)</td>
<td>Jcs Verhagen</td>
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<tr>
<td>Mentor B-VAT II (Mentor O&amp;O Inc, USA)</td>
<td>OPSM Pty Ltd</td>
<td>02 334 2413 / 02 334 2311</td>
<td>complete unit including computer $4,877 to $8,730</td>
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<td></td>
<td>99 St Hillers Road, Auburn, NSW 2144</td>
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<td>Pelli-Robson contrast threshold chart (Clement</td>
<td>British Optical Co</td>
<td>02 557 2666 (008 80 4331) /</td>
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<td>18 Cox Road, Windsor, QLD 4030</td>
<td>07 357 9677 / 07 357 5649</td>
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<td>Vistech Contrast Sensitivity Charts (Vistech</td>
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<td>02 334 2413 / 02 334 2311</td>
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<td>Consultants, USA)</td>
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<td>Designs for Vision</td>
<td>07 357 5533 (008 22 5307) /</td>
<td>single distance chart (VCTS 6500-1) $900</td>
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<td>02 550 3853</td>
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<td>3 distance &amp; 3 near charts $3,125</td>
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<td></td>
<td>contrast test slide (VCTS 7006) $750</td>
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<td>Multivision tester (MCT 8000) $11,250</td>
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Table 3. A list of suppliers of contrast sensitivity charts, contrast letter charts and related computer-based tests available in Australia.
reasonable ability to screen for ocular disease, the Arden gratings are no longer regarded as an efficient or accurate method for measuring contrast sensitivity. Though the test has been largely superseded it is still in use in some clinics.

**Vistech contrast sensitivity charts**
The Vistech charts, probably the most commercially successful charts, improved on the Arden plates by using a superior psychometric method as suggested by Vaegan and Halliday. Each chart contains five rows and nine columns of circular photographic plates (discs) on a grey background. Each plate contains a sine wave grating. Each row has a different spatial frequency (1.5 to 18 c.p.d. at three metres) and the contrast within each row reduces from left to right. The gratings are presented in three orientations: vertical (90°), 15° left (105°), or 15° right (75°). The claim of a forced-choice protocol is not accurate because the choice of ‘blank’ is allowed. The last disc correctly identified at each spatial frequency is plotted on a graph provided. A set of ‘normal’ contrast sensitivity values is provided with the charts, but these have been shown to vary between practices and do not include information about changes in contrast sensitivity with age. Three distance charts (94 x 66 cm) are available with different orientations. There is also a near chart (17.5 x 14 cm) for use at 45 cm. A luminance of between 103 and 240 cd/m² is recommended and a small photometer is provided. However, it can be difficult to produce even lighting over the entire chart without producing surface glare.

These charts probably provide the most common measure of contrast sensitivity in clinical practice. Some extravagant claims were made regarding their ability to:
1. screen for eye disease,
2. monitor visual function (for example, to determine the efficacy of vision training of amblyopes and the progression or remission of disease),
3. evaluate occupational vision by discriminating small differences in the visual performance of normal observers,
4. document the performance of low vision patients.

Unfortunately, few if any of these claims have been substantiated as the reliability of the Vistech charts is poor, and the ability to detect changes in vision is limited and the ability of the test to screen for ocular disease has been disappointing. The Vistech test will detect reductions in vision which would not otherwise be noted. Maugdal and co-workers reported that 22 of 211 randomly selected patients had a reduction in medium spatial frequency sensitivity despite having normal high spatial frequency sensitivity. Analysis of test results indicates that the measurement of five spatial frequencies may be redundant and measurement of one spatial frequency (for example 3 c.p.d.) in conjunction with visual acuity may be sufficient to assess visual function.

**Cambridge contrast charts**
This simple test, an A4-size (28 x 22 cm) spiral-bound book with square wave gratings of decreasing contrast, measures a single median spatial frequency (4 c.p.d. at six metres). The gratings are composed of fine dots, which while not visible at six metres, may be visible at shorter distances. Each grating is presented on one page with a facing page of uniform grey and the patient must indicate which side the grating is seen. This is a true forced choice procedure. Gratings are presented until an incorrect response is made, this is then repeated, and the sum of four incorrect responses is recorded. The normal score (total of four responses) should reduce from about 35 at age 25 years to about 29 at age 70 years. Similarly, an abnormal score (95 per cent confidence limit) is reported to reduce from a score of less than 27 at age 25 years to less than 23 at age 70 years. Reliability of the test is moderate. The luminance requirement of 100 cd/m² is relatively easily met on this small chart which can be displayed via a mirror. Despite the low price, the very robust methodology and the simplicity of this test, it has not been commonly used in clinical practice. The six-metre viewing distance may be a disadvantage for domiciliary use.

