1040-5488/05/8211-0970/0 VOL. 82, NO. 11, PP. 970–975
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

An Evaluation of the Mars Letter Contrast Sensitivity Test

BRADLEY E. DOUGHERTY, BS, ROANNE E. FLOM, OD, FAAO, and MARK A. BULLIMORE, MCOptom PhD, FAAO

The Ohio State University College of Optometry, Columbus, Ohio

ABSTRACT: *Purpose.* The Mars Letter Contrast Sensitivity Test (initially known as the Lighthouse Letter Contrast Sensitivity Test) is similar in design to the Pelli-Robson Test but may offer several advantages. This study evaluates the repeatability of the Mars test and its agreement with the Pelli-Robson test in normal and low-vision subjects. *Methods.* Fifty-four subjects were tested (age 22–86 years), including 20 normally sighted young adults, 17 normally sighted older adults, and 17 adults with low vision (20/16 to 20/250). Subjects were tested with both contrast sensitivity tests and with the ETDRS visual acuity chart. After a short break, subjects were retested with an alternate form of each contrast sensitivity test. The chart forms used (two Pelli-Robson and three Mars) and the order of testing were varied systematically. Testing was monocular with habitual correction and, for subjects over 40 years of age, included appropriate near add. Letter-by-letter scoring was used for both tests. Repeatability and agreement were assessed by determining the 95% limits of agreement (LoA): ± 1.96 standard deviations of the differences between administrations or tests. *Results.* The Mars test showed excellent agreement with the Pelli-Robson test, with 95% LoA of ± 0.21 log units for all subjects. The Mars test was similarly repeatable (95% LoA = ±0.20 log units) to the Pelli-Robson test (95% LoA = ±0.20 log units) among all subjects. *Conclusion.* The new Mars Letter Contrast Sensitivity Test shows excellent agreement with the Pelli-Robson test and has similar repeatability. There are subtle differences in the actual contrast levels on different forms of the Mars test, and adjusting for these differences leads to superior repeatability of the Mars test. Thus, the Mars test may be a useful alternative to the Pelli-Robson test offering several advantages, including smaller size, improved durability, and ease of use. (Optom Vis Sci 2005;82:970–975)

Key Words: contrast sensitivity, low vision, Mars test, Pelli-Robson test, repeatability

Contrast sensitivity (CS) testing has been suggested as a useful means of providing a more complete assessment of vision in a variety of clinical situations.[1] It has been used as an indicator of mobility[2,3] and reading speed[4] in low-vision patients and of quality of life in patients with glaucoma.[5] Other ways in which CS testing is used include quantifying vision loss resulting from cataract[6] and evaluating vision after refractive surgery.[7,8]

One commonly used test for the measurement of contrast sensitivity is the Pelli-Robson test,[9] a letter chart with optotypes of constant size and varying levels of contrast. The Pelli-Robson test has been used to measure CS in large-scale studies.[10,11] It is easy to administer and has been demonstrated to be very repeatable,[12] especially when a by-letter scoring method is used.[13]

A new contrast test was introduced by Mars Perceptrix Corporation (Chappaqua, NY) in 2004. The Mars Letter Contrast Sensitivity Test[14]—initially marketed as the Lighthouse Letter Contrast Sensitivity Test—has several features that might make it desirable for use in clinical practice, including its small size, durability, and portability. It uses the same Sloan letter set as the Pelli-Robson test, but the manner in which the contrast of the letters varies is slightly different.

In the present study, we assess the agreement of the Mars test with the Pelli-Robson test and its repeatability in subjects with normal vision as well as subjects with low vision. We also investigate potential differences in the contrast levels of various forms of the Mars test and the effects of these differences on its repeatability.

