Takagi Glare Tester CGT-1000 for Contrast Sensitivity and Glare Testing in Normal Individuals and Cataract Patients

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ABSTRACT

PURPOSE: To investigate the sensitivity and repeatability of the Takagi Contrast Glare Tester CGT-1000 in normal individuals and those with cataracts.

METHODS: A prospective observational study was performed. The Takagi Contrast Glare Tester measures contrast sensitivity (CS) at 6 target sizes and 13 contrast levels (2.00 to 0.34 logCS). Testing follows a method of descending limits paradigm with a single reversal determining threshold. The CGT-1000 was administered with and without glare in 95 eyes of 61 cataract patients and 13 controls. The percentage floor (unable to see the highest contrast) and ceiling (able to see the lowest contrast) effects and correlations between CS and cataract grades were determined. The repeatability was evaluated using Bland-Altman limits of agreement and expressed as the coefficient of repeatability (COR). Factor analysis was used to test for redundancy within the 6 spatial frequencies.

RESULTS: In normal individuals, a high rate of ceiling effect varying with target size was noted—for 6.3°, 4.0°, 2.5°, 1.6°, 1.0°, 0.7°, ceiling effects were 68%, 58%, 18%, 11%, 4%, 2%, respectively, for no glare, and 47%, 42%, 8%, 2%, 2%, 2%, respectively, with glare. In cataract patients, floor effects were noted—3%, 0%, 3%, 7%, 19%, 62%, respectively, for no glare, and 3%, 3%, 6%, 14%, 44%, 79%, respectively, with glare. Correlations with cataract grades ranged from 0.10 to 0.61, being best for nuclear cataract. Repeatabilities expressed as COR were ±0.11, ±0.14, ±0.28, ±0.38, ±0.38, ±0.47 logCS, respectively. All spatial frequencies loaded heavily on one factor, indicating no gain in information from testing multiple target sizes.

CONCLUSIONS: Sensitivity to the presence of cataract was good, but ceiling effects in normal individuals and floor effects in cataract patients limit accuracy. Repeatability was poor, but could be improved by testing less spatial frequencies more rigorously. [*J Refract Surg*. 2007;23:492-498.]

Visual acuity as the sole measure of visual outcome for cataract and refractive surgery is inadequate and visual outcome should be measured in terms of contrast vision.[1-3] Many outcome studies now include a measure of vision in the contrast domain, most commonly, contrast sensitivity (CS).[4-6] However, debate surrounds which CS tests are most appropriate for outcomes research. Unfortunately, not all commercially available CS tests have good measurement properties. The Vistech chart and Functional Acuity Contrast Test (FACT) have previously been shown to suffer from ceiling effects in normal eyes, floor effects in eyes with cataract, and poor retest repeatability.[7,8] The Pelli-Robson contrast sensitivity chart is free from ceiling and floor effects and has good retest repeatability.[9-12] However, little validation data exist for other commercially available systems. The purpose of this study was to partially address this shortfall by investigating the sensitivity and reliability of the Takagi Contrast Glare Tester CGT-1000 (Takagi Seiko Co Ltd, Nagano-Ken, Japan).

On their website (http://www.takagi-j.com/seihin_e/katarogu_e/cgt1000_e.html), the manufacturer of this device claims that the Takagi CGT-1000 is "effectively available for diagnosis before and after the cataract surgery, observing the progress after the surgery of the corneal refractive surgery, relatively examining the contrast sensitivity and glare sen-

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sitivity for loss of visual function." To address these claims, we specifically set out to evaluate design and procedural aspects of the machine, to test the sensitivity of measurement to the presence of cataract, to test the sensitivity of measurement in normal individuals, and to test the ability to detect change by establishing retest repeatability in normal individuals. In addition, we used factor analysis to investigate whether having CS data for six spatial frequencies gives six independent pieces of information, or whether effectively fewer results exist due to interdependence of these data.