The Cambridge gratings attracted widespread interest when Wilkins and colleagues reported their ability to detect deficits present in patients with normal Snellen letter acuity, who also suffered from diabetes, multiple sclerosis, optic neuritis or glaucoma. However, these claims have not been substantiated by other workers. Wood and Lovie-Kitchin found the Cambridge gratings to be poor in the detection of ocular hypertension and primary open-angle glaucoma.

**Melbourne Edge Test**
The Melbourne Edge Test (MET) is a simple measure of the ability to detect an edge of varying contrast. Edge detection is related to the peak contrast sensitivity and has been correlated with mobility in low vision patients. This small, robust test consists of 20 test patches (discs) of 25 mm diameter in which the contrast between the two sides of the edge is reduced in logarithmic steps. The patient must indicate at which of the four possible orientations (45°, 90°, 135°, 180°) the edge is seen. The last disc identified correctly is recorded. A repeated measure is obtained by rotating the chart through 90 degrees. There is probably no significant effect due to age, as average scores were found to be about 205 at age 50 years and about 195 at age 70 years. The small (30 x 25 cm) chart is held at 40 to 57 cm with a luminance of 18 to 85 cd/m². The test is robust to variations in viewing distance and to poor refractive correction. Edge sensitivity is luminance dependent so that if the lighting is not even across the chart the contrast of the edge can be altered. If a single light source is used the angle of incidence should be 45 to 60 degrees.

The MET was advocated as a reliable indicator of the peak of the CSF with potential for screening for abnormal ocular conditions. Verbaken and Johnston also alluded to the fact that the MET could be used for the functional assessment of patients with low vision. Despite these claims, studies have demonstrated that the MET is a poor screening device for the detection of primary open angle glaucoma and general eye disease. Similarly,
the claims regarding the use of the MET for low vision assessment have yet to be substantiated, apart from a conference report\(^2\) which suggested that MET scores were correlated with mobility.

### CONTRAST LETTER CHARTS

Letter charts have the great advantage of being familiar to the patient and to the practitioner. Contrast letter charts come in two forms. The first is a reduced contrast version of a visual acuity chart and may be called a low contrast acuity chart. The second uses letters of a fixed size and varies the contrast of the letters and hence is probably best called a variable contrast letter chart. Both of these charts have a role in clinical practice and are proving to be extremely useful adjuncts to conventional visual acuity.

Contrast for letter-based tests \(C_{\text{letter}}\) may be defined as:

\[
C_{\text{letter}} = \frac{L_{\text{max}} - L_{\text{min}}}{L_{\text{max}}}
\]

Though this definition is different from that used for grating-based tests (Equation 1), it is possible to convert between these formulae as:

\[
C_{\text{grating}} = \frac{C_{\text{letter}}}{2 \cdot C_{\text{letter}}}
\]

**Bailey-Lovie charts**

To overcome many of the shortcomings of the traditional Snellen chart, Bailey and Lovie\(^3\) proposed a new design for visual acuity charts. This design uses 10 letters of approximately equal legibility, live to a line, spaced such that the separation between lines and between letters gives similar ‘crowding’ effects at all levels. This avoids the major objection to Snellen charts that the task varies at different levels (lines on chart or distances from the chart). As the letter size varies on a logarithmic scale, visual acuity can be scored according to the logMAR system. By this system, each letter correct scores -0.02 logMAR units and each correct line of live letters scores -0.1 logMAR units. The patient must read until no correct responses are made on a line.\(^4\)\(^6\) A Snellen fraction of 6/6/6 scores 0 logMAR, and 6/60 (10 lines larger) scores 1.0 logMAR and 6/3 (three lines smaller than 6/6) scores -0.3 logMAR. A visual acuity reduces from about -0.15 logMAR (6/4) at age 30 years, through 0 logMAR at age 60 years to about 0.3 logMAR (6/12) at age 80 years.\(^7\)

Measurement of high contrast (90 per cent) visual acuity, in contrast sensitivity terms, involves a horizontal movement towards the right at a contrast sensitivity of approximately 1 (just above the x-axis in Figure 2). The spatial frequency is increased (letter size is reduced) until the resolution limit is reached.