METHODS

Subjects

Fifty-four subjects participated in the study (age range = 22–86 years). Subjects were from three groups: 20 younger normal-vision subjects (mean [± standard deviation] age = 24.4 ± 2.0 years), 17 older normal-vision subjects (mean age = 58.9 ± 11.7 years), and 17 low-vision subjects (mean age = 56.9 ± 24.3 years). Normal

vision subjects (visual acuity [VA] = 20/25 or better) were recruited primarily from staff and first year students of The Ohio State University College of Optometry. Low-vision subjects (VA = 20/16 to 20/250) were recruited from the Vision Rehabilitation Service at The Ohio State University College of Optometry. Informed consent was obtained from all participants before testing and after an explanation of the procedure was given. Study procedures were approved by The Ohio State University Office of Responsible Research Practices.

Contrast Sensitivity Tests

The Mars Letter Contrast Sensitivity test measures approximately 23 × 35.5 cm and is printed on rigid plastic. It consists of 48 letters, 1.75 cm high, arranged in eight rows of six letters each. Stated contrast varies from 91% (−0.04 log units) to 1.2% (−1.92 log units) with the contrast of each letter decreasing by a constant factor of 0.04 log units. Each letter subtends 2° at the test distance of 0.5 m (equivalent to 20/480). The Pelli-Robson test measures approximately 59 × 84 cm and is printed on rigid cardboard. It consists of 48 letters arranged in eight rows of six letters each. Each line consists of two triplets of letters. Each triplet contains letters of equal contrast, and the contrast of each triplet decreases by a factor of 0.15 log units. Stated contrast varies from 100% (0.00 log units) to 0.56% (−2.25 log units). Each letter subtends 2.8° at the test distance of 1 m (equivalent to 20/672).

Procedure

All testing was monocular with habitual correction and the appropriate near add. All subjects over 40 years of age were provided with a +2.00 D near add for the Mars test and with a +0.75 D near add for the Pelli-Robson test, as specified by the manufacturers' instructions for each test. Each normal-vision subject used his or her right eye, but each low-vision subject was allowed to use his or her better eye.

The Mars test was placed on a reading stand and the Pelli-Robson test was wall-mounted. Chart luminance ranged from 95 to 140 cd/m^2 on the Pelli-Robson test and 95 to 120 cd/m^2 on the Mars test. Both were illuminated by multiple ceiling-mounted fluorescent lamps.

Contrast sensitivity was measured with both the Pelli-Robson and Mars tests, and visual acuity was taken with the ETDRS acuity chart at 4 m. After a short break, contrast sensitivity was measured again using alternate forms of both tests. The chart forms used (two Pelli-Robson and three Mars) and the order of testing were varied systematically. Half of the subjects were tested first with the Pelli-Robson test and then with the Mars test, whereas the other half were tested first with the Mars test and then with the Pelli-Robson test. For all subjects, the order of testing was reversed for the second administration. The three forms of the Mars test were used in balanced fashion across subjects using all six possible two-chart permutations.

For both CS tests, subjects were instructed to read all letters on each CS test beginning with the highest contrast letters. Sideways head movements were also allowed. On the Mars test, subjects responding with a letter not part of the 10-letter set used on the chart were informed of the set and instructed to give another response, as specified by the manufacturer's instructions. Subjects were allowed up to 30 seconds per letter if needed and forced to guess until the stopping rule was reached. Testing ended on the Mars test when the subject missed two consecutive letters. Contrast sensitivity was scored as –log contrast of the final correct letter minus 0.04 for each letter missed before that. Because of the design of the chart, this simplifies to 0.04 multiplied by the number of letters correct. Testing on the Pelli-Robson test ended when the subject missed two of three letters in a triplet. Contrast sensitivity was scored as 0.05 multiplied by the number of letters correct minus 0.15 because the first three letters are 100% contrast.

All subject responses were recorded on standard score sheets. When an incorrect response was made, the incorrect letter was recorded on the sheet so that corrections could be made later. Specifically, responses of "O" for "C" and "C" for "O" were accepted as correct[15] when scoring both tests and when applying the stopping rule. This represents a small deviation from the published instructions. Correction was made for letters missed before the stopping point was reached.

