Title:

The Letter Contrast Sensitivity Test: Clinical Evaluation of a New Design

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ABSTRACT

PURPOSE: To compare the reliability, validity and responsiveness the Mars Letter Contrast Sensitivity (CS) Test to the Pelli-Robson CS Chart.

METHODS: One eye of 47 normal control subjects, 27 open angle glaucoma patients, and 17 age-related macular degeneration (AMD) patients was tested twice with the Mars test and twice with the Pelli-Robson test, in random order, on separate days. Also, 17 patients undergoing cataract surgery were tested, once pre-surgery and once post-surgery.

RESULTS: Mean Mars CS was 1.62 log CS (SD, 0.06 log CS) for normal subjects aged 22 to 77 years, with significantly lower values for glaucoma and AMD patients ($P<0.001$). Mars test-retest 95% limits of agreement (LOA) were $\pm$0.13, $\pm$0.19 and $\pm$0.24 log CS for normal, glaucoma and AMD subjects, respectively. In comparison, Pelli-Robson test-retest 95% LOA were $\pm$0.18, $\pm$0.19 and $\pm$0.33 log CS. The Spearman correlation between the Mars and Pelli-Robson tests was 0.83 ($P<0.001$). However, systematic differences were observed, particularly at the upper/normal end of the range, where Mars CS was less than Pelli-Robson CS. Following cataract surgery, Mars and Pelli-Robson effect size statistics were 0.92 and 0.88, respectively.

CONCLUSIONS: The results indicate the Mars test has test-retest reliability equal to or better than the Pelli-Robson test and comparable responsiveness. The strong correlation between the tests provides evidence the Mars test is valid. However, systematic differences indicate normative values are likely to be different for each test. The Mars Letter CS Test is a useful and practical alternative to the Pelli-Robson CS Chart.

KEYWORDS: contrast sensitivity, Mars Letter Contrast Sensitivity Test, Pelli-Robson Contrast Sensitivity Chart, test-retest reliability, responsiveness, effect size, glaucoma, age-related macular degeneration, cataract

INTRODUCTION

Contrast sensitivity (CS) is a fundamental aspect of vision. Its measurement provides useful independent information in relation to a patient's visual function, which may not be revealed by visual acuity (VA).[1-5] There is considerable evidence that it is a strong predictor of real-world performance, providing insight into a patient's disability and quality of life.[6] Specifically, studies have shown a significant relationship between CS and driving performance,[7] mobility and walking speed,[8] postural stability and falls,[9, 10] face recognition,[11] reading speed,[12, 13] computer task accuracy[14] and ability to perform activities of daily living.[15, 16] Furthermore, there is evidence to suggest CS measurement may have some value in the detection and progression of ocular diseases, such as cataract;[17] glaucoma;[2, 18] age-related macula degeneration (AMD);[19, 20] diabetic retinopathy,[21] and optic neuritis.[22] Also, CS tests have been useful for evaluating cataract surgery;[23] YAG laser capsulotomy;[24] intraocular lenses;[25, 26] medications and surgery for glaucoma;[27, 28] verteporfin and radiation therapy for AMD;[29] laser photocoagulation and pharmaceutical therapeutics for diabetic retinopathy;[30, 31] contact lens use;[32] and laser refractive surgery.[33] Thus, the measurement of CS has substantive importance and value in vision research and clinical care.

Several CS tests with good psychometric properties have been developed, which are easily administered in a clinical setting.[6, 34] They have been used in numerous clinical research studies and have become standard in low vision care. The most widely used test is the Pelli-Robson CS Chart.[35] Briefly, it is a large wall-mounted chart, with letters

of a fixed size (comprising spatial frequencies appropriate for estimating peak CS), which decrease in contrast. Recently, a similar, portable test called the Mars Letter CS Test has been developed,[36] facilitating convenient administration and out-of-clinic testing. Another advantage is that its termination and scoring rules are simple and unambiguous; whereas, various rules have been applied to the Pelli-Robson test, there being no established standard.[36] Perhaps the most important new design feature of the Mars test is the use of a finer contrast scale. Contrast changes by 0.04 log units with the Mars test, compared to 0.15 log units with the Pelli-Robson test. The finer scale of the Mars test may result in less variability,[36] and hence, improved test-retest reliability,[37] and accuracy.[35, 38] Indeed, in computer simulations, the Mars test has been shown to have lower variability than the Pelli-Robson test.[36] However, these potential advantages of the Mars test have not been confirmed by sufficient empirical study. We are aware of only one recent publication, in which findings for normal subjects and a heterogeneous low vision group are reported.[39]

The central objectives of this study were to acquire empirical data and to evaluate the psychometric properties of the Mars test in a clinical sample. Our more specific objectives were to determine its discriminability, test-retest reliability and criterion validity for normal subjects compared to patients with glaucoma and patients with AMD; and the responsiveness of the Mars test to cataract surgery.

METHODS

Subjects

The sample contained 47 normal control subjects, 27 open angle glaucoma patients, 17 AMD patients and 17 cataract patients. Control subjects were recruited by placement of a study information sheet on hospital noticeboards and patient groups were recruited from the Eye Care Centre, Queen Elizabeth II Health Sciences Centre (Halifax, NS). Inclusion criteria for the control subjects were a normal ocular examination and VA better than 0.30 logMAR (20/40). For glaucoma patients, the inclusion criteria were a glaucoma specialist's diagnosis of open angle glaucoma, characteristic glaucomatous optic disc (e.g. notching or progressive thinning of the neuroretinal rim), and visual field impairment detected with the Humphrey Field Analyzer (HFA). For AMD patients, the inclusion criteria were characteristic macular changes with fluorescein angiography (e.g. drusen, retinal pigment epithelium abnormalities, choroidal neovascularisation, sub-retinal haemorrhage or fibrous tissue),[40] and stable disease (as indicated by ophthalmoscopy and a difference in VA of less than 0.20 logMAR at the first study visit compared to a clinic visit at least 1 month prior to participation). For cataract surgery patients, the inclusion criterion was lens opacification equal to or worse than grade II (Lens Opacities Classification System II [LOCS II]).[41] To determine eligibility, a full ocular examination was performed and the medical history was recorded for all subjects. Exclusion criteria were concomitant ocular disease, lens opacification worse than grade II[41] (except for the cataract surgery group), and VA worse than 1.60 logMAR (20/800).

The study design and protocol was approved by the Institutional Ethics Review Board and adhered to the tenets of the Declaration of Helsinki. Subjects gave informed written consent prior to participation.

Contrast Sensitivity Measures

All subjects were tested with the Mars Letter CS Test (Mars Perceptrix, Chappaqua, NY; http://www.marsperceptrix.com/; previously supplied as the Lighthouse Letter CS Test), a portable chart measuring 23 x 36 cm, and intended for use at 50 cm.[36] The Mars test has several design principles in common with the Pelli-Robson test. There are 8 rows of letters, with 6 Sloan[42] letters per row. Letters of constant size are used, which decrease in contrast across and down the chart, and the scale is in units of $\log_{10}$ CS (CS=1/[contrast$_{Weber}$]; contrast$_{Weber}$=[$L_{background}$ - L_{letter}]/$L_{background}$; L=luminance). The Mars test letters subtend 2 degrees (at 50 cm), the change in contrast between successive letters is 0.04 log units (10%) and the range is from 0.04 to 1.92 log CS. To score the test, a value of 0.04 log CS is given per letter named correctly. Three chart forms are supplied, each with a different letter sequence. The charts are printed on sheets of resin-coated paper, using half-tone screening methods, and separately mounted.

Subjects were also tested with the Pelli-Robson CS Chart (Haag-Streit UK, Essex, UK). It measures 59 x 84 cm in size and at the recommended 1 m test distance, all letters subtend 2.8 degrees. Each of the 8 rows comprises 2 triplets of letters. The 3 letters within each triplet have equal contrast; however, each triplet decreases in contrast across and down the chart. The change in contrast between successive triplets is 0.15 log units (41%) and the range is from 0.00 to 2.25 log CS. The scoring rule

92 recommended by the manufacturer is the log CS of the last triplet for which 2 letters (2-
93 of-3), are named correctly. However, this is not an established standard and various
94 rules have been applied to the Pelli-Robson test.[36] Assigning a value of 0.05 log CS per
95 correct letter has been shown to improve accuracy and reliability,[36, 38] and this scoring
96 rule is used regularly. Two chart forms are provided and are printed using methods
97 similar to those used for the Mars test.
98
99 **Testing Procedures**
100 For the normal control group, one eye was randomly selected for study. For the
101 glaucoma and AMD groups, the eye with worse HFA mean deviation or VA,
102 respectively, was selected. The study eye was tested twice with the Mars test and twice
103 with the Pelli-Robson test, in random order. The median time between the test and the
104 retest session was 7 days. As differences between available charts/forms were
105 determined to be non-significant in a pilot study ($P>0.05$), one chart/form of each test
106 was used (chart 1). Background chart luminance was within the range recommended by
107 each manufacturer (Mars test, 113 cd/m^2; Pelli-Robson test, 120 cd/m^2).
108
109 For both tests, subjects were instructed to begin reading the letters at the top of the
110 chart, and to continue reading across and down the chart. The Mars test was terminated
111 when 2 consecutive letters were named incorrectly,[36] and the Pelli-Robson test when 2-
112 of-3 letters were named incorrectly.[35] Subjects were encouraged to observe letters for at
113 least 20 s, as this is often necessary for perception at threshold.[38] Subjects were also
114 encouraged to guess. Although accepting a response of “O” for a presented “C” has
115 been suggested,[43] this method was not applied in our study. Both tests were scored

using the letter-by-letter method,[38, 44] where a value of 0.04 log CS and 0.05 log CS was given per correct letter for the Mars and Pelli-Robson tests, respectively.

The responsiveness of the Mars and Pelli-Robson tests to cataract surgery was evaluated by testing patients once pre-surgery and once post-surgery (median time pre-surgery, 2 days; median time post-surgery, 8 weeks). The tests were administered and scored for this group in the same manner as described above. All cataract patients underwent small-incision phacoemulsification in the study eye, with implantation of a monofocal posterior chamber intraocular lens, by the same surgeon.

For all subjects, distance VA was also tested at each study session, using the Early Treatment Diabetic Retinopathy Study (ETDRS) logMAR chart,[45] with background luminance in the recommended range,[46, 47] a termination rule 4-of-5 letters named incorrectly,[48] and letter-by-letter scoring. All tests were performed with optimal spectacle refractive error correction.

Data Analysis

Data were analysed using SPSS, 12.0 for Windows (SPSS Inc., Chicago, IL). Mars test and Pelli-Robson test descriptives were calculated and analysis of variance (ANOVA) used to evaluate the significance of group differences. Linear regression analysis was used to evaluate the relationship between age and each CS test. Spearman's rank correlation coefficient was used to determine the association between Pelli-Robson CS and Mars CS. All analyses were 2-tailed and P-values less than 0.05 were considered statistically significant.

Test-retest reliability was determined using Bland-Altman analysis.[49] Specifically, we evaluated plots of the difference between the test-retest CS against the mean of the test-retest CS, and the test-retest 95% limits of agreement (LOA; where 95% LOA=mean test-retest difference ± 1.96SD). Differences in 95% LOA between tests were evaluated using F-tests. Responsiveness was investigated by comparing mean change scores (difference in pre- and post-surgery CS) and effect size (ES) statistics for the Mars and Pelli-Robson tests. ES statistics are expressions of the magnitude of change in terms of standard units of test variability (SD units), and thereby facilitate comparisons between tests. We selected the Cohen's *d* ES statistic for this study,[50] as it is well-established and there are guidelines for comparing results.[51] Cohen's *d* ES was calculated as follows: $ES=(\text{mean } CS_{\text{post-surgery}} - \text{mean } CS_{\text{pre-surgery}})/SD_{\text{pooled}}$. Cohen has suggested that ES statistics of 0.2, 0.5, 0.8, represent small, medium and large effects, respectively.[50]

RESULTS

Subject Characteristics

Descriptive statistics for the characteristics of each subject group are given in Table 1.

Table 1. Subject Characteristics by Group*

Characteristic	Normal Control (n=47)	Glaucoma† (n=27)	AMD (n=17)	Cataract‡ (n=17)
Age, years				
mean (SD)	48 (17)	67 (11)	73 (7)	73 (8)
range	22 to 77	41 to 89	58 to 83	58 to 85
Gender				
male:female	22:25	10:17	6:11	9:8
Best VA, logMAR				
mean (SD)	-0.02 (0.09)	0.04 (0.11)	0.82 (0.51)	0.45 (0.32)
range	-0.18 to 0.24	-0.16 to 0.34	0.16 to 1.62	0.02 to 1.40

*Abbreviations: VA, visual acuity.
†Mean Humphrey Field Analyzer mean deviation, -6.42 dB (SD, 7.96 dB; range, -31.09 to +1.47 dB).
‡VA pre-surgery.

Descriptives and Normative Data

The Mars and Pelli-Robson tests were both appropriate for use with all subject groups, with no upper or lower end-of-scale limitations. For the normal control group, mean results with the Mars and Pelli-Robson tests were 1.62 log CS (SD, 0.06 log CS) and 1.79 log CS (SD, 0.11 log CS), respectively. There was a significant decrease in both Mars CS and Pelli-Robson CS with age (slope of fitted regression line=0.012 log CS and 0.028 units per decade [R^2=0.17 and 0.22, P=0.004 and 0.001], for Mars CS and Pelli-Robson CS, respectively; Figure 1). The Mars test prediction interval (Figure 1) suggests that, for a person aged 25 years, the upper and lower limits of normal Mars CS were

176 approximately 1.72 log CS and 1.56 log CS, respectively. For a person aged 60 years,
177 the upper and lower limits of normal Mars CS were approximately 1.68 log CS and 1.52
178 log CS, respectively.
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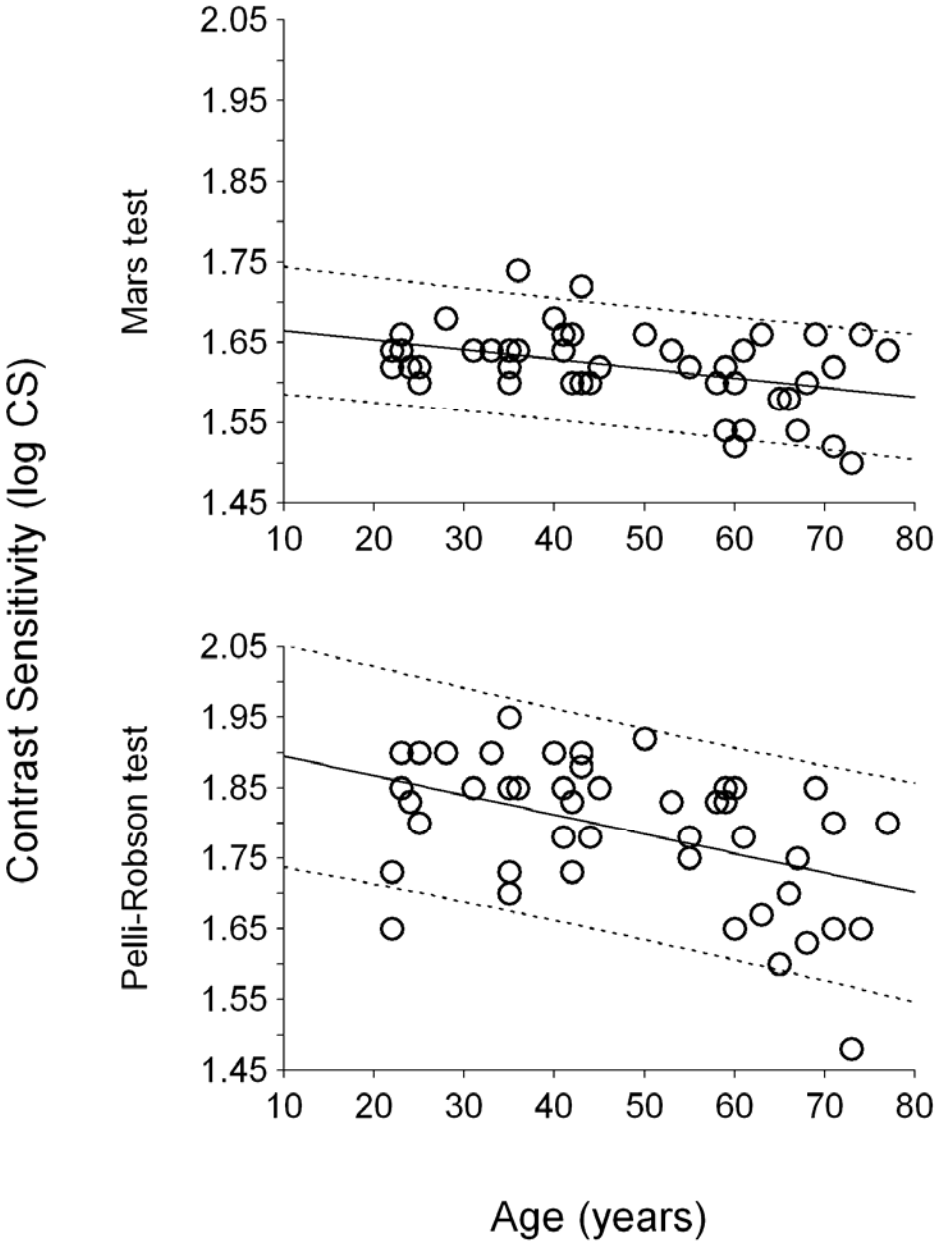

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Figure 1. Relationship between contrast sensitivity (CS) and age, with the Mars test (top graph) and the Pelli-Robson test (bottom graph)–for the normal control group (n=47). For each graph, the solid line indicates the fitted linear regression line (Mars log CS=-0.0012*age + 1.68, [R^2=0.17, P=0.004]; Pelli-Robson log CS=-0.0028*age + 1.92, [R^2=0.22, P=0.001]); dashed lines indicate the 90% prediction interval.

Mean CS with the Mars test and the Pelli-Robson test for each group is given in Table 2. The difference between groups was statistically significant with both tests (Mars test ANOVA $F_{2,88}$=56.5, P<0.001; Pelli-Robson test ANOVA $F_{2,88}$=59.0, P<0.001).

Table 2. Mean Contrast Sensitivity with the Mars Test and Pelli-Robson Test by Group*

Test	Normal Control (n=47)	Glaucoma (n=27)	AMD (n=17)
Mars, log CS			
mean (SD)	1.62 (0.06)	1.56 (0.15)	1.03 (0.43)
range	1.44 to 1.84	0.96 to 1.76	0.04 to 1.44
Pelli-Robson, log CS			
mean (SD)	1.79 (0.11)	1.64 (0.21)	0.98 (0.53)
range	1.45 to 1.95	1.05 to 2.00	0.00 to 1.60

*Abbreviations: CS, contrast sensitivity.

Test-Retest Reliability

Measures of test-retest reliability are presented in Table 3. The Mars mean test-retest difference for the normal control group was 0.02 log CS (SD, 0.07 log CS), indicating a small learning effect. Similarly small mean test-retest differences were observed with both the Mars and Pelli-Robson tests for all groups (mean test-retest difference ≤ 0.02 log CS, P>0.05); the only exception being for the AMD group with the Mars test (mean test-retest difference=0.11 log CS, 95% CI, 0.04 to 0.17 log CS; *t*=3.66, P=0.002).

Table 3. Test-Retest Reliability of the Mars Test and Pelli-Robson Test by Group*

Test	Normal Control (n=47)	Glaucoma (n=27)	AMD (n=17)
Mars, log CS			
mean test-retest diff. (SD)†	0.02 (0.07)	-0.01 (0.10)	0.11 (0.12)
test-retest 95% LOA	0.13	0.19	0.24
Pelli-Robson, log CS			
mean test-retest diff. (SD)†	0.02 (0.09)	0.01 (0.10)	0.00 (0.17)
test-retest 95% LOA	0.18	0.19	0.33

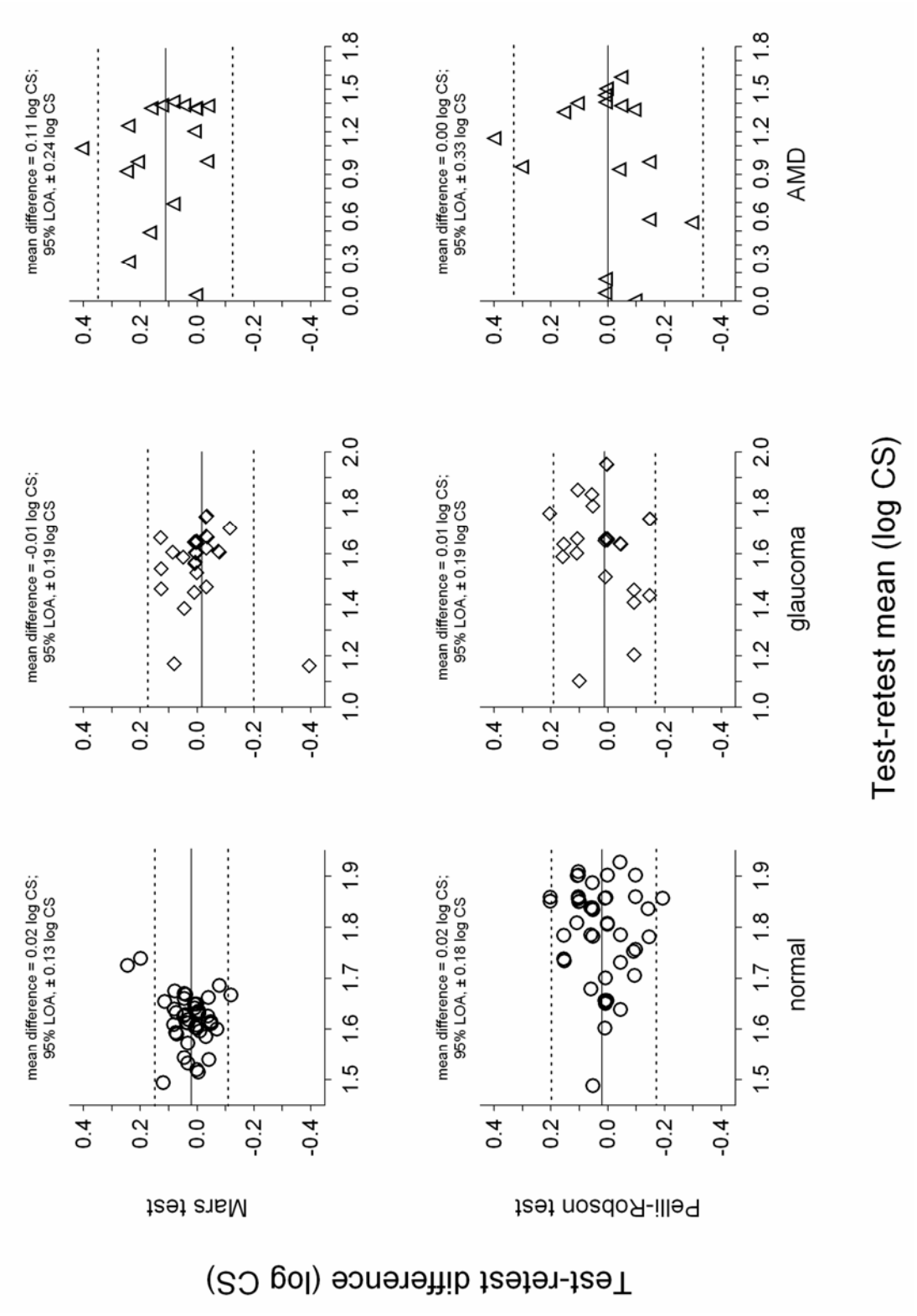
*Abbreviations: CS, contrast sensitivity; diff., difference; LOA, limits of agreement (± 1.96SD).
†Test CS subtracted from retest CS, such that a positive value indicates an improvement in CS on retest and a negative value indicates a worsening.

The 95% LOA were the same or narrower (less test-retest variability) with the Mars compared to the Pelli-Robson test, for all groups (Table 3). For the normal control group, the 95% LOA were ±0.13 log CS with the Mars test compared to ±0.18 log CS with the Pelli-Robson test (F-statistic=1.91, P=0.03). Comparing the subject groups, the 95% LOA were narrowest for the normal control group, followed by the glaucoma group and widest for the AMD group (Table 3). The increased test-retest variability of AMD patients, compared to the normal control subjects, was statistically significant with both

the Mars and the Pelli-Robson test (F-statistic=3.62 and 3.39, respectively, P<0.005). The test-retest difference as a function of the test-retest mean is presented in Figure 2, for each CS test and each group. The mean test-retest differences and 95% LOA from Table 3 are indicated on each plot. In all cases, test-retest differences did not vary in a systematic manner over the CS range measured (Figure 2).