PATIENTS AND METHODS

Study Population

Two populations were included in this study. A population of normal individuals was drawn from staff and students of the Department of Ophthalmology at Flinders Medical Centre. Thirteen normal individuals (mean age 36.1±11.1 years) were enrolled in the study. One eye of each of the 13 normal individuals was measured on 4 separate occasions to obtain retest data. Cataract patients were drawn from the Cataract Assessment Clinic of the Eye Clinic, Flinders Medical Centre. All patients presenting to the clinic between February 2005 and October 2005 were invited to be involved in the study. For cataract patients, exclusion criteria were any comorbid eye disease, previous eye surgery, neurological problems, any systemic disease, taking of any medication that may affect CS, inability to speak English sufficiently to be instructed to perform the tests, insufficient mental ability to perform the tests, and physical disability that would make it arduous to perform the tests (eg, wheelchair-bound). Sixty-one cataract patients (mean age 75.3±8.4 years) had 95 eyes measured. For normal individuals, the same criteria were used in addition to excluding those eyes with any eye disease. Informed consent was obtained from all participants after the nature of the study had been fully explained. The tenets of the Declaration of Helsinki were followed and the study gained approval from the Flinders Medical Centre Clinical Ethics Committee.

Takagi Contrast Glare Tester CGT-1000

The Takagi CGT-1000 is a self-contained unit for the measurement of CS with and without the presence of glare (Fig 1). Contrast sensitivity is measured at six target sizes: 6.3°, 4.0°, 2.5°, 1.6°, 1.0°, and 0.7°. There are 13 contrast levels (0.01 to 0.64 contrast or 2.00 to 0.34 $\log_{10}$CS) with an average step size of 0.15 $\log_{10}$CS. The stimulus is a dark ring on a light background and has duration of either 0.2, 0.4, or 0.6 seconds, with an interval of 1, 2, or 3 seconds between presentations

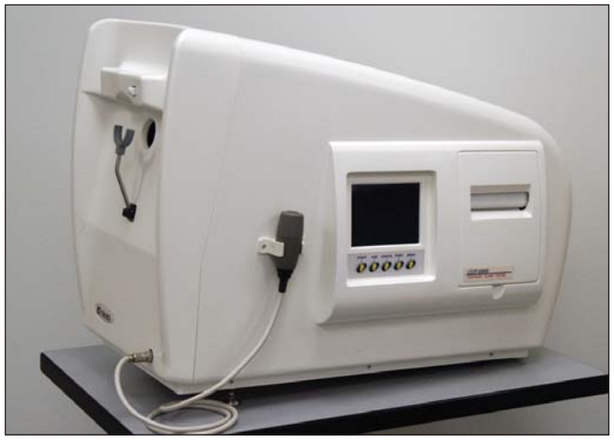

Figure 1. The Takagi Contrast Glare Tester CGT-1000.

(user-defined options). Targets are reported as seen by the pressing of a button and unseen by no response.

The testing paradigm commences with the 4.0° target, followed by the 6.3° target, and then the 2.5° target through to the 0.7° target. The initial presentation is at maximal contrast with "seen" targets being followed by the same size target presented at the next lower contrast level (method of descending limits paradigm). Threshold is determined by the first failure to see a target and denoted by the lowest contrast target seen. Therefore, threshold relies on a single reversal. There is no retesting, other than if the threshold at 6.3° is at a lower contrast level than at 4.0°, then the 4.0° threshold is retested. Two checks for false negative responses are performed during the entire testing cycle. False positive testing is performed by randomly presenting the lowest contrast target. Therefore, if the individual can see the lowest contrast level, no effective false positive testing is present.

Glare testing follows CS testing. The glare source is 12 white light emitting diodes located in a ring around the screen at 11.8° from the center for the screen. This glare angle is constant for the center of all sizes of target, although the glare angle to outer edge of each target varies by target size. There are three glare settings: low, medium, and high. To assess the intensity of the glare source at the eye and the illumination of the screen with and without the glare source on, a Gossen Starlite All-In-One photometer and luxmeter (Gossen Foto und Lichtmeβtechnik GmbH, Nurnberg, Germany) was used. The luminance at the viewing hole for contrast testing was 33 lux and for glare testing was 60 lux on low, 90 lux on medium, and 138 lux on high. The screen illumination was 11 cd/m^2 measured with the glare lights off and 21 cd/m^2 measured with the

TABLE 1

Percentage Rates of Ceiling Effects in Normal Eyes and Floor Effects in Cataract Eyes

	Target Size (°)					
	6.3	**4.0**	**2.5**	**1.6**	**1.0**	**0.7**
Ceiling effect (normal eyes)						
No glare	68	59	19	11	4	2
Glare	47	42	8	2	2	0
Floor effect (cataract eyes)						
No glare	3	0	3	7	19	62
Glare	3	3	6	14	44	79

glare lights on (high setting). This level of illumination is within the photopic range for both conditions.