Data Analysis

Repeatability and agreement were assessed by determining the 95% limits of agreement (LoA): ± 1.96 standard deviations (SD) of the differences between tests.[16] This method has been shown to be more appropriate in assessing the repeatability and validity of clinical tests than the correlation coefficient.[16] The difference between the CS scores for each administration or test was calculated for each subject. The distribution of these differences was described by calculating the mean, SD, and the 95% LoA. The breadth of these LoA indicates the repeatability of the test. The narrower these LoA, the more repeatable the test.

RESULTS

Table 1 shows mean CS scores for each test and each subject group. Mean CS scores from the Pelli-Robson test and the Mars test did not differ significantly for the group as a whole ($t = 0.11$, $p = 0.90$) or for any subgroup ($t < 1.29$, $p > 0.11$). Mean CS scores were not significantly different between the younger normal and older normal-vision groups on either test (Pelli-Robson: $t = 1.47$, $p = 0.15$; Mars: $t = 1.88$, $p = 0.07$). As expected, CS scores were reduced in the low-vision group (Pelli-Robson: $t = 6.52$, $p < 0.001$; Mars: $t = 9.45$, $p < 0.001$).

The agreement between the Pelli-Robson and Mars tests is shown in Figure 1. The difference between CS scores from the first administration of both tests is plotted as a function of the mean of these scores. Agreement was good, with 95% LoA of ± 0.21 log units. There is some evidence that in subjects with the poorest CS, scores are lower for the Pelli-Robson test than for the Mars test (Fig. 1). In the five low-vision subjects with the poorest CS, the mean difference is 0.12 log units. A similar difference of 0.09 log units is observed if scores from the second administration of each test are compared.

In Figure 2, the difference between CS scores from the two administrations of each test is plotted as a function of the mean of the two CS scores to illustrate the repeatability of each test. The repeatability of the Pelli-Robson test and the Mars test is summa-

TABLE 1.
Mean (± standard deviation) scores for each administration of the Pelli-Robson and Mars test[a]

	Pelli-Robson		Mars	
	Test	Retest	Test	Retest
Young normal vision	1.70 ± 0.08	1.70 ± 0.08	1.72 ± 0.06	1.73 ± 0.08
Older normal vision	1.74 ± 0.09	1.70 ± 0.08	1.76 ± 0.05	1.74 ± 0.07
Low vision	1.30 ± 0.47	1.29 ± 0.48	1.27 ± 0.41	1.30 ± 0.43
All subjects	1.59 ± 0.29	1.57 ± 0.30	1.59 ± 0.27	1.60 ± 0.27

[a]Values are given for all subjects and for each subgroup.

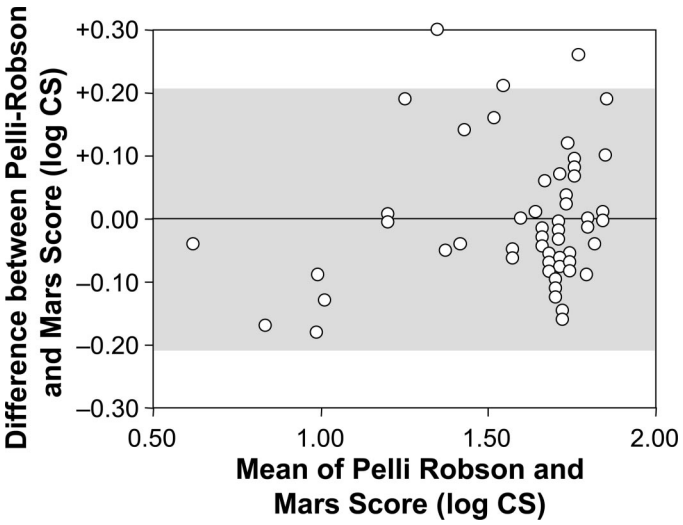

FIGURE 1.
Agreement between the Pelli-Robson and Mars tests. The difference between the scores for the first administration of each test is plotted against the mean for the two tests. The shaded area represents the 95% limits of agreement. Overlapping points have been dithered.

