Asian Biomedicine Vol. 8 No. 3 June 2014; 361 - 369 DOI: 10.5372/1905-7415.0803.300

Original article

Repeatability assessment of the New Numbers Contrast Sensitivity Chart

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Background: The validity and agreement of the New Numbers Contrast Sensitivity Chart with the original Mars chart have been found to be good. The two charts can be used interchangeably; however, evidence of the repeatability of the new chart remains to be sought. This study was to assess the repeatability of the New Numbers Contrast Sensitivity Chart.

Objectives: We assessed the repeatability of the Numbers Contrast Sensitivity Chart.

Methods: Two hundred subjects from the ophthalmic clinic of the King Chulalongkorn Memorial Hospital, who were able to communicate and read Arabic numerals were recruited. The contrast sensitivity (CS) scores were collected by reading the same Numbers Contrast Sensitivity Chart in the same environment with each eye and both eyes ten minutes apart. The repeatability of the CS score was assessed by Bland–Altman plot analysis.

Results: The visual acuity of subjects with variety in diagnoses ranged from 20/480 to 20/20. The mean differences were –0.006, –0.008, –0.002 log CS and the coefficients of repeatability were 0.155, 0.141, and 0.093 for the right eye, left eye, and both eyes, respectively. The plots showed a narrow range of 95% limit of agreement, which were (+0.146, –0.159) in the right eye, (+0.130, –0.147) in the left eye, and (+0.089, –0.093) in both eyes.

Conclusions: The New Numbers Contrast Sensitivity Chart has good repeatability. With proven good validity and repeatability, this easy and convenient numbers chart is beneficial for practical use in a clinical setting where English is not used as the primary language.

Keywords: Chart, contrast, numbers, test, visual acuity

Contrast is the difference in luminance levels between an image and its surroundings. The ability to discern the amount of luminance difference is called contrast sensitivity [1, 2]. It is one of the essential visual functions apart from visual acuity and color vision. Additional information about visual acuity-independent image quality can be obtained by contrast sensitivity measurement. It is strongly associated with reading performance [3, 4], ambulation mobility [5], driving [6], face recognition [7], and tasks of daily living [8, 9]. Moreover, contrast sensitivity can be used as indicator of disease and disease progression in many ophthalmic conditions including cataract [10, 11], glaucoma [12], corneal disease [13], retinal disease [14], and optic neuropathy [15].

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Currently, there are two methods for measuring contrast sensitivity, which are periodic pattern and nonperiodic pattern [1]. Periodic pattern uses sine-wave gratings. Whereas nonperiodic pattern uses dark targets as letters on white background charts. In recent years, the nonperiodic method, with the use of large letters that have the only one spatial frequency band where contrast sensitivity is peak [16], has been the preferred method of contrast sensitivity measurement in clinical settings. This method has good reproducibility and is easy to perform, making it suitable for general use.

The Mars Contrast Sensitivity Chart is a nonperiodic pattern method. This Sloan-letters chart has been used widely in clinical practice because of its portability, convenience, and accuracy [17-19]. Previous studies have reported the good repeatability of Mars Chart and the correlation between contrast scores measured by the Mars Chart and Pelli–Robson Chart, which is the most accepted chart in many clinical setting and clinical research studies [20-22].

The result showed that the Mars test is valid and can be used as an alternative to the Pelli–Robson Chart [19, 23].

In Thailand, the periodic test has been used routinely for many years. The nonperiodic test, which is easier and more convenient for patients is still not widely used because lots of Thai people are English-alphabet-illiterate. To solve this limitation, the New Numbers Contrast Sensitivity Chart has been invented and uses numbers instead of letters of the Mars Chart (**Figure 1**). By using the numbers, not only Thai people, but also patients of other nationalities can easily understand and have more expedient communication with the examiner.

In our previous study, the validity and agreement of this new chart with the original Mars chart were found to be good. We concluded that the New Numbers Contrast Sensitivity Chart can be used interchangeably with the original Mars Chart [24]; however, evidence of repeatability of the chart remained to be sought. The objective of this study was to assess the repeatability of the New Numbers Contrast Sensitivity Chart.