Testing Methods

The Takagi CGT-1000 was administered with and without glare in cataract patients and normal controls. Both eyes were used from cataract patients. This is because some asymmetry is likely in cataract patients, so both eyes can add useful information. Although including data from both eyes in general linear models with other variables is problematic due to the correlation between fellow eyes,[13,14] this is not an issue for the main outcome measures of percentage floor and ceiling effects and repeatabilities. For the Takagi CGT-1000, the glare setting was set to "high" as this was thought most likely to yield information different to the no glare situation. Stimulus duration of 0.2 seconds and interval of 1.0 second were used. Visual acuity was measured with logMAR charts and by-letter scoring. Mean visual acuity was 0.28±0.21 (range: −0.20 to 0.88). Cataract was graded using the Lens Opacities Classifications System III (LOCS III)[15] and reported as nuclear opalescence, cortical, and posterior subcapsular cataract. Mean LOCS III scores were nuclear opalescence 3.4±0.8 (range: 2.0 to 6.0), cortical 2.6±1.1 (range: 0.1 to 5.5), and posterior 1.5±1.3 (range: 0.1 to 5.0). This represents a well-distributed and full range of scores on each grade.

Analyses

Contrast levels for the Takagi CGT-1000 were converted to logCS by taking $-\log_{10}$(contrast level) to linearize the measurement data thus facilitating statistical analyses. The percentage floor (unable to see highest contrast target) and ceiling (able to see lowest contrast target) effects for contrast measurement were determined for both normal and cataract individuals. Pearson correlations between contrast sensitivity and cataract grades were determined and stepwise multiple linear regression was used to see which target size for contrast sensitivity or glare testing best predicted cataract grade. The test-retest repeatability of the Takagi CGT-1000 was evaluated in normal controls using Bland-Altman limits of agreement method and expressed as the coefficient of repeatability. Factor analysis was performed to investigate for redundancy within the Takagi CGT-1000 test. The results from the six spatial frequencies were included in analyses for no glare and glare data, with the number of factors (with eigenvalues >1.0) and the correlations taken from the Varimax rotated solution. All statistical analyses were performed on SPSS for Windows v 12.0.1 (SPSS Inc, Chicago, Ill) except for Bland-Altman limits of agreement, which were calculated in Microsoft Excel v2003 (Microsoft Corp, Redmond, Wash).

RESULTS

In normal individuals, a high rate of ceiling effect was noted for contrast sensitivity measurement; this varied with target size (Table 1). The pattern was marginally better for glare testing (Table 1). In cataract patients, floor effects were observed on contrast sensitivity measurement for the two smaller target sizes for both glare and no glare conditions (Table 1). These floor effects indicated that these variables (1.0° and 0.7° targets) were not normally distributed and were not included in correlation and regression analyses; summary data are presented in Table 2. For normal eyes, the CS decreases as target size decreases and under glare the same pattern occurs with an average difference of one step (0.15 logCS) between glare and no glare states. For cataract eyes, the same pattern occurs, although CS is depressed at all target sizes compared to normal. The difference between the glare

TABLE 2

Summary Data of Contrast Sensitivity Scores in Normal and Cataract Eyes for the Glare and No Glare Conditions

	Target Size (°)					
	6.3	**4.0**	**2.5**	**1.6**	**1.0**	**0.7**
Normal eyes						
No glare	2.00 (1.85-2.00)	2.00 (1.70-2.00)	1.85 (1.40-2.00)	1.70 (1.22-2.00)	1.40 (0.80-2.00)	0.96 (0.49-1.85)
Glare	1.85 (1.40-2.00)	1.85 (1.40-2.00)	1.70 (1.22-2.00)	1.52 (1.10-2.00)	1.22 (0.49-2.00)	0.96 (0.21-1.70)
Cataract eyes						
No glare	1.40 (0.21-2.00)	1.40 (0.35-2.00)	1.22 (0.21-2.00)	0.96 (0.21-2.00)	0.64 (0.21-2.00)	0.21 (0.21-1.85)
Glare	1.10 (0.21-1.70)	0.96 (0.21-1.70)	0.96 (0.21-1.52)	0.64 (0.21-1.40)	0.35 (0.21-1.10)	0.21 (0.21-0.80)

Note. The minimum contrast level is 2.00 logCS for all spatial frequencies; the median normal can see the minimum contrast level at low spatial frequency.