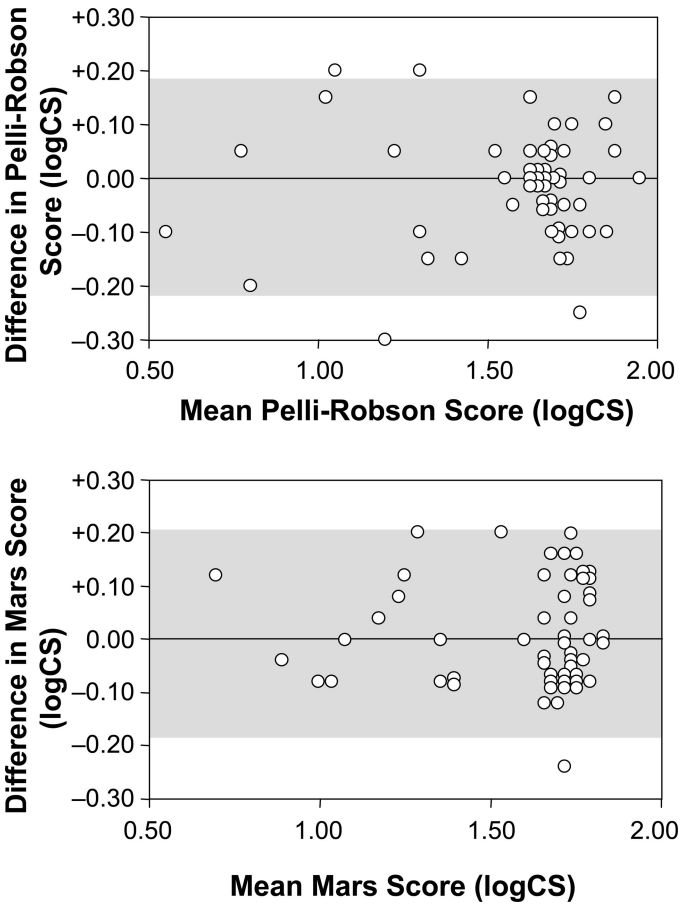

FIGURE 2.
Repeatability of the Pelli-Robson and Mars tests. The difference between the scores for the second and first administration of each test is plotted against the mean of the two scores. The shaded area represents the 95% limits of agreement. Overlapping points have been dithered.

rized in Table 2. Overall, repeatability was similar for both tests, with 95% LoA of ± 0.20 log units for the Pelli-Robson test and 95% LoA of ± 0.20 log units for the Mars test. Interestingly, in the low-vision subjects, repeatability was slightly better for the Mars test than for the Pelli-Robson test (95% LoA = ±0.20 vs. ±0.28). Conversely, in normal-vision subjects, repeatability was slightly better for the Pelli-Robson test (Table 2).

Further inspection of the data for normal-vision subjects revealed that mean CS scores varied with different forms of the Mars test. The mean scores for each of the three forms are shown in Table 3. The mean score for Form 3 is around 0.08 log units, or two letters, better than the mean for Forms 1 and 2 ($t = 3.80$, $p < 0.001$ and $t = 5.46$, $p < 0.001$, respectively), suggesting that the contrast of the letters is slightly higher on Form 3. Pairwise comparison of normal-vision subjects tested with Forms 1 and 3 (n = 12, mean difference = 0.08 ± 0.06 log units) and with Forms 2 and 3 (n = 12, mean difference = 0.09 ± 0.06 log units) led to similar conclusions. Frequency of seeing curves were plotted for the last 12 letters of each form of the Mars test to further explore any possible differences in contrast between forms of the Mars test (Fig. 3). For each letter, the percentage of all normal- (young and old) vision subjects who correctly identified that letter was plotted. Frequency of seeing curves for all normal-vision subjects for each of the three forms of the Mars test are shown in Figure 3. From the figure, it again appears that the contrast of Form 3 is slightly higher than those of the other two forms and that there are some individual letters on certain forms whose contrast is different from the stated value. For example, the 44th letter of Form 3 (V) was identified correctly by 75% of normal-vision subjects, but the 44th letter of Form 2 (Z), which has the same stated contrast, was not identified correctly by any normal-vision subjects.

Given the apparent higher contrast of Form 3 of the Mars test, a correction factor was calculated by subtracting the average of the mean CS scores of normal-vision subjects on Forms 1 and 2 from the mean CS score on Form 3. This factor was then applied to all CS scores of normal-vision subjects on Form 3, and new mean CS scores and 95% LoA were calculated. This correction factor im-

TABLE 2.
Repeatability of the Pelli-Robson and Mars tests for all subjects and for each subgroup[a]

	Pelli-Robson	Mars	Mars With Correction Factor
Young normal vision	±0.14	±0.18	±0.14
Older normal vision	±0.17	±0.20	±0.13
Low vision	±0.28	±0.20	—
All subjects	±0.20	±0.20	—

[a]All values represent the 95% LoA in log units. The final column shows the 95% LoA when a correction factor of −0.08 log units is applied to all scores from Form 3 of the Mars test.

LoA, limits of agreement.

TABLE 3.
Mean scores for each form of the Mars test in normal-vision subjects[a]

Mars Test Form	n	Mean (± SD) Contrast Sensitivity Score
1	25	1.72 ± 0.07
2	24	1.70 ± 0.06
3	25	1.79 ± 0.05

[a]Number of subjects tested is around two thirds of the total (37) as a result of the experimental design.

SD, standard deviation.

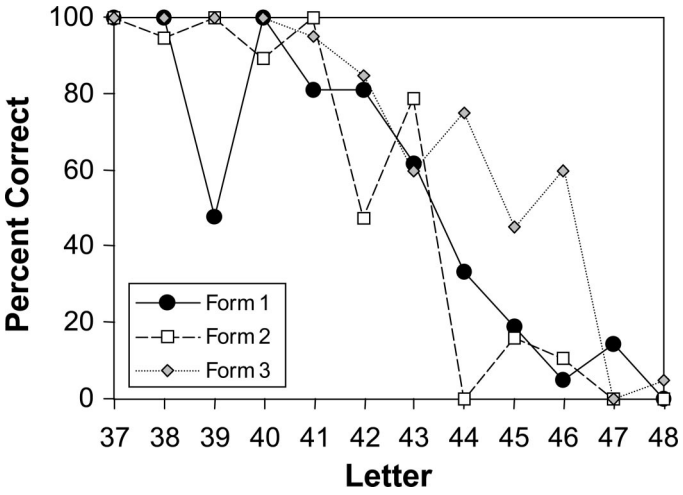

FIGURE 3.
Frequency of seeing curves derived from the responses of normal-vision subjects reading each form of the Mars test. Data are shown for the last 12 letters (two lines) on each chart corresponding to stated log contrasts of −1.48 to −1.92 (3.3–1.2%). Note that not all subjects had the opportunity to read all letters because testing stopped once two consecutive letters were missed. For the purposes of this analysis, all subsequent letters were assumed to be missed.

proves the repeatability of the Mars test from 95% LoA of ±0.18 to ±0.14 log units in the young normal vision subjects and from ±0.20 to ±0.13 log units in the older normal-vision subjects.

DISCUSSION

The new Mars Letter Contrast Sensitivity Test shows good agreement with the Pelli-Robson test and similar test–retest repeatability. These findings suggest that it may be a viable alternative to the Pelli-Robson chart for testing CS in clinical practice and research.