Materials and methods

This cross-sectional analytic study was conducted at King Chulalongkorn Memorial Hospital, Bangkok, Thailand during December 2010 and February 2011. Subjects aged over 18 years old, able to communicate well, and understand Arabic numbers were recruited using an accidental sampling technique from our ophthalmology outpatient clinic. The subjects were required to be able to read Arabic number sized 2° (1.75 centimeters) at 50 centimeters distance under luminance of not less than 85 candela per square meter (cd/m^2) by each eye separately. This study had been approved by the Institutional Review Board, Faculty of Medicine, Chulalongkorn University. Written informed consent was obtained from all research subjects before study commencement.

The New Numbers Contrast Sensitivity Chart was used. The details of the development of this chart was previously described [24].

Sample size calculation

Estimated sample size was calculated by the method recommended by Martin Bland [25]. With the estimation of within-subject standard deviation equal to ten, each subject repeats the same test two times, the number of subjects calculated from this formula was 192.08, which was then rounded up into 200.

Data collection

After collecting the diagnosis and visual acuity, the patients were asked to read the numbers on the contrast sensitivity chart using their right eye, left eye, and both eyes with three different chart forms. Reading was started at the top line from the left to the right, and preceded downward. An appropriate refractive correction and addition for 50 centimeters distance were given. The test was stopped when the patient made two consecutive errors. Each number represents 0.04 log units of contrast sensitivity scores (logCS). The scoring sheet [24] for each chart form was used to calculate contrast scores in term of logCS (log CS of the final correct number, minus 0.04 for any errors before) and record the data.

The subjects were asked to repeat reading the contrast charts with the right eye, left eye, and both eyes again at ten minute intervals by the examiner who randomly used the three different chart forms. All subjects were tested in the same clinical room, with a light source from the overhead fluorescence light bulbs. The luminance was regularly measured using a digital light meter and confirmed to be more than 85 cd/m^2.

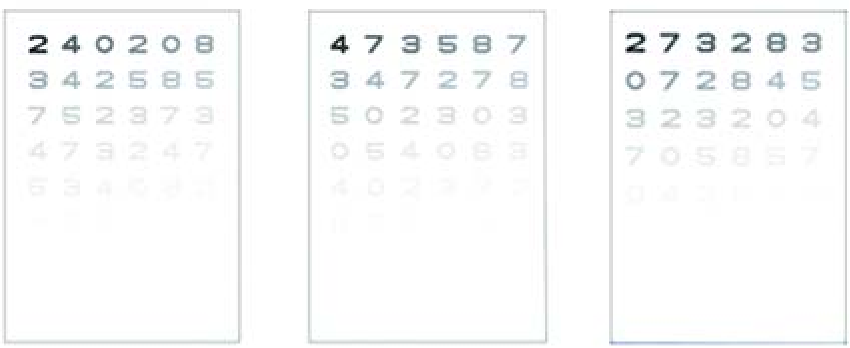

Figure 1. The New Numbers Contrast Sensitivity Chart

Statistical analysis

The repeatability of the CS score for the right eye, left eye, and both eyes was assessed by Bland–Altman plot analysis. Data were analyzed by using Medcalc statistical software version 11.6.1.

Results

Of the 200 subjects randomly recruited from outpatient clinic, 60 were men (30%) and 140 were women (70%). Their average age was 52.7 ± 15.3 (SD) (range 19 to 87 years). Their visual acuity ranged from 20/480 to 20/20 in the both eyes. In these patients, there were various primary diagnoses including routine eye checkup, refractive error, glaucoma, optic nerve disease, vitreoretinal disease, cataract and lens abnormality, corneal disease, disease of conjunctiva and sclera, strabismus, and disease of eyelid and orbit (**Table 1**).

The Bland–Altman plot analysis showed that the mean differences were –0.006, –0.008, –0.002 log CS and the coefficients of repeatability were 0.155, 0.141, and 0.093 for the right eye, left eye, and both eyes respectively. The plots showed a narrow range of 95% limit of agreement (LOA) which were (+0.146, –0.159) in right eye, (+0.130, –0.147) in left eye, and (+0.089, –0.093) in both eyes. There were 14, 16, and 13 subjects from right eye data, left eye data, and both eyes data who had a mean difference out of the LOA (**Figures 2, 3, 4**).