TABLE 3

Correlation Matrix Showing the Relationship Between Cataract Grades and Contrast and Glare Measures

	Target Size (°)							
LOCS III Scale	**6.3**	**4.0**	**2.5**	**1.6**	**6.3 glare**	**4.0 glare**	**2.5 glare**	**1.6 glare**
Nuclear opalescence	−0.44	−0.54	−0.61	−0.53	−0.58	−0.51	−0.46	−0.40
Cortical	−0.10	−0.19	−0.26	−0.27	−0.21	−0.25	−0.32	−0.28
Posterior subcapsular	−0.31	−0.45	−0.48	−0.47	−0.29	−0.40	−0.42	−0.37

Note. This gives an indication of the sensitivity of the test to cataract. All spatial frequencies give similar results, with weaker correlations only occurring for the largest target size. Glare and no glare testing gave similar results.

and no glare states is larger at approximately 2 steps (0.30 logCS).

Takagi CGT-1000 contrast and glare scores showed variable sensitivity to cataract with correlations ranging from 0.10 to 0.61 (Table 3). Correlations were highest for nuclear cataract, good for posterior subcapsular, but poorer for cortical grades (Table 3). The correlation findings are backed up in stepwise multiple linear regression analyses, which show that the variance in nuclear opacity is best explained by Takagi CGT-1000 contrast sensitivity at 2.5°: nuclear opalescence = 5.29−1.14Takagi2.5° (Fig 2). At 46% of variance explained, this is a reasonable relationship. However, for cortical cataract, only 10% of the variance is explained by the best measure (cortical = 3.52−1.03Takagi2.5°glare) and for posterior subcapsular cataract, 19% of the variance is explained by the best measure (posterior = 2.88−1.61Takagi1.6°).

Retest repeatabilities for the Takagi CGT-1000 were poor (Table 4). Only the two large targets were comparable to the known repeatability of the Pelli-Robson chart (±0.17),[16] but these were probably artificially improved by the high rate of ceiling effect at these target sizes. Because the Takagi CGT-1000 chart design uses finite step sizes, which average 0.15 logCS difference, the actual 95% limits for judging change must be at the next largest step above the 95% interval. Because the step sizes average 0.15 logCS, the actual limits for change are shown in multiples of 0.15 logCS in Table 4.

Factor analysis was performed on the no glare and glare data separately. In each case, the six spatial frequencies were revealed to measure one concept: contrast sensitivity. Only the lowest and highest spatial frequencies have different information (Table 5). This pattern of results was the same if floor and ceiling effect cases were removed (data not shown).

DISCUSSION

Two aspects of the machine's design and operation raised concerns. First, the doubling of screen illumina-

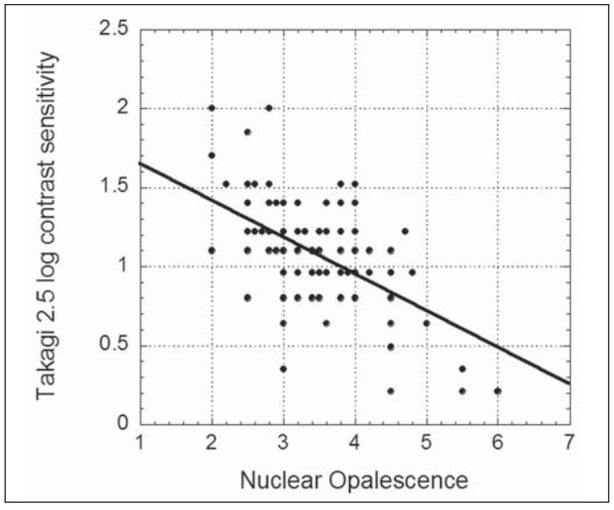

Figure 2. Scatterplot illustrating the relationship between nuclear opalescence and contrast sensitivity measured for a 2.5° target with the Takagi CGT-1000.