Table 4 shows historical mean CS scores and repeatability data for the Pelli-Robson test, as well as those measured in the present study. Mean CS scores for the Pelli-Robson test in normal-vision subjects in the present study were slightly worse than those of some other studies.[13,17,18] Repeatability of CS scores from the Pelli-Robson test in the present study was quite comparable to that of previous studies.[18–20]

Mean CS scores for different forms of the Mars test (Table 3) suggest that the contrast values of the lower letters on Form 3 of the test are slightly higher than those of the other two forms. Frequency of seeing curves plotted for the last 12 letters (the last two lines) on each of the three forms (Fig. 3) also suggest that Form 3 has a slightly higher level of contrast. Some of the variations between and within charts may also be the result of differences in legibility of letters.[15] Nonetheless, this cannot explain all of the differences between forms, especially given that the 46th letter of all three forms of the test is a "D." Given that it is in the same position on all three forms, its contrast should theoretically be the same, as would be the frequency with which normal-vision subjects identify the letter correctly. Nonetheless, 60% of normal-vision subjects correctly identified the "D" on Form 3, whereas only 5% correctly identified it on Form 1 and 10.5% on Form 2.

The mean CS score in normal-vision subjects was 1.79 for Form 3 compared with 1.72 and 1.69 for Forms 1 and 2, respectively. This represents about a two-letter discrepancy and adversely affects the repeatability of the test, so scores from Form 3 were adjusted by a correction factor of −0.08 log units for all normal-vision subjects (Table 2). This correction factor improved the repeatability of the test, narrowing the 95% LoA to ±0.14 log units in all normal-vision subjects (n = 37), which is actually better than the repeatability of the Pelli-Robson test (95% LoA = ±0.18 log units). This agrees with other recently reported values.[21] It should be noted that these contrast discrepancies did not affect the repeatability of the Mars test in low-vision subjects, because they were unlikely to reach the lower contrast portions of the charts. Until the manufacturers of the Mars test can resolve these between-chart discrepancies, clinicians and researchers may need to apply similar correction factors or avoid using different forms of the test.

We made some photometric measurements of the contrast of the charts used in the present study using a Spectra Pritchard Photometer Model 1980 A (Kollmorgen Corp., Burbank, CA). As expected, accurately measuring the contrast of letters with stated contrast values of 1% to 2% was very difficult. In most cases, the letters could not be seen through the eyepiece of the photometer and estimates of contrast were highly variable. Given that subjects with poorer contrast sensitivity had slightly higher scores on the Mars test than on the Pelli-Robson test (Fig. 1), we also measured the contrast of letters in the 0.75- to 1.00-log unit range on both tests. We found that the contrast of the letters on the Mars test was on average 0.07 log units higher than the stated value, whereas the values on the Pelli-Robson test were within 0.02 log units of the stated value. This is consistent with the low-vision subjects scoring higher on the Mars test.

Researchers have shown that the repeatability of a visual acuity or CS test is related to the number of letters per unit change in size

TABLE 4.
Previous studies of the repeatability of the Pelli-Robson test[a]

Author	Method	Subjects	Mean ± SD	95% LoA
Elliot et al.[13]	Monocular, dominant eye, best correction	Age range = 22–79, N = 40, VA > 6/9	1.83 ± 0.14	±0.20
Elliot et al.[19]	Monocular, dominant eye, best correction	Young normal, N = 30	1.88 ± 0.08	±0.16
		Older normal, N = 42	1.75 ± 0.12	±0.23
Lovie-Kitchin and Brown[20]	Monocular, better eye, habitual correction, test distance = 3 m	Young and older normal, N = 79	1.74	±0.17
Elliot and Bullimore[18]	Monocular, best correction	Young normal, N = 24	1.86 ± 0.09	±0.18 (41 subjects from all 3 groups)
		Older normal, N = 23	1.80 ± 0.11	
		Cataract group: VA > 6/21, N = 33	1.48 ± 0.25	
Haymes and Chen[17]	Monocular, better eye, best correction in low vision subjects; right eye with habitual correction in soft contact lens subjects	Low-vision group: mean age = 74, N = 22; VA range = 0.36–1.50	1.11 ± 0.38	±0.25
		logMAR, soft contact lens group: mean age = 22, N = 20, VA range = –0.12 to 0.16	1.88 ± 0.08	±0.18
Present study	Monocular, right (or better) eye with habitual correction	Young normal (N = 20)	1.70 ± 0.08	±0.14
		Older normal (N = 17)	1.74 ± 0.09	±0.18
		Low vision (N = 17)	1.30 ± 0.47	±0.20