We further grouped the subjects' data for the right eye, left eye, and both eyes based on their visual acuity, into the good visual acuity group and the low visual acuity group. The good visual acuity (good VA) group had a visual acuity equal to or better than 20/60. The low visual acuity (low VA) group had the visual acuity worse than 20/60, which has been classified as low vision by the WHO definition since 1992 [26]. The data obtained from both eyes reading was categorized by the visual acuity of the worst eye. The numbers of subjects in each group are shown in **Table 2**.

The contrast sensitivity scores in each group were again analyzed by the Bland–Altman plot technique. From the right eye data, the plot showed that the mean differences were –0.006, –0.005 log CS and the coefficients of repeatability were 0.155, 0.140 for the good VA group and the low VA group, respectively. The range of 95% LOA were (+0.149, –0.161) in the good VA group and (+0.136, –0.146) in the low VA group. There were 11 and 4 subjects from the good VA group and the low VA group that had a mean difference out of the limit of agreement.

From the left eye data, the plot showed that the mean differences were –0.006, –0.014 log CS and the coefficients of repeatability were 0.132, 0.157 for the good VA group and the low VA group, respectively. The range of 95% LOA were (+0.126, –0.139) in the good VA group and (+0.142, –0.171) in the low VA group. There were 11 and 4 subjects from the good VA group and the low VA group that had a mean difference out of the LOA.

Table 1. Primary diagnosis of each patient and average contrast scores categorized by the diagnosis

Diagnosis	No. of subjects	Average contrast score of RE* log CS ± SD	Average contrast score of LE* log CS ± SD	Average contrast score of BE* log CS ± SD
Vitreoretinal disease	36	1.36 ± 0.35	1.41 ± 0.35	1.54 ± 0.21
Dry eye	34	1.65 ± 0.07	1.65 ± 0.07	1.67 ± 0.02
Glaucoma	27	1.51 ± 0.13	1.50 ± 0.24	1.60 ± 0.11
Cataract and lens disorder	23	1.53 ± 0.19	1.46 ± 0.34	1.60 ± 0.10
Conjunctiva and sclera disease	21	1.58 ± 0.15	1.53 ± 0.24	1.65 ± 0.06
Corneal disease	11	1.35 ± 0.34	1.30 ± 0.31	1.62 ± 0.10
Refractive error	10	1.58 ± 0.13	1.59 ± 0.13	1.69 ± 0.06
Lid and orbit disease	9	1.62 ± 0.09	1.62 ± 0.10	1.67 ± 0.03
Strabismus	4	1.08 ± 0.79	1.32 ± 0.72	1.59 ± 0.18
Optic nerve disease	3	1.28 ± 0.31	1.44 ± 0	1.65 ± 0.01
Routine eye checkup (normal)	22	1.65 ± 0.06	1.66 ± 0.09	1.69 ± 0.05
Total	200	1.53 ± 0.24	0.10 ± 0.27	1.63 ± 0.12

*Average contrast score of first and second reading.