TABLE 4

Retest Repeatability or the Takagi CGT-1000 Expressed as Coefficient of Repeatability (COR) in logCS*

	Target Size (°)					
	6.3	**4.0**	**2.5**	**1.6**	**1.0**	**0.7**
COR	±0.11	±0.14	±0.28	±0.38	±0.38	±0.47
Limits for change	±0.15	±0.15	±0.30	±0.45	±0.45	±0.60

**Rounded up to multiples of 0.15 logCS (actual average step size) to give actual increments for change.*

TABLE 5

Correlation Matrix of the Varimax Orthogonal Transformation Factor Analysis Including Takagi Contrast Sensitivity Results From the No Glare and Glare States

	Target Size (°)						% Variance Explained
	6.3	**4.0**	**2.5**	**1.6**	**1.0**	**0.7**	
No glare							
Factor 1	0.78	0.91	0.96	0.95	0.91	0.76	74
Glare							
Factor 1	0.87	0.94	0.96	0.94	0.90	0.73	75

tion between glare off and on conditions was caused by reflection of the glare lights off the predominantly white inside surface of the machine housing. This causes a veiling glare across the screen, which would decrease the contrast of the target relative to the background so that the reported contrast levels must be considered inaccurate. This may account for the drop in median CS in normal individuals, being more than would be expected for the relatively weak level of glare source[17-19] and only marginally less drop than seen in cataract patients (Table 2). The fact that the angle from the glare source to the outer edge of the target varies by target size is also a suboptimal design element. Second, the use of a single reversal to determine threshold is the least reliable procedure possible, with reliability increasing proportional to the number of reversals used.[20] This most likely explains the poor retest reliability at all target sizes, except those with high ceiling effects. A ceiling effect improves repeatability by half, as the response can only vary in one direction. This is reflected in the better repeatability for low spatial frequency targets (Table 4), which were the ones with the highest rate of ceiling effect (Table 1); this should be considered a biased finding of good repeatability. Otherwise, overall retest reliability is poorer than published data on the Pelli-Robson chart.[16] Poor repeatability impairs the ability of a test to distinguish between two groups, for example pre- and postoperative patients, or patients with different types of intraocular lenses or refractive surgery. This argues against use of the test in outcomes studies, although this point can be countered partially by using large populations.[7] Certainly, retest reliability should be taken into account when determining whether a study is adequately powered.

The high incidence of ceiling effects in normal individuals prevents accurate measurement of contrast sensitivity with and without glare by underestimating CS of individuals who see better. Again, this impairs the

ability of the test to distinguish between groups. This limits the value of the Takagi CGT-1000 for use in eyes with good visual performance such as before and after refractive surgery, and possibly after cataract surgery.

In cataract patients, the Takagi CGT-1000 was sensitive to the presence of cataract, especially nuclear cataract. This is true for glare and no glare testing and provides further evidence of the sensitivity of contrast and glare testing in cataract patients. The correlations between LOCS III grades and contrast sensitivity scores are particularly impressive given the heterogeneous nature of the population, many of whom had mixed cataracts. The correlations would be expected to be higher if patients with only one type of cataract were included in the analyses.

A purported advantage of sine-wave grating CS tests is that they can measure CS at different spatial frequencies. However, this assumes that CS from neighboring spatial frequencies provides useful additional information, which may not be the case.[21,22] Principal components factor analysis with Varimax orthogonal transformation illustrated that only one concept was measured. Therefore, the number of target sizes tested could be reduced without losing information. Certainly, the measures at 4.0°, 2.5°, 1.6°, and 1.0° were equivalent. Arguably, the 6.3° and 0.7° targets provide some additional information although the evidence for this is weak. It is possible that the ceiling and floor effects hampered the performance of these two target sizes in particular because they had the highest rates. These results support previous findings that CS charts with multiple target sizes repeatedly measure the same concept.[7] If the number of target sizes measured was reduced, the testing time saved could be spent better thresholding at the remaining target sizes, which would improve the reliability of the instrument (as reliability increases proportional to the number of reversals used for determining threshold).[20] Alternatively, the four measures (4.0°, 2.5°, 1.6°, and 1.0°) could be considered together to improve reliability and repeatability, averaging these four scores for these data would give a coefficient of repeatability of ±0.24 and an actual limit for change of ±0.30. Better still, these measures could simply be replaced by the Pelli-Robson contrast sensitivity chart, which is sensitive and reliable (coefficient of repeatability of ±0.17) and free from ceiling and floor effects.[9-12] It should be noted that the task for the Takagi CGT-1000 (detection) is different from the Pelli-Robson contrast sensitivity chart (letter recognition), so these measure contrast sensitivity in different ways, nevertheless, they are both measures of contrast sensitivity.

The Takagi CGT-1000 is less than ideal for cataract or refractive surgery outcomes research due to ceiling and floor effects, poor repeatability, and defective calibration of contrast under glare conditions. It could be improved through redesign with a larger range of contrast, fewer target sizes, more rigorous thresholding procedures, and better control over screen illumination.

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