Comparison of Mars Contrast Sensitivity and Pelli-Robson Contrast Sensitivity

The correlation between Mars and Pelli-Robson CS–for subjects in the normal control, glaucoma and AMD groups combined–was strong (Spearman's r=0.83, P<0.001). Even so, there were systematic differences between the tests, as indicated by a plot of the difference between the tests as a function of Pelli-Robson CS (Figure 3). The data do not form a horizontal band across the measurement range. In particular, the difference between Mars CS and Pelli-Robson CS was greater at the upper 'normal' end compared with the lower end of the measurement range, where Mars CS was less than Pelli-Robson CS. Both CS tests were moderately correlated with ETDRS VA (Spearman's r=-0.64 and -0.68, with the Mars test and Pelli-Robson test, respectively; P<0.001).


Mars test
Pelli-Robson test
Test-retest difference (log CS)
Test-retest mean (log CS)
mean difference = 0.02 log CS;
95% LOA, ± 0.13 log CS
mean difference = -0.01 log CS;
95% LOA, ± 0.19 log CS
mean difference = 0.11 log CS;
95% LOA, ± 0.24 log CS
mean difference = 0.02 log CS;
95% LOA, ± 0.18 log CS
mean difference = 0.01 log CS;
95% LOA, ± 0.19 log CS
mean difference = 0.00 log CS;
95% LOA, ± 0.33 log CS
normal
glaucoma
AMD

240

241

Figure 2. Difference between the test and retest contrast sensitivity (CS) plotted against mean of the test and retest CS, for the Mars test (top row) and the Pelli-Robson test (bottom row)–for normal control (first column, circles; n=47), glaucoma (second column, diamonds; n=27) and AMD subjects (third column, triangles; n=17). All differences are test log CS subtracted from retest log CS. A small amount of noise was applied to allow overlapping data points to be differentiated. For each graph, the solid line indicates the mean of the test-retest differences and the dashed lines indicate the test-retest 95% limits of agreement (LOA, where 95% LOA=mean test-retest difference ± 1.96SD). Note that to facilitate comparisons, the y-axis scale is the same for all graphs. However, because of widely different ranges, the x-axis for each group is scaled independently in order to show the data with clarity.

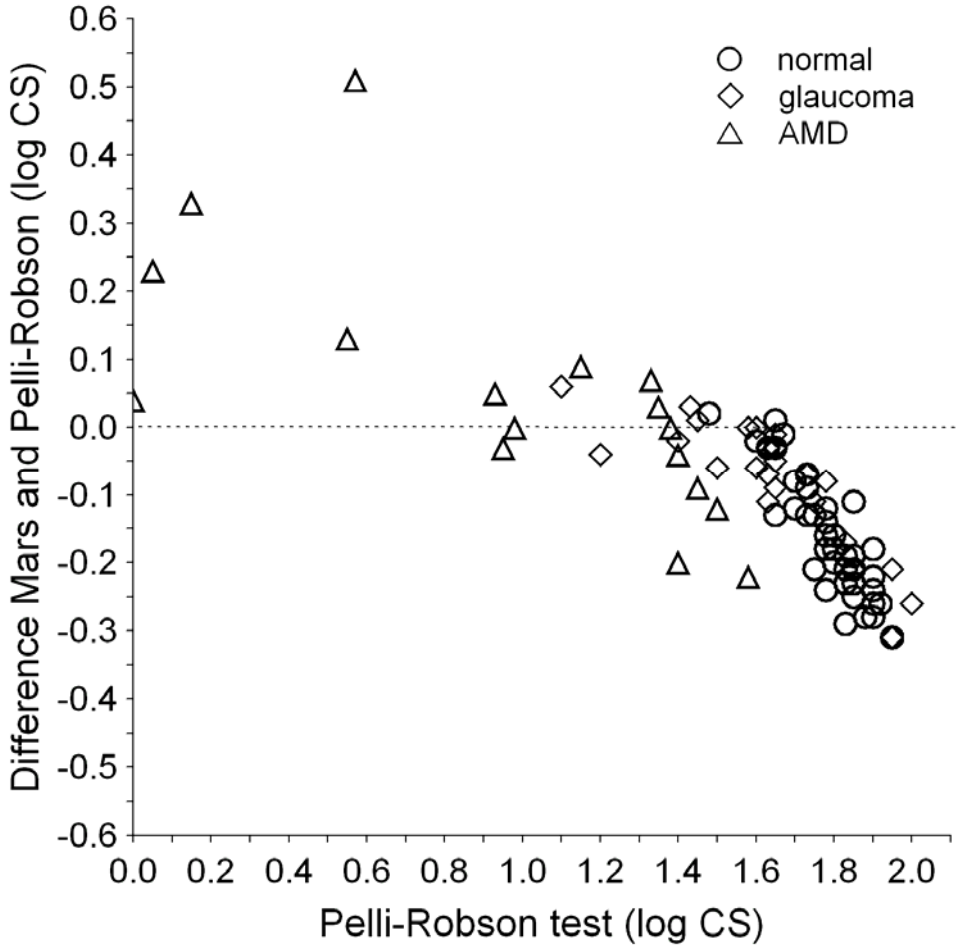


Figure 3. Comparison between Mars contrast sensitivity (CS) and Pelli-Robson CS: difference between Mars and Pelli-Robson CS as a function of Pelli-Robson CS for normal control (circles, n=47), glaucoma (diamonds, n=27) and AMD subjects (triangles, n=17). All differences are Mars log CS minus Pelli-Robson log CS. Each data point was calculated using the mean of the test and retest CS scores. The dashed line indicates the line of equality.

Test Responsiveness

Following cataract surgery, mean improvement in best spectacle corrected VA was 0.39 logMAR (SD, 0.33 logMAR; range, 0.00 to 1.28 logMAR), with 15 out of 17 patients (88%) improving by more than 0.10 logMAR. Change scores following cataract surgery and ES statistics for the Mars and Pelli-Robson tests are given in Table 4. Mean CS change following cataract surgery was 0.21 log CS (SD, 0.27 log CS) and 0.24 log CS (SD, 0.31 log CS) with the Mars and Pelli-Robson test, respectively. Although the mean change was slightly smaller with the Mars compared to the Pelli-Robson test, lower variability resulted in a slightly larger ES statistic (0.92 and 0.88, respectively).

Table 4. Responsiveness of Mars Test and Pelli-Robson Test to Cataract Surgery (n=17)*

Test	Post-Surgery Mean (SD) log CS	Pre-Surgery Mean (SD) log CS	Change Score† Mean (SD) log CS	Effect Size (95% CI)‡
Mars	1.53 (0.08)	1.32 (0.31)	0.21 (0.27)	0.92 (0.20 to 1.61)
Pelli-Robson	1.57 (0.13)	1.33 (0.37)	0.24 (0.31)	0.88 (0.16 to 1.56)

*Abbreviations: CS, contrast sensitivity.
†Pre-surgery CS subtracted from post-surgery CS, such that a positive value indicates an improvement following surgery and a negative value indicates a worsening. P=0.01 and 0.02 for Mars and Pelli-Robson test, respectively.
‡ Effect Size: Cohen's *d*=(mean $CS_{post\text{-}surgery}$ - mean $CS_{pre\text{-}surgery}$)/SD_{pooled} where, $SD_{pooled}=\sqrt{([SD_{post\text{-}surgery}^2 + SD_{pre\text{-}surgery}^2] / 2)}$.

COMMENTS

CS is important because it provides valuable information, independent of VA. Furthermore, it is an important predictor of real-world performance, and may be useful for monitoring ophthalmologic treatment and detecting disease.[6] Therefore, it is imperative that we have convenient tests with good psychometric properties for measuring CS. A new test–the Mars Letter CS Test–has been designed to improve upon the reliability of and practicality of current tests, in particular the well-established Pelli-Robson test. In this study, we evaluated the properties of the Mars test (discriminability, test-retest reliability, criterion validity and responsiveness), for a sample of normal control subjects and patients with glaucoma, AMD and cataract. Data from the normal control subjects were also used to establish reference values.

Mean Mars CS was 1.62 log CS (SD, 0.06 log CS), for our sample of normal subjects aged 22 to 77 years. As expected from other studies of the CS function[52, 53] and letter CS,[3, 4, 54, 55] we found a small, but statistically significant decrease in Mars CS with age, of 0.012 log CS units per decade (P=0.004). This decline was less than that for Pelli-Robson CS (0.028 log CS units per decade, P=0.001). Also, the Mars test was able to discriminate between different patient groups. Compared to normal subjects, Mars CS was lower for glaucoma and AMD patients (mean Mars CS=1.62 [normal], 1.56 [glaucoma] and 1.03 log CS [AMD]; P<0.001). These group differences with the Mars test were comparable to those obtained with the Pelli-Robson test (mean Pelli-Robson CS=1.79 [normal], 1.64 [glaucoma] and 0.98 log CS [AMD]).

To evaluate the consistency of our findings, there are several studies that have provided normative data for the Pelli-Robson test,[1, 3-5, 39, 54, 56-60] with which we can make comparisons. In general, our results are consistent with those that used similar methods. For example, Elliott and Bullimore found mean Pelli-Robson CS was 1.83 (SD, 0.14 log CS) for normal subjects,[57] slightly greater than our finding of 1.79 log CS (SD, 0.11 log CS). The small difference is likely to be because on average, their sample was younger than our sample. On the contrary, Lovie-Kitchin and Brown found a slightly lower value (mean Pelli-Robson CS=1.74 log CS),[3] possibly because the test was administered at 3 m rather than at 1 m, and because the habitual rather than the optimal refraction was used. During the review of this paper, a recent clinical study comparing the Mars test and Pelli-Robson test was also published.[39] Compared with our results, Dougherty et al. found a lower mean Pelli-Robson CS of 1.70 log CS for their sample of normal subjects.[39] Again, this may be because the habitual refraction was used, whereas we used the optimal refraction. For the Mars test, mean CS was 1.72 log CS (SD, 0.07 log CS),[39] somewhat higher than our finding of 1.62 log CS (SD, 0.06 log CS). The reason for this difference is unclear. We would have expected mean Mars CS to be lower rather than higher using the habitual refraction. A possible explanation is that “C” and “O” miscalls were accepted,[39] whereas we did not accept any miscalls.

Mars test-retest 95% LOA were ±0.13 log CS for the normal control group in this study, suggesting that a significant change based on actual scale values would be ±0.16 log CS (4 letters). As hypothesised, the 95% LOA for the normal subjects indicate that the

Mars test was somewhat less variable (or more reliable) than the Pelli-Robson test (95% LOA=±0.13 log CS and ±0.18 log CS, with the Mars and Pelli-Robson test, respectively; P=0.03). This finding is supported by previous studies of the Pelli-Robson test, where test-retest reliability has been found to be in the range ±0.15 to ±0.20 log CS for normal subjects.[3, 38, 54, 57, 61] Furthermore, Dougherty et al. found a similar difference between Mars and Pelli-Robson test-retest reliability for their sample of normal subjects (95% LOA=±0.14 log CS and ±0.18 log CS, with the Mars and Pelli-Robson test, respectively; after correction for the differences in the Mars chart forms used).[39] We also found that the reliability of the Mars test was equal to or better than that of the Pelli-Robson test for patient groups (glaucoma and AMD; Figure 2), which is consistent with results for a heterogeneous group of low vision patients.[39] We suggest that the improved reliability of the Mars test over the Pelli-Robson test is most likely due to the incorporation of a finer contrast scale.

The 95% LOA found in this study also suggest that test-retest reliability is worse in glaucoma and AMD patients compared to normal subjects (Figure 2), with AMD patients having the lowest reliability of the 3 groups (Mars test 95% LOA=±0.24 log CS; Pelli-Robson 95% LOA=±0.33 log CS). This finding is supported by several other studies of CS,[39, 58, 62, 63] and studies of VA,[63-66] in which poorer test-retest reliability has been found for samples comprising vision impaired patients. For example, Haymes and Chen[62] found Pelli-Robson test-retest 95% LOA were ±0.18 log CS and ±0.25 log CS for normal subjects and low vision patients, respectively.

The strong linear correlation found between the Mars test and the Pelli-Robson test in this study provides evidence that the Mars test is valid (Spearman's r=0.83, P<0.001). However, systematic differences between the Mars test and the Pelli-Robson test were observed (Figure 3). At the upper/normal end of the range, Mars CS was less than Pelli-Robson CS and, conversely, Mars CS was greater than Pelli-Robson CS at the lower end of the range. Contrary to this, a difference between the Mars test and Pelli-Robson test was not observed in Arditi's Monte Carlo computer simulation study of the upper range, in which the Mars test had almost negligible bias relative to the Pelli-Robson test.[36] Indeed, our clinical findings do not support his suggestion that scores between the two tests and with published norms for the Pelli-Robson test are directly comparable. With regard to the lower range, there is evidence to support our finding that Mars CS measures were greater than Pelli-Robson CS measures for subjects with poorer CS.[39] However, it should be noted that the samples of subjects investigated with poorer CS have been small.

Our findings indicate that there are differences in CS measurements obtained with the Mars test and the Pelli-Robson test. Given the similarity of the test designs, we suggest the differences are most likely due to discrepancies in the actual contrast levels. Letter contrast in the mid-range has been measured and found to be on average 0.07 log units higher than the stated value for the Mars test, but within 0.02 log units of the stated value for the Pelli-Robson test,[39] providing support for this hypothesis. However, it is difficult to verify the contrast levels of letters in the normal CS range.[67]

As expected, Mars CS improved after cataract surgery (mean change score=0.21 log CS; SD, 0.27 log CS). The ES statistic for the Mars test was 0.92 (95% CI, 0.20 to 1.61), suggesting a large effect and good responsiveness.[50] In comparison, the Pelli-Robson ES statistic was slightly less, 0.88 (95% CI, 0.16 to 1.56). The ES statistic is equal to the magnitude of change divided by the test variability, and although CS with the Mars test changed less, lower variability resulted in a larger ES statistic compared to the Pelli-Robson test (SD_{pooled}=0.23 and 0.28 log CS with the Mars and Pelli-Robson test, respectively). Nevertheless, the small difference between tests is unlikely to be clinically important.[50]

This clinical study has shown that the reliability, validity and responsiveness of the new Mars Letter CS Test are at least equal to those of the Pelli-Robson CS Chart. However, we found systematic differences between Mars CS and Pelli-Robson CS, indicating that normative values are likely to be different for each test. Although we provide data from a group of normal control subjects for reference, we propose that normative values may need to be established from a larger sample. The Mars Letter CS Test is a useful and practical alternative to the Pelli-Robson CS Chart, with broad applicability in clinical research, low vision care, disease monitoring, and outcomes research.

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