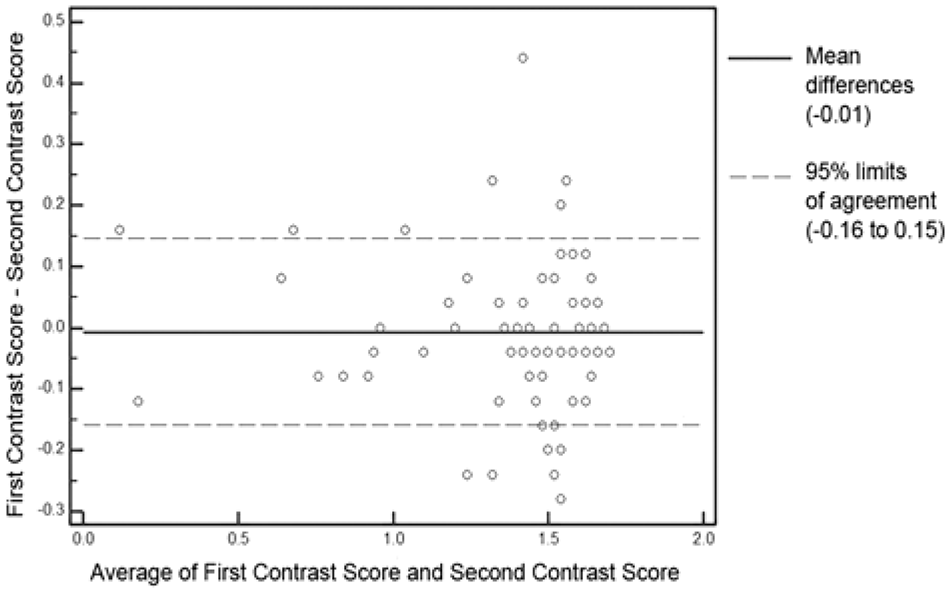

Figure 2. Bland–Altman analysis from the right eye between difference of number score at 0 and 10 minutes apart, and mean. The differences between the scores for the first administration of each test is plotted against the mean for the two tests. The dotted lines represent the 95% limits of agreement.

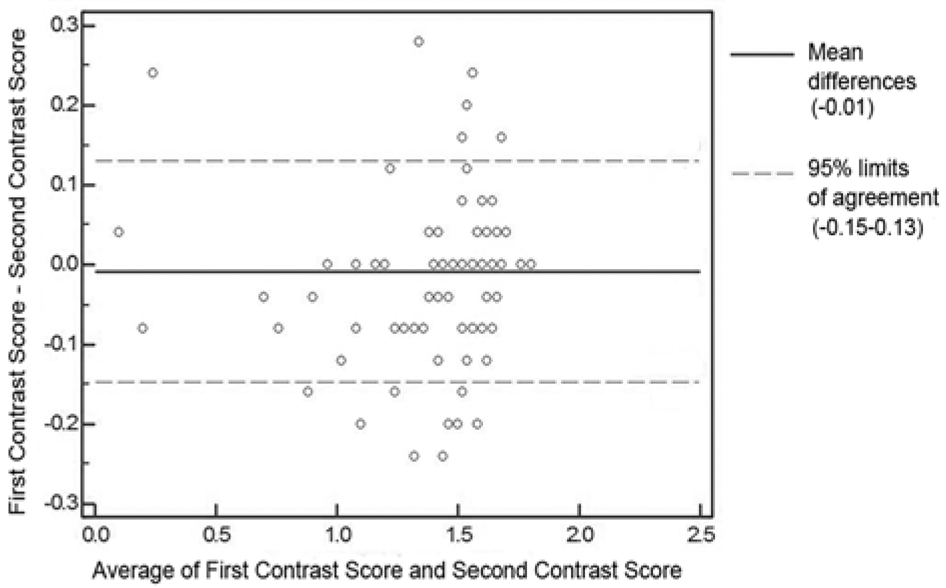

Figure 3. Bland–Altman analysis from the left eye between difference of number score at 0 and 10 minutes apart, and mean. The differences between the scores for the first administration of each test is plotted against the mean for the two tests. The dotted lines represent the 95% limits of agreement.

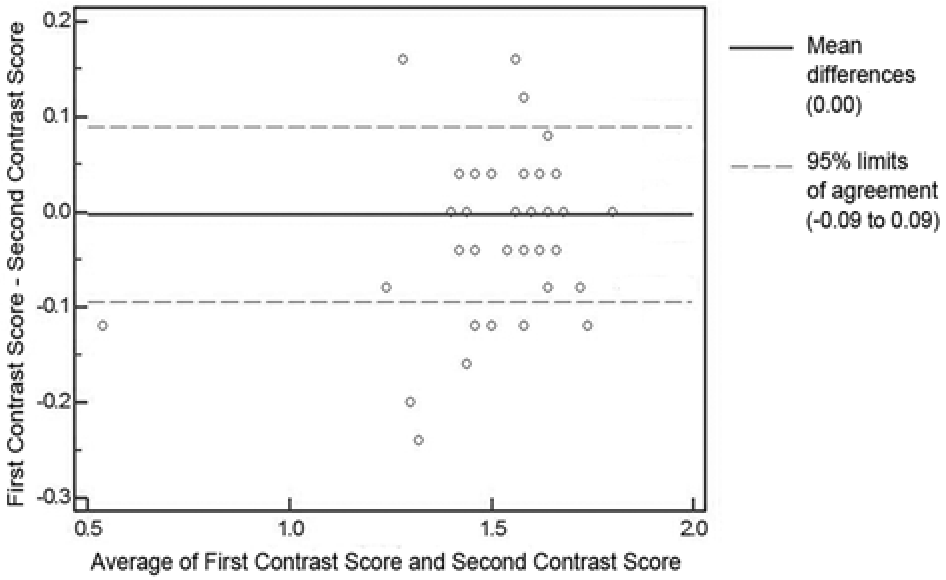

Figure 4. Bland–Altman analysis for both eyes between difference of number score at 0 and 10 minutes apart, and mean. The differences between the scores for the first administration of each test is plotted against the mean for the two tests. The dotted lines represent the 95% limits of agreement.

Table 2. The numbers of subjects in each group and average contrast score categorized by visual acuity.

Data	Visual acuity	No. of subjects	Average contrast score (log CS)† ± SD
Right eye	Equal to/Better than 20/60 (good VA group)	168	1.59 ± 0.12
	Worse than 20/60 (low VA group)	32	1.23 ± 0.42
Left eye	Equal to/Better than 20/60 (good VA group)	151	1.61 ± 0.13
	Worse than 20/60 (low VA group)	49	1.30 ± 0.38
Both eyes*	Equal to/Better than 20/60 (good VA group)	137	1.66 ± 0.07
	Worse than 20/60 (low VA group)	63	1.56 ± 0.18

*The data obtained from both-eyes was categorized by the visual acuity of the worst eye, †Average contrast score of first and second reading.

From both eyes data, the plot showed that the mean differences were –0.002, –0.013 log CS and the coefficients of repeatability were 0.072, 0.122 for the good VA group and the low VA group, respectively. The range of 95% LOA were (+0.075, –0.070) in the good VA group and (+0.109, –0.135) in the low VA group. There were 10 and 4 subjects from the good VA group and the low VA group that had a mean difference out of the limit of agreement. (**Figures 5 and 6**)

Discussion

The New Numbers Contrast Sensitivity Chart was developed and was found to have good validity and could be used interchangeably with the original Mars Chart [24]. This study demonstrated that the chart also had the good repeatability in both good VA and low VA groups.

A broad spectrum of the subjects were recruited, therefore the results of the study may be generalized widely. We included 200 subjects with various diagnoses, which mostly were vitreoretinal disease 18%, dry eye 17%, and glaucoma 14%. The patients with normal ocular finding accounted for 11%. Approximately two-thirds of the subjects had a visual acuity better than 20/60.

From the contrast data categorized by the primary diagnosis, the difference of the contrast score between each group of diagnosis was demonstrated. Based on the Mars Chart's "Approximate norms for log contrast sensitivity scores" [27], which divided the log contrast score into normal, moderate, severe, and profound CS