Practitioners should be using Bailey-Lovie charts as these have become the standard chart for accurate visual acuity measurements.\(^7,7\) The charts are more reliable than Snellen charts and are the chart of choice for low vision assessment.\(^4,6,7\) Charts are available in a number of different formats from the National Vision Research Institute of Australia (Table 3).

**Low contrast acuity charts**

Despite 19th-century descriptions of low contrast acuity charts, it is only in the last decade that low contrast acuity has been applied clinically.\(^8\)\(^6\) Low contrast acuity charts conventionally have grey letters on a white background.\(^8,8\)\(^1\) Measurement of low contrast (10 per cent) visual acuity involves a horizontal movement at a contrast sensitivity of approximately 10 (Figure 2). The typical difference between high (90 per cent) and low contrast (10 per cent) acuities in normal patients is just over two lines.\(^9,9\)\(^2\) The difference in visual acuity between the high and low contrast acuity charts is an indicator of the slope of the right hand portion of the CSF and hence an indicator of changes in medium spatial frequency contrast sensitivity. There may be a small increase in the acuity difference with age from approximately 0.21 logMAR at age 30 years to about 0.24 logMAR worse by age 60 years.\(^9,9\)

Regan and co-workers\(^81,83\) pioneered the use of low contrast charts in the detection of ocular disease and produced commercially available charts which are unfortunately a Snellen-like design. The locally made Australian Vision Charts use a Bailey-Lovie design.\(^7,8\) The luminance requirement of 85 cd/m\(^2\), or an illumination of 280 lux, is easily met in most practices. Fluorescent lights at an angle of 30 to 60 degrees are recommended. Spotlights are not recommended as the luminance gradient (hot spot) may alter the contrast by introducing a veiling glare,\(^8\) although in practice we have found that with careful selection of the spotlight good even illumination is possible. The charts come in a range of sizes and formats as detailed in Table 3.

Low contrast acuity charts have been popularised as a screening tool for a number of ocular diseases including glaucoma, diabetes and neurological disorders.\(^8\) However, recent studies seem to confirm that the low contrast acuity charts, despite convincing theoretical advantages, offer little extra clinical information over accurate high contrast visual acuity measures in the examination of patients with age-related maculopathy,\(^86,87\) glaucoma\(^86\) and other elderly patients.\(^8\) However, low contrast acuity has been reported to be useful in describing visual function in soft contact lens wearers,\(^8\)\(^6\)\(^9\)\(^2\)\(^3\)\(^4\)\(^5\)\(^6\)\(^7\) bifocal contact lens wearers\(^8\)\(^7\) and in patients with cataracts, especially in the presence of glare.\(^5,9\)

Recently, a different low contrast acuity chart with black letters on a dark grey background has been described for use with low vision patients.\(^8\)\(^9\)\(^1\) It is presumed that this chart (the SKILL chart) will give a measure of low contrast acuity similar to that of a ‘conventional’ low contrast acuity chart used under low contrast conditions. The relative benefits of this interpretation of low contrast acuity have not been determined.

**Pelli-Robson contrast threshold chart**

The Pelli-Robson\(^9\) variable contrast letter chart consists of 16 groups of three letters (a ‘triplet’) arranged on eight lines. The contrast of each triplet reduces in...
Contrast charts in practice Woods and Wood

logarithmic steps. As the letter size (spatial frequency) is fixed and the contrast is varied the test procedure is more like conventional contrast sensitivity measurement. As the patient reads down the chart the letters reduce in contrast and in contrast sensitivity terms they move up Figure 2 until the detection limit is reached near the peak of the CSF. In the manufacturer's description and in most reports the test is administered at one metre and would be expected to measure sensitivity at approximately one cycle per degree (fundamental frequency) but higher harmonics (3, 5 and 7 c.p.d.) will also be detected. We suggest that the test may be better at three or four metres, where the fundamental spatial frequency tested is approximately three or four cycles per degree and therefore nearer the peak of the CSF.