Values are in log units.
[a]Test distance = 1 m, unless specified.
SD, standard deviation; LoA, limits of agreement; VA, visual acuity.

or contrast.[22,23] In essence, CS tests with finer scales, in which each letter represents a smaller change in contrast, should have better repeatability. On the Mars test, each letter corresponds to 0.04 log units and thus the test should have better repeatability, and narrower 95% LoA, than the Pelli-Robson test when, although the contrast decreases in 0.15-log unit steps, each letter can be taken to correspond to 0.05 log units.[14] This theory is supported by our results once the correction factor is applied to Form 3 of the Mars test (Table 2).

Previous studies have reported that vision tests in low-vision subjects are likely to be less repeatable than in people with normal vision.[24,25] Given that CS testing is frequently indicated in low-vision patients, it is crucial that a new test of CS has comparable repeatability to those tests that are commonly used. The fact that the Mars test uses letters of smaller size and a lesser angular subtense than the Pelli-Robson test (2 vs. 2.8 deg) may raise some concerns about its use in subjects with poorer visual acuity. Nonetheless, the Mars test performed well in the low-vision subjects tested in this study. The Mars test had better repeatability (95% LoA = ±0.20 log units) than the Pelli-Robson test (95% LoA = ±0.28 log units) in low-vision subjects. Agreement between the two tests in low-vision subjects (95% LoA = ±0.30 log units) was poorer than in all subjects (95% LoA = ±0.21 log units), and we did not test subjects with visual acuity worse than 20/250. Overall, our results suggest that the Mars test is an appropriate test for use in a low-vision population. Using the test at a distance of 40 cm instead of the recommended 50 cm would result in the letters having a similar angular subtense as the letters on the Pelli-Robson test at 1 m.

Elliot et al. demonstrated the value of accepting a response of "C" for "O" and "O" for "C" on the Pelli-Robson test.[15] The data presented for our main analyses in the current study are based on accepting these common miscalls on both the Pelli-Robson test and the Mars test. Nonetheless, we recorded such miscalls and analyzed repeatability with and without their acceptance. We found that CS scores from the Mars test demonstrated improved repeatability when "C" and "O" miscalls were accepted with 95% limits of agreement of ± 0.20 log units when the miscalls were accepted and ± 0.22 log units when they were not accepted. These results suggest that there is value in accepting "C" for "O" and "O" for "C" responses on the Mars test.

There are several physical features of the Mars test that make it desirable for use in a clinical setting. The charts are small, measuring 23 cm by 35.5 cm. This makes them much easier to transport and store than the Pelli-Robson test, which is considerably larger. A plastic folder is provided for storing the Mars charts, protecting them from damage. The Mars test is also printed on a durable plastic, which may make it less susceptible to damage than the Pelli-Robson test, which is printed on thin cardboard. Finally, the smaller dimensions of the Mars test make it easier to illuminate evenly. All of these features make the Mars test fairly versatile and

likely more convenient for use in a wide variety of patient care settings than the Pelli-Robson test.

ACKNOWLEDGMENTS

Supported in part by grant T3507,151 from the National Eye Institute, National Institutes of Health, Bethesda, Maryland, and by the Ohio Lions Eye Research Foundation. The authors thank Aries Arditi, Ian L. Bailey, and Thomas W. Raasch for their suggestions.

Received March 31, 2005; accepted June 7, 2005.