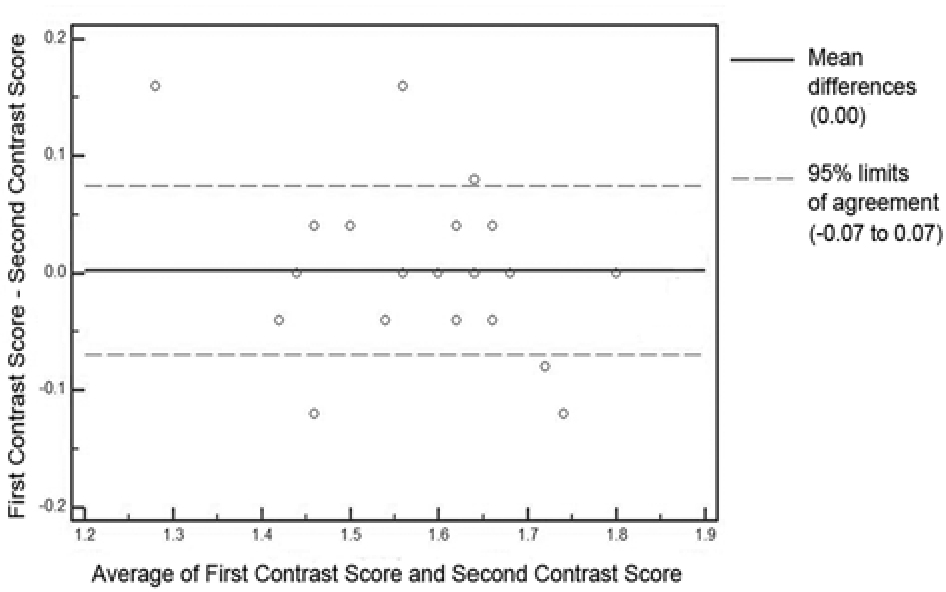

Figure 5. Bland–Altman analysis from both eyes in good VA group (VA ≥ 20/60) between the difference of number score at 0 and 10 minutes apart, and mean. The differences between the scores for the first administration of each test is plotted against the mean for the two tests. The dotted lines represent the 95% limits of agreement.

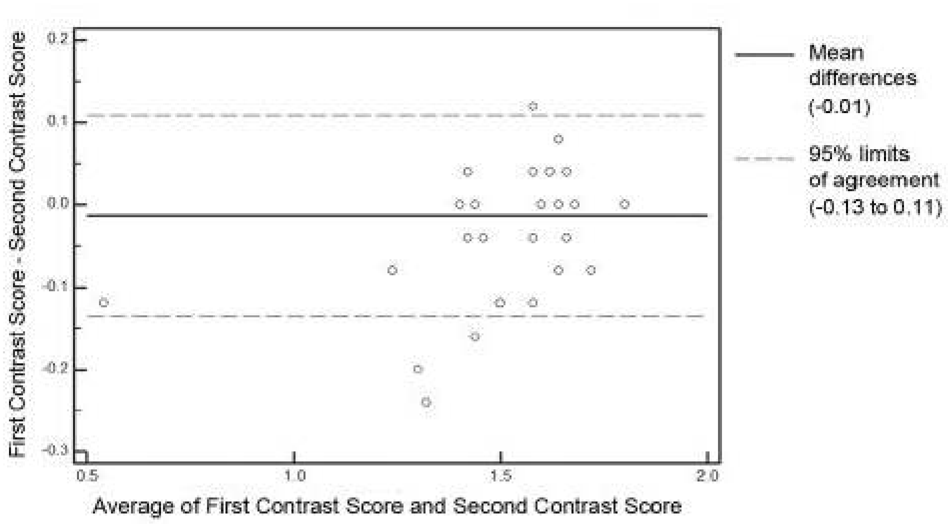

Figure 6. Bland–Altman analysis from both eyes in low VA group (VA < 20/60) between the difference of number score at 0 and 10 minutes apart, and mean. The differences between the scores for the first administration of each test is plotted against the mean for the two tests. The dotted lines represent the 95% limits of agreement.

loss, the subjects with a diagnosis of normal, refractive error, dry eye, conjunctiva and sclera disease, and eyelid and orbit disease had the contrast scores in the normal range. Glaucoma, lens disease, corneal disease, and strabismus patients were in the moderate CS loss group, whereas the patients with optic nerve disease and vitreoretinal disease had moderate to severe CS loss (or even profound CS loss in some cases).

The total subjects data showed a very small mean difference (right eye –0.006, left eye –0.008, both eyes –0.002), which indicated a minimal variation between the two readings. These small differences were still found even when the patients categorized according to the 1992 WHO low vision definition into a good VA group (VA equal to or better than 20/60) and low VA group (VA worse than 20/60) [26]. The mean differences in this study were compared to the previously reports that had tested the Mars Chart against the Pelli–Robson Chart [18-19]. As shown in **Table 3**, the mean differences in this study were not wider than the others in all subjects, good VA, and low VA data.