In the original description of the test, the last triplet where at least two letters are read correctly is scored. To improve reliability, Elliott and colleagues suggested scoring correct a call of 'O' or a call of 'C'. To further improve reliability, they then suggested scoring correct each correct letter as 0.05 units. At one metre, the average Pelli-Robson score should reduce from about 1.90-1.85 at age 20 to 30 years to about 1.80-1.75 at age 70 years. If a different distance such as three metres is used, 'normal' values will need to be established. Lighting requirements of 85 cd/m² (acceptable range 60 to 120 cd/m²) can require some manipulation to get this large (64 x 85 cm) chart evenly lit.

Pelli-Robson charts have proven to be quick and reliable in clinical practice and to have significant uses in the description of visual performance. Studies by a number of workers have demonstrated that the Pelli-Robson chart can detect a reduction in visual function in patients with cataracts probably due to narrow angle light scatter from the 'white' areas of the chart. When the test is combined with a peripheral glare source it has a high correlation with stray light and excellent discrimination between patients. Similarly, studies have shown that the Pelli-Robson chart is useful in reflecting the loss in contrast sensitivity experienced by intraocular lens wearers and bifocal contact lens wearers.

Recent studies by the vision and driving group at the Queensland University of Technology found that Pelli-Robson scores correlated highly with driving performance of patients with simulated visual impairment and these results were supported by studies of patients with true visual impairment. Whitaker and Lovie-Kitchin have described the use of the Pelli-Robson chart to determine the contrast reserve which is used to predict the ability of low vision patients to read text.

Low luminance testing

It has been suggested that testing under low luminance conditions is more sensitive to changes in vision. Greater differences between single vision and bifocal contact lens designs have been noted with low luminance-low contrast acuity tests than with conventional high luminance-high contrast tests. Differences in the effects of changes in luminance on high contrast acuity have been reported for a range of ocular diseases. In optic nerve lesions (optic atrophy and optic neuritis), suppression amblyopia, retinal lesions (disease of Bruch's membrane and macular toxoplasmosis), although visual acuity is reduced under normal luminances, under reduced luminance visual acuity does not decrease as much as for normal patients. Patients with age-related macular degeneration have a reduction in acuity with reduction in luminance similar to that experienced by normal patients. Those with retinitis pigmentosa have a greater reduction in acuity with reduced luminance than normal subjects. Whether this test can be used for early detection of retinitis pigmentosa has not been evaluated.

Rather than reducing the lighting on the chart, it is usually simpler and more accurate to reduce the amount of light reaching the eye, typically by using neutral density filters. Low luminance testing can be performed with neutral density (ND) filters in a pair of goggles (welding goggles with the lenses replaced work well). Typically a ND of two (reduction in luminance of 10²) is used. As pupil size is not controlled, much of the reported differences may have been due to variations in ocular aberrations which occur with the increase in pupil size resulting from changes in luminance, but this may still be related to functional vision. Depending on the conditions, with young patients, the reduction with a two ND filter is about 0.1-0.35 logMAR with high contrast visual acuity, about 0.3-0.7 logMAR with low contrast (10 per cent) acuity, and 0.04 log units with the Pelli-Robson charts. The differences are greater for older patients. As these values vary between studies, due to differences in the conditions, it is necessary to establish 'in practice' normal values. The value of low luminance testing for detection of disease and the assessment of 'real world' visual function has yet to be demonstrated.

Computer-based test units

Medmont AT-20

The Medmont AT-20 visual acuity tester is a commercially-available computer-based system for the presentation of variable contrast Bailey-Lovie visual acuity charts and gratings. Eight contrast levels can be used on a range of visual acuity charts and a grating display. A randomised display of different characters can be used to avoid learning effects. In addition to standard visual acuity chart displays, a staircase procedure can be used to determine average acuity. Other facilities include duochrome, cross cylinder targets, binocular vision tests (Worth four dot and fixation disparity), astigmatic fan and animated fixation targets for children. The AT-20 (board and controller) is fitted to a PC computer. The system comes with a handheld control unit and has many more facilities than projector charts. 'Normal' values are not yet available.

Mentor B-VAT II

The Mentor B-VAT II video acuity system is a commercially-available computer-based system for the measurement of variable contrast visual acuity and grat ing acuity. Optotypes include letters,
numbers, Landolt rings, tumbling E, HOTV and children’s symbols. A randomised display of different characters can be used to avoid familiarity. Unfortunately the visual acuity charts are not of a Bailey-Lovie design. Nine contrast levels are available. It also has the ability to present duochrome, astigmatic fan, binocular vision tests, stereopsis and animated targets for children. The more expensive Mentor B-VATII-SG system can also present sine wave gratings for the measurement of contrast sensitivity at up to 16 spatial frequencies. The system comes with a hand-held control unit and has many more facilities than projector charts, ‘Normal’ values for contrast sensitivity are available.  

**LSV Acuity program**

A shareware (pay if you use it) computer program, developed at the Visual Functions and Optical Sciences Laboratories of the University of Melbourne, allows assessment of high and low contrast visual acuity Visual acuity scores might be expected to be slightly different from those of a Bailey-Lovie chart as only single letters are presented. The low contrast letters are approximately 30 per cent contrast. The program runs under Windows 3.1 on a PC computer.

**PUTTING THE TESTS INTO OPTOMETRIC PRACTICE**

Before contrast sensitivity charts or contrast letter charts are introduced into clinical practice the chart must be properly lit. Age and ophthalmic disease will affect scores and the reliability of measurement. To enable correct detection of reduced visual performance the variance of the expected scores must be considered.

Contrast sensitivity charts or contrast letter charts may also be used to demonstrate the effects of cataract, refractive blur or bifocal contact lenses on vision (Table 4).

**Lighting requirements**

While the precise lighting requirements for each of these tests are different, all are performed under photopic conditions similar to those found in most practices and most perform equally well with small changes in overall illuminance. Most of these tests can be used in clinical practice with few changes to lighting arrangements. The larger charts are more problematic as even lighting may be difficult to achieve. Glare sources on the chart from poorly placed lights must be avoided. Smith has described how a photographic light meter (separate or built into a camera) can be a useful substitute for a photometer for measurement of the luminance of the charts. Luminance \( L \) can be estimated by the equations:

\[
L = \frac{13.1 \cdot (F)^2}{t \cdot A} \quad \text{cd/m}^2 \tag{4}
\]

\[
L = \frac{13.1 \cdot 2^4}{A} \quad \text{cd/m}^2 \tag{5}
\]

where \( F \) is the F-number, \( t \) is the exposure duration, \( A \) is the ASA rating, and \( E \) is the exposure value. The illuminance requirement is specified for some charts. In simple terms, illuminance is the light falling

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Expected results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cataract simulators</strong></td>
<td>The reduction in high contrast visual acuity should be minimal (otherwise the perspex was rubbed to heavily) but the reduction in vision of low contrast letters will be much more dramatic. Vision at lower spatial frequencies (e.g. Pelli-Robson or Cambridge tests) will also be reduced.</td>
</tr>
<tr>
<td><strong>Bioclar Contact lens</strong></td>
<td>Vision will be affected at all but the very low spatial frequencies. Test this by using the Cambridge or Pelli-Robson tests at a range of distances.</td>
</tr>
<tr>
<td><strong>Refractive blur</strong></td>
<td>High contrast visual acuity will be reduced more than tests of lower spatial frequencies such as the Pelli-Robson tests.</td>
</tr>
</tbody>
</table>

Table 4. Some practical demonstrations of the use of contrast sensitivity charts or contrast letter tests. These examples may be used to demonstrate the value of these tests to the practitioner, to patients or to a patient’s relative or carer.
on a surface, while luminance is the light coming from the surface. The illuminance \( I \) can be approximated by the equation:

\[
I = \pi \cdot L \cdot r
\]

The reflectance \( r \) of the white areas of most charts is about 0.8 to 0.9. The reflectance of grey charts will be different (for example, MET reflectance = 0.3). A small photometer is supplied with Vistech charts.

**Population norms**

Population norms (the average scores expected within the ‘normal’ population where there is no ocular or visual disturbance) allow the practitioner to compare the visual performance of a new patient with the age-matched norms to determine whether visual function is reduced. Published population norms have been included where available. These norms are applicable only under certain conditions as detailed in the relevant publications. The conditions include the luminance and test protocol used during the study. Most contrast measures are sensitive to changes in luminance. As an example of the effects of changes in protocol, Reeves and co-workers demonstrated that differences between the mode of application of the Arden grating test accounted for much of the difference in measured contrast sensitivity. If the same conditions are used the published norms are very useful. Alternatively, the scores of the first few hundred ‘normal’ patients may be used to establish population norms in a particular setting. The population norm is the mean of the responses of normal patients as shown in Figure 4. Limits to the normal range are typically established by multiplying the standard deviation by two or 2.6 to give the 95 per cent or 99 per cent confidence limits respectively. Only five per cent or one per cent, respectively, of normal individuals will fall outside these ranges.

**Reliability**

Reliability is a measure of the ability to get the same result on repeated measurement. Two methods for assessing reliability of visual performance have been suggested. The first approach uses the coefficient of repeatability as proposed by Bland and Altman. The second approach uses the variability of the individual patient’s visual performance as proposed by Brown and Lovie-Kitchin. Both approaches have a place in optometric practice.

**Coefficient of repeatability**

The variance (spread) of the distribution of differences between two (repeated) measures made on separate occasions (that is, test-retest) can be used to assess repeatability. This is achieved by measuring vision twice on the same person under the same conditions and subtracting one from the other to get the difference score. As in the determination of population norms, the distribution of the difference scores for the group of patients is used to determine the coefficient of repeatability (twice the standard deviation of the difference scores). The coefficient of repeatability represents the 95 per cent confidence limits (Figure 4). In practical terms, this means that a difference between vision scores greater than the coefficient of repeatability will only occur by chance five per cent of the time, that is, there is a 95 per cent probability that the difference is a real change in vision.

**Individual variability**

The coefficient of repeatability measures typical changes in a population. Some patients are more reliable in their responses than others and hence the variability within the group measured by the coefficient of repeatability may overestimate the reliability of many patients. Measurement of the visual performance on a number of occasions (for example, during initial consultation, after frame selection, at collection, subsequent consultation, etc.) allows determination of the standard deviation of the response for that individual. Again, typically the 95 per cent confidence limit (twice the standard deviation) is used to determine what
constitutes a real change in vision for that individual (Figure 4). Brown and Lovie-Kitchin demonstrated that individual variability can be a much more sensitive measure of change for an individual. Unfortunately, it is not possible to determine an individual reliability for all patients and thus the coefficient of repeatability and population norms are still important.

The effects of age
Vision as assessed with most visual performance measures shows a reduction after about the fourth decade. Much of the loss is due to optical changes in the older eye, but reductions in neural integrity at all levels of the visual system are likely to play a role. Visual acuity peaks in the third decade and then reduces with increasing age. The effect on low contrast letters is slightly greater. The reduction in visual acuity is more pronounced under low luminance and most pronounced for low contrast charts under low luminance. Contrast sensitivity reduces with age for median and high spatial frequencies and the peak contrast sensitivity moves to a lower spatial frequency. This is noted over a wide range of luminances.

Age-related changes must be considered when tests of visual function are applied. Increases in the range of responses for older patients, whereby some older patients have excellent vision and some have poor vision without any apparent visual disease, makes the detection of visual dysfunction in the elderly more difficult.

Ophthalmic disease
Ocular and visual dysfunction reduce the reliability of visual performance measurement. For example, Reeves and co-workers have demonstrated with patients suffering from stable ocular diseases that the coefficient of repeatability is much larger for Arden, high and low contrast acuity, Pelli-Robson and Vistech chart tests than reported in other studies with 'normal' patients. Similarly, when optically degraded by wearing bifocal contact lenses, the coefficient of repeatability is much larger for the scores with high and low contrast acuity and Pelli-Robson charts. Hence, as the responses of patients with a visual dysfunction are less reliable, detection or monitoring of disease is more difficult.

The clinical significance of change
Before a clinical management decision for referral or alteration of treatment (for example, contact lens wear), it is essential to determine whether a measured change is significant. The latest finding must be compared with some 'standard' or reference. That standard may be the finding at the previous consultation, the finding for the other eye or it may be the established 'normal' value. A knowledge of the variance of the measurement technique will allow the practitioner to be confident that the measured change is significant. This indicates the importance of determining reliability and norms for clinical tests. While 95 per cent confidence limits are often quoted as levels for the acceptance of a significant (that is, real) change in visual function, Reeves and co-workers noted that the level of acceptance of change must be altered to account for differences in the possible outcome and cost of an inappropriate action. For example, if the likelihood of a serious result (such as loss of vision) from failure to take appropriate action was high and the cost of an inappropriate clinical action when no real change had occurred was low, then acceptance of a lower level of change may be more appropriate (such as 1.6 standard deviation change: 90 per cent confidence limit). If the probable outcome of a failure to take clinical action is negligible and the cost of inappropriate action is high then a higher confidence limit may be more appropriate (such as three standard deviations of change: 99 per cent confidence limit). If the probable outcome of a failure to take clinical action is negligible and the cost of inappropriate action is high then a higher confidence limit may be more appropriate (such as three standard deviations of change: 99 per cent confidence limit). Reducing the confidence limit will increase the number of patients without the condition for whom action is taken (false positive rate), while increasing the confidence limit will increase the number of patients with the condition for whom no action is taken (false negative rate).

The decision to take clinical action based on the belief that a patient suffers from a particular condition must be tempered by a knowledge of the incidence of that condition within a population. For example, as the incidence of congenital colour vision defects differs between males and females, a 'failing' score on a colour vision screening test is more likely to indicate a true defect in a male patient than in a female patient. Where the incidence of a disease is low, to avoid inappropriate referral, confirmatory evidence from a number of tests should be sought. The likelihood that a patient has a particular condition can be formally evaluated given knowledge of the incidence in the population and the ability of the test to detect the condition using Bayesian theory. As may be appreciated from consideration of reliability, a single response may be subject to considerable variance. Repeated measurement (for example, after a break or the next day) will increase the confidence of a reliable result. A knowledge of the expected variance on the particular test and confirmatory evidence from a range of tests will assist in clinical decision making.

RECOMMENDATIONS
Contrast sensitivity charts and contrast letter tests have a limited ability to screen for ocular disease. Screening will detect patients with an otherwise undetected visual reduction, but the incidence of such conditions is low. As most of the chart-based tests can be quickly and easily applied, screening can be performed by trained ancillary staff. Some diseases produce changes in vision which are not detected with visual acuity (for example some optic neuropathies) but most diseases which reduce contrast sensitivity also reduce visual acuity or are detected by other routine ophthalmic tests. Where visual acuity is reduced, a measurement of contrast sensitivity at low to medium spatial frequencies (Cambridge grating or Pelli-Robson test) or low contrast visual acuity will give further information about visual function. If this aspect of vision is reduced, the patient may suffer from difficulties in mobility and orientation, especially in poor lighting conditions and where contrast is reduced.
(such as on a rainy day). The practitioner is then able to assist with advice on how the patient may reduce these difficulties. As the results with these tests (Cambridge grating, Pelli-Robson test and low contrast visual acuity) are highly correlated only one test is necessary.

Similarly, the vision of a patient with normal visual acuity who complains of reduced vision should be investigated with one of these tests. A reduction in vision may warrant further investigation and the practitioner can offer advice on means of ameliorating the visual difficulties. Of course, there may be other reasons for the complaint of reduced vision such as the effects of glare. Glare can be assessed easily in practice. For patients whose occupation (such as professional drivers) or interests (such as certain sports) makes detection of relatively large objects often of low contrast very important, the routine use of a measure of low to medium spatial frequencies is recommended. Hence, contrast sensitivity tests and contrast letter charts are an essential supplementary test which optometrists may use to further evaluate vision.

CONCLUSIONS

Evaluation of the commercially available contrast sensitivity charts and contrast letter tests indicates that their most important role in clinical practice is in the description of a patient’s vision and visual problems. As such, they provide an important component of a clinician’s testing battery as they reflect the visual experiences of patients in the ‘real world’ better than visual acuity.

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DECLARATION

The authors have no proprietary interests in any of the vision tests mentioned here.

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Author’s address:
Dr RL Woods
Centre for Eye Research
School of Optometry
Queensland University of Technology
Locked Bag 2, Red Hill
Queensland 4059
AUSTRALIA

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