REFERENCES

1. Arden GB. Testing contrast sensitivity in clinical practice. Clin Vision Sci 1988;2:213–24.
2. Haymes S, Guest D, Heyes A, Johnston A. Mobility of people with retinitis pigmentosa as a function of vision and psychological variables. Optom Vis Sci 1996;73:621–37.
3. Hassan SE, Lovie-Kitchin JE, Woods RL. Vision and mobility performance of subjects with age-related macular degeneration. Optom Vis Sci 2002;79:697–707.
4. Leat SJ, Woo GC. The validity of current clinical tests of contrast sensitivity and their ability to predict reading speed in low vision. Eye 1997;11:893–9.
5. Nelson P, Aspinall P, Papasouliotis O, Worton B, O'Brien C. Quality of life in glaucoma and its relationship with visual function. J Glaucoma 2003;12:139–50.
6. American Academy of Ophthalmology. Contrast sensitivity and glare testing in the evaluation of anterior segment disease. Ophthalmology 1990;97:1233-7.
7. Kaiserman I, Hazarbassanov R, Varssano D, Grinbaum A. Contrast sensitivity after wave front-guided LASIK. Ophthalmology 2004; 111:454–7.
8. Mutyala S, McDonald MB, Scheinblum KA, Ostrick MD, Brint SF, Thompson H. Contrast sensitivity evaluation after laser in situ keratomileusis. Ophthalmology 2000;107:1864–7.
9. Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clin Vision Sci 1988;2:187–99.
10. Klein BE, Moss SE, Klein R, Lee KE, Cruickshanks KJ. Associations of visual function with physical outcomes and limitations 5 years later in an older population: the Beaver Dam eye study. Ophthalmology 2003;110:644–50.
11. Rubin GS, West SK, Munoz B, Bandeen-Roche K, Zeger S, Schein O, Fried LP. A comprehensive assessment of visual impairment in a population of older Americans. The SEE Study. Salisbury Eye Evaluation Project. Invest Ophthalmol Vis Sci 1997;38:557–68.
12. Rubin GS. Reliability and sensitivity of clinical contrast sensitivity tests. Clin Vision Sci 1988;2:169–77.
13. Elliott DB, Bullimore MA, Bailey IL. Improving the reliability of the Pelli-Robson contrast sensitivity test. Clin Vision Sci 1991;6:471–5.
14. Arditi A. Improving the design of the letter contrast sensitivity test. Invest Ophthalmol Vis Sci 2005;46:2225–9.
15. Elliott DB, Whitaker D, Bonette L. Differences in the legibility of letters at contrast threshold using the Pelli-Robson chart. Ophthal Physiol Opt 1990;10:323–6.
16. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1: 307–10.
17. Haymes SA, Chen J. Reliability and validity of the Melbourne Edge Test and High/Low Contrast Visual Acuity chart. Optom Vis Sci 2004;81:308–16.
18. Elliott DB, Bullimore MA. Assessing the reliability, discriminative ability, and validity of disability glare tests. Invest Ophthalmol Vis Sci 1993;34:108–19.
19. Elliott DB, Sanderson K, Conkey A. The reliability of the Pelli-Robson contrast sensitivity chart. Ophthal Physiol Opt 1990;10: 21–4.
20. Lovie-Kitchin JE, Brown B. Repeatability and intercorrelations of standard vision tests as a function of age. Optom Vis Sci 2000;77: 412–20.
21. Haymes SA, Roberts KF, Cruess AF, Nicolela MT, LeBlanc RP, Chauhan BC, Artes PH. Evaluation of the new Lighthouse Letter Contrast Sensitivity Test. Invest Ophthalmol Vis Sci 2005;46:E-Abstract 4605.
22. Bailey IL, Bullimore MA, Raasch TW, Taylor HR. Clinical grading and the effects of scaling. Invest Ophthalmol Vis Sci 1991;32: 422–32.
23. Raasch TW, Bailey IL, Bullimore MA. Repeatability of visual acuity measurement. Optom Vis Sci 1998;75:342–8.
24. Reeves BC, Hill AR, Aspinall PA. The clinical significance of change. Ophthal Physiol Opt 1987;7:441–6.
25. Elliott DB, Sheridan M. The use of accurate visual acuity measurements in clinical anti-cataract formulation trials. Ophthal Physiol Opt 1988;8:397–401.

Bradley E. Dougherty
The Ohio State University College of Optometry
Columbus, OH 43210
e-mail: bdougherty@optometry.osu.edu