Table 3. Comparing the mean difference for contrast sensitivity tests with the New Numbers Contrast Sensitivity Chart, Mars Chart, and Pelli–Robson Chart

	New Numbers Chart (RE)	Mars Chart (RE)	Pelli–Robson Chart (RE)
This study			
All subjects	–0.006	–	–
Good VA (≥20/60)	–0.006	–	–
Low VA (<20/60)	–0.005	–	–
Dougherty et al.[18]			
All subjects	–	0.02	–0.01
Low vision*	–	–0.03	0.01
Haymes et al.[19]			
Normal	–	0.02	0.02
Glaucoma	–	–0.01	0.01
AMD	–	0.11	0.00

RE, right eye. *Low vision subject subjects recruited from the Vision Rehabilitation Service at The Ohio State University College of Optometry (VA = 20/16-20/250)[18]

The coefficients of repeatability calculated from the total subjects data in this study were 0.153 for the right eye, 0.138 for the left eye, and 0.092 for both eyes. Comparing with the previous studies, the coefficient of repeatability from the New Numbers Contrast Sensitivity Chart and the Mars Chart were quite similar; however, the New Numbers Chart seemed to have better repeatability than the Pelli–Robson Chart (**Table 4**).

Because some studies mentioned the lower repeatability in patients with poorer visual acuity [29], we could not conclude the similar tendency from this study. We found that the mean differences of the low VA groups were somewhat greater than differences in the good VA groups in the data from the left eye (–0.006 in the good VA group, –0.014 in the low VA group), and both eyes (–0.002 in the good VA group, –0.013 in the low VA group), but not the data from the

Table 4. Comparing the coefficient of repeatability for contrast sensitivity tests with the New Numbers Contrast Sensitivity Chart, Mars Chart, and Pelli–Robson Chart

	New Numbers Chart (RE)	Mars Chart (RE)	Pelli–Robson Chart (RE)
This study			
All subjects	0.153	–	–
Good VA (≥20/60)	0.155	–	–
Low VA (<20/60)	0.140	–	–
Thayaparan et al.[23]	–	0.121	0.182
Dougherty et al.[18]			
All subjects	–	0.20	0.20
Low vision*	–	0.20	0.28
Haymes and Chen et al.[28]			
Low vision†	–	–	0.25
Haymes and Roberts et al.[19]			
Normal	–	0.13	0.18
Glaucoma	–	0.19	0.19
AMD	–	0.24	0.33

RE, right eye. *Low vision subject subjects recruited from the Vision Rehabilitation Service at The Ohio State University College of Optometry. (VA = 20/16-20/250)[18]

†Low vision subjects recruited from the Vision Australia Foundation Kooyong Low Vision Clinic. (HCVA = 20/40-20/1000)[28]

right eye (–0.006 in the good VA group, –0.005 in the low VA group). In addition, the coefficient of repeatability showed less reproducibility in the low VA group only in the data from the left eye (0.132 in good VA group, 0.157 in low VA group), and both eyes (0.072 in the good VA group, 0.122 in the low VA group), but not from the right eye (0.155 in the good VA group, 0.140 in the low VA group).

Both the mean difference and the coefficient of repeatability represented a variation of the test between the two readings. The narrower this difference and the smaller the coefficient, the less variation; in the other words, the better the repeatability of the test. However, some variation still occurred as seen from the results that some of the differences of the means exceeded the LOA. This might the result of limitations of the subjective test itself. Nevertheless, these variations were very subtle, and might have no clinical significance.

To diminish the effect of short term memory that may interfere with the result of repeatability testing, three different chart forms were assigned to read in the different random sequences between two readings. Together with 10-minute breaks between reading sets; thus, made it more difficult for the subjects to remember the number by memorizing.

Conclusions

We concluded from this study that the New Numbers Contrast Sensitivity Chart had the good repeatability in both the normal to mild visual impairment group, and moderate or more severe visual impairment group. With proven good validity and repeatability, this easy and convenient numbers chart will be beneficial for practical use in clinical settings, especially in countries where English is not used as the primary language.

Acknowledgments

The authors thank all the staff in ophthalmology outpatient clinic, King Chulalongkorn Memorial Hospital, for kindly assisting in the data collecting process.

The “Repeatability Assessment of the New Numbers Contrast Sensitivity Chart” had been reviewed by TCTR Committee. TCTR identification number is TCTR-2012-00006.

Conflicts of interest

Bharkbhum Khambhiphant, Mathu Busayarat, and Wasee Tulvatana hold the petty patent for the New Numbers Contrast Sensitivity Chart.

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