Article • Normal Values for Mesopic and Photopic Contrast Sensitivity Function with and without Glare using a Sinusoidal Bull's-Eye Target

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ABSTRACT

Purpose: To determine the normal mesopic and photopic contrast sensitivity function in young, healthy individuals with a sinusoidal bull's-eye with and without glare.

Methods: Contrast sensitivity (CS) was measured on 105 healthy volunteers with 20/20 BCVA. A sinusoidal bull's-eye target was used for all tests. After dark adaptation, four different spatial frequencies under mesopic and five different spatial frequencies under photopic conditions were presented in a two-choice, forced-choice paradigm. Each of the nine conditions was tested under three different levels of glare and without glare. The targets were varied in each trial from high contrast to threshold using a staircase method.

Results: The without-glare condition demonstrated the expected CS curve; each of the different glare conditions dropped CS statistically significantly. Low- and medium-glare levels dropped CS by similar amounts, showing a 0.1 log (NOTE: all log units in this paper are log10) decrease under both conditions. The high-glare condition dropped the CS by greater than an additional 0.1 log compared with the low and medium conditions. Standard deviations were small in each condition tested, which leads to the conclusion that in this group of 105 healthy subjects, the differences seen from condition to condition are demonstrable.

Conclusion: Glare testing, combined with the sinusoidal bull's-eye target, may become a valuable clinical and research tool to aid in the diagnosis of visual conditions affecting the CSF, as well as for measuring the effects of optical and medical interventions on visual performance.

Keywords: bull's-eye, circular Bessel-function, circular sine wave, contrast sensitivity, glare, J0 targets, mesopic, photopic, rectilinear sine-wave gratings, sinusoidal bull's eye

Introduction

Contrast sensitivity (CS) has been a staple of optometric testing for 40+ years. Glare testing has been mostly research-based. CS testing is used to measure the performance of optical corrections, from contact lenses to ophthalmic lenses to implanted intraocular lenses (IOL), particularly multifocal IOLs. Clinical CS testing is often quite time-consuming, and glare testing has not established itself yet in the clinic. The new bull's-eye concentric rings, sine-wave grating targets, and automated testing protocols combine CS and glare testing in an easy-to-use testing system for both research and clinical use. This study was undertaken to determine values with healthy subjects for all conditions, using the testing system and methods for possible adoption for both research and clinical use.

Many disciplines look to measure human visual performance precisely in meaningful and clinically relevant ways. Visual acuity has been the mainstay of clinical human visual performance measurements.[1] Though there have been many improvements over the years, searches for more insightful probes of visual performance continue.

CS testing has evolved to meet some of the perceived shortcomings of visual acuity testing. The primary targets for contrast testing have been letters (Pelli-Robson and Bailey-Lovie charts), linear sine wave gratings (Vistech, FACT, and many others), and radial or circular types of targets (J0 or Bessel-function target and sinusoidal–radial sine wave). "Shortcomings of the letter charts include letters having different degrees of contrast thresholds and patients' varying levels of language ability."[2]

The value of CS testing is its objectivity and the ability to detect small but significant changes in a short period of time. When there is loss of contrast sensitivity, many activities of daily living are negatively impacted, including reading, using tools, finding objects, mobility, and driving, to name a few.[3] Contrast sensitivity also plays a role in many aspects of vision, specifically motion detection, visual field, pattern recognition, and dark adaptation, besides its obvious effect on visual acuity.[2] On a clinical basis, CS is important because it predicts functional vision better than other visual diagnostics.[4]

CS testing has also been done in both mesopic and photopic conditions, with and without glare, in order to assess how the person performs in a variety of conditions that have been related to different aspects of daily living, but never with all combinations being assessed at the same time. Although contrast sensitivity tests under high-illumination conditions show the best reproducibility, measurements of the full spectrum of the contrast sensitivity function under various light conditions might give information about the patients' visual abilities in daily life situations.[5] This is echoed in the recent recommendations by the Food and Drug Administration (FDA), where they state that vision testing should be performed in dark or dim ambient lighting conditions.[6]

Many of the early charts of CS, such as the Vistech chart, had sine wave gratings of different spatial frequencies and contrast levels.[7] However, astigmatism and higher-order aberrations (coma, trefoil, and tetrafoil) cause lines to appear darker (higher contrast) in one angular orientation than in the orthogonal orientation, where they appear much lighter (lower contrast).[8] The first targets developed were circular or bull's-eye sine-wave gratings. These were to overcome a potential problem of orientation bias from astigmatism with linear vertical sine-wave gratings.[7] In order to address these issues, Holladay developed a rotationally symmetric target (sinusoidal bull's-eye target). The sinusoidal bull's-eye has a spatial frequency that is the same as linear gratings, but the target is rotationally symmetric. Patients with astigmatism and other non-rotationally symmetric aberrations will have no advantage or disadvantage based on the orientation of the appearance of the target. For two patients with the same amount (magnitude) of astigmatism but at different orientations, the target will appear the same, only rotated. The result is no difference in the apparent contrast of the target.[8]

A recent development in CS testing has been the addition of glare testing in both the mesopic and photopic conditions. Disability glare is the reduction in visual acuity or CS resulting from a nearby glare source and is the result of forward intraocular light scatter.[9] In looking at the reliability, validity, and discriminative ability of glare testing, unless good chart design and psychophysics are used, the geometry and the intensity of the glare source are of little importance.[9]

Figure 1. *The system used, with one of the sinusoidal bull's-eye CS targets shown. The four outboard lights provide the glare source; luminance was calibrated with a lux meter at the plane of the face of the subjects.*

Figure 2. *The tablet that is placed before the subject on which they make their responses. Subjects are instructed to press the bull's-eye on the screen or the solid circle on the right if they do not detect a bull's-eye.*

Computerization of the presentation of stimuli has been taking hold both clinically and in research settings in many fields, with the vision care field being no exception. In testing CS, computerization has allowed for finer and more accurate control of many facets of the testing protocols, as well as making the targets highly consistent over time. Using digitized charts aids with the sensitivity and randomization of the grating presentations,[6] and computerized testing can exploit adaptive testing strategies that greatly improve testing efficiency without experimenter intervention.[4]

The testing protocol that was used in this study follows the recommendations cited in both the FDA consensus statement and in the work on the quick CSF method. As a critical outcome measure for clinical trials, contrast sensitivity must be measured with and without glare at four spatial frequencies: 3, 6, 12, and 18 cycles per degree for photopic (85 cd/m^2) vision and 1.5, 3, 6, and 12 cycles per degree for mesopic (3 cd/m^2) vision.[4,6]

Methods

One hundred and five subjects were recruited from the Southern College of Optometry student population with the following characteristics: 23 male, 82 female; mean age 25.25 years (range 22.7 to 40.3 years); and best-corrected visual acuity 20/20 or better in each eye. Visual acuities were tested using the automated ETDRS testing protocol (Clinical Trial Suite (CTS) M&S Technologies Systems, Niles, IL). All testing was done with room lights off, and background luminance was verified to be 0 cd/m^2. Prior to each testing session, the system was calibrated with screen luminance set to 85 cd/m^2.

The CTS system is shown in Figure 1, with the bull's-eye target as seen by subjects with glare lights off. The Asus Zenbook UX303UB laptop shown has a pixel resolution of 3200 x 1800, with a mean luminance of 170 cd/m^2, allowing a target with a constant space-averaged stimulus luminance of 85 cd/m^2 at all contrast levels. The gray-level resolution is 24 bit, with the capability of displaying 0.4% or -2.4 log CS. Four glare lights were chosen surrounding the screen to give an equal distribution of light over the surface of the eyes. A diffuser covers each light to mitigate optical aberrations in the light path. The diffuser breaks up any aberrations introduced by the focusing lens in front of the LED.

Subjects were seated 8 feet from the screen, and a tablet (Figure 2) paired to the computer via Bluetooth was placed before them. The system follows a protocol as described here:

Testing begins at 0.6 log above previously calculated expected levels of CS in the general population. If the patient answers correctly, the test reduces the contrast in 0.3 log unit steps with every "Yes" or "Correct" until an incorrect is recorded. The protocol then goes up 0.2 log units and will reduce in 0.1 log unit steps until the next incorrect answer. Next, the best (lowest) two contrast levels are averaged for the final result, recorded numerically. Final results are plotted on printouts after all testing is complete. Five to 8 gray disks (not sinusoidal bull's-eyes) are randomly displayed throughout the test to evaluate for possible false positives as an indicator of patient reliability.

Subjects were oriented as to what would transpire during the testing. At the beginning of the first visit, the study was briefly explained to the subject. Because some of the tests being used were likely to be unfamiliar and to use forced-choice procedures, the subject is informed that he/she will be required to make decisions about stimuli that might be very difficult to see and that for all observers, there would probably be some stimuli that might not be discernable. It was stressed that subjects should not become anxious because of the uncertainty that they might experience. They were encouraged to try as hard as possible when the stimuli were difficult to see.[10] Subjects often felt like they were guessing as the targets approached threshold. After preliminary testing during the pilot phase of the study, we found that using the criteria of seeing at least two parts of circles going at least one-third of the way around helped to reduce subjects' anxiety of guessing.

CS was measured under mesopic (4 spatial frequencies) and photopic (5 spatial frequencies) conditions, with three different levels of glare and without glare, for a total of 36 different testing conditions. All 36 thresholds were identified in about 25 minutes of testing for each subject. A digital lux meter was positioned directly where the subject's face would be, and the glare lights were calibrated at 8 feet prior to beginning the study to be: low = 120 lux, medium = 150 lux, and high = 450 lux. To conduct the mesopic tests, subjects were dark adapted for 5 minutes prior to beginning testing. A large filter was placed over the entire CTS, including the 4 glare lights, reducing all light levels to 3.53% of the photopic levels (mean target luminance was 3 cd/m^2)(Appendix A).

Statistical Analysis

Data were examined using mixed-effects linear regression, fitting separate models for experiments at photopic and mesopic luminance. The dependent variable for each model was the log contrast sensitivity value (reciprocal of contrast threshold value). Fixed parameters included a spatial frequency factor (in cycles per degree, for photopic: 1.5, 3, 6, 12, and 18; for mesopic: 1.5, 3, 6, and 12), a glare level factor (baseline, low, medium, and high), and their interaction to characterize the effect of glare level at each spatial frequency. Each model included a subject-specific random intercept to account for repeated measurement on the same individuals. Model-predicted means, standard errors, and 95% confidence intervals were computed. Statistical significance was tested for contrasts at each spatial frequency, comparing baseline against each level of glare (i.e., baseline vs. low; baseline vs. medium; baseline vs. high). Finally, contrasts comparing low to medium glare were examined at each spatial frequency.

Results

CSF plots for all conditions under mesopic and photopic thresholds were plotted and compared. Results showed that all levels of glare reduced CS. The low and medium levels of glare reduced CS to about the same level; both were significantly different than no glare but were not different from each other. High

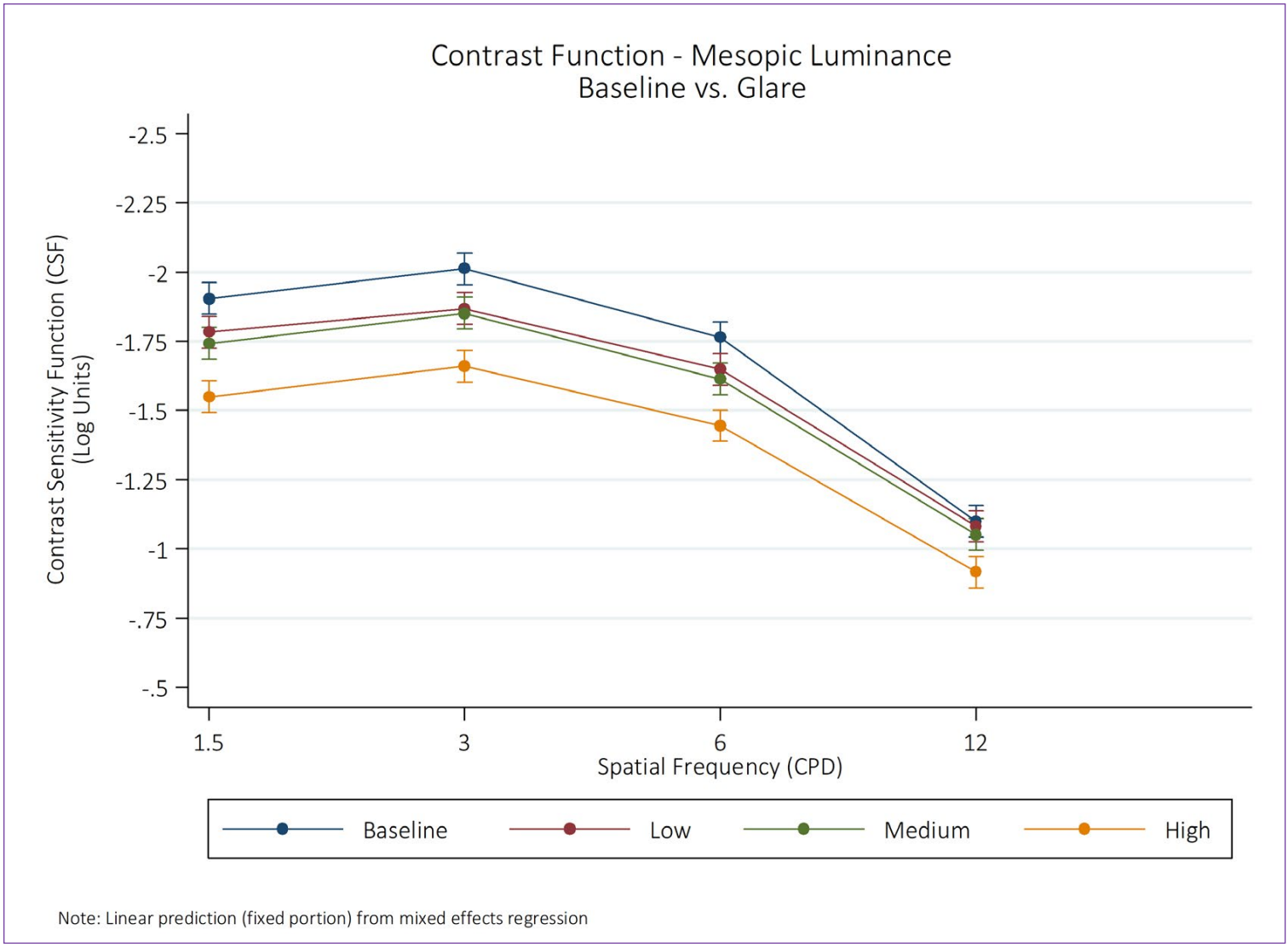

Figure 3. *Results of the mesopic testing conditions*

glare reduced CS statistically significantly from no glare, as well as from both the low- and medium-glare conditions.

Figure 3 shows the results of testing under mesopic conditions at each of the four spatial frequencies tested. The highest line is the no-glare baseline condition, showing maximum CS without glare. The bars above and below each data point show the 95% confidence interval (CI). The lowest line is the high-glare condition, and the two almost-superimposed lines in the middle represent the low- and medium-glare conditions.

Figure 4 shows the results for testing under photopic conditions at each of the five spatial frequencies tested. The configuration of the lines, with the no-glare baseline condition on top and the high-glare on the bottom, with the other conditions overlapping in the middle, repeats itself here, as in Figure 3.

Table 1 shows the data for all subjects combined for both the mesopic and photopic conditions. For each comparison, the value of the contrast, the 95% confidence limits, and the p-value are shown.

Contrasts comparing glare levels at each spatial frequency showed significant differences between glare levels at most frequency comparisons, with some exceptions (Table 1). In the mesopic data, there were no significant differences between low- and no-glare (baseline) at 12 cpd (p=0.57), between medium- and no-glare (baseline) at 12 cpd (p=0.13), or between low- and medium-glare at any frequency level (all p values>0.05). All remaining contrasts showed significant

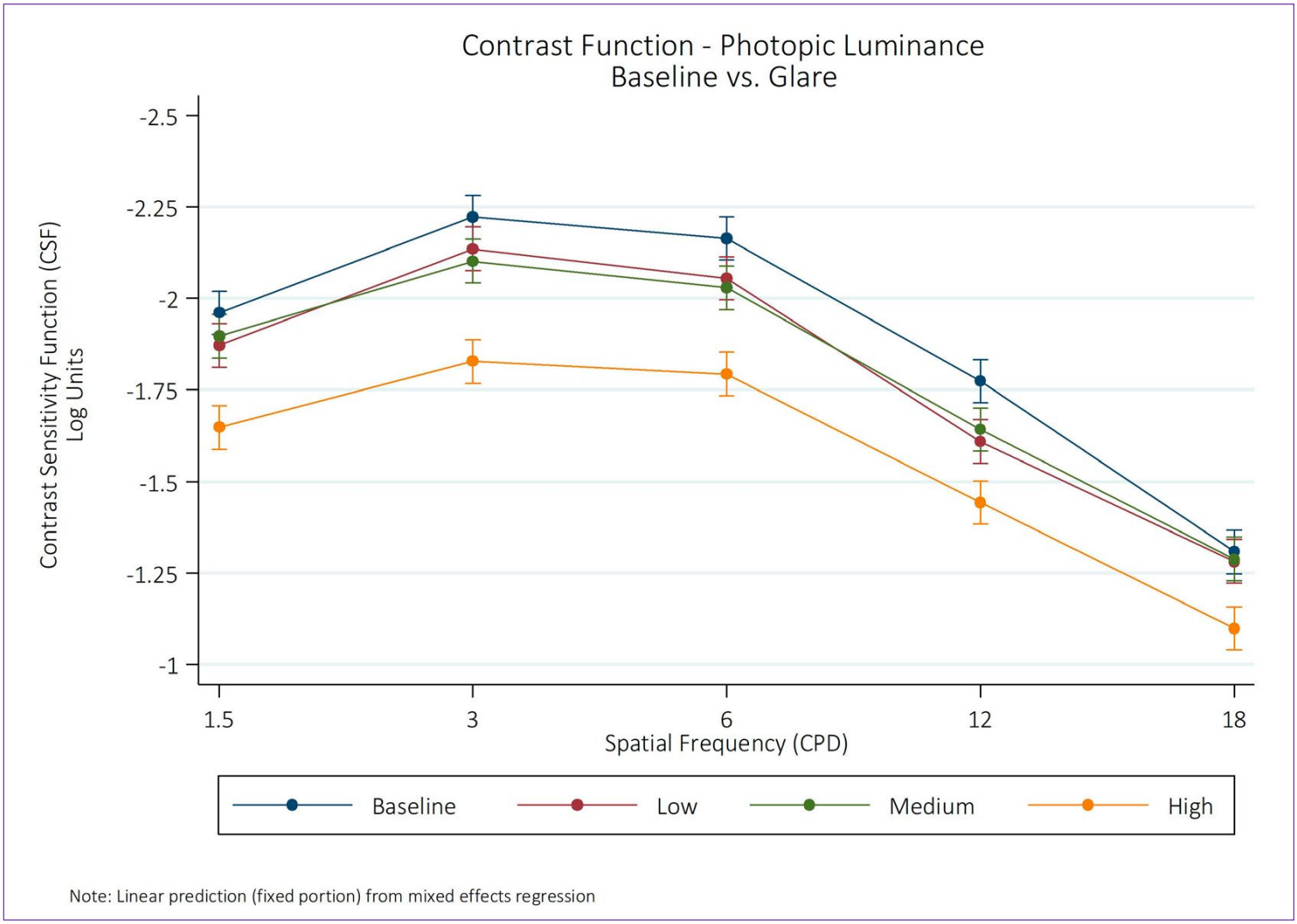

Figure 4. *Results for all five spatial frequencies under photopic conditions*

differences between glare levels. The photopic data yielded a similar pattern of significant differences, again with few exceptions. Low-glare did not differ from no-glare (baseline) at 18 cpd (p=0.47), while medium-glare did not differ from no-glare (baseline) at 1.5 cpd (p= 0.07) or 18 cpd (p=0.58). As in the mesopic data, there were no significant differences between low- and medium-glare levels at any frequency (all p values >0.05), suggesting that low- and medium-glare levels yield very similar results on contrast sensitivity. All remaining glare comparisons were significantly different at each frequency examined.

Discussion

Light Levels

In a pilot version of this study, each of the glare light levels were lower, with the prior value for high being set at the current medium value and the others scaled down from there. With these reduced glare levels, at the low level of glare, a number of subjects actually showed a slight improvement in CS. This could have been due to a small amount of pupillary constriction, possibly improving CS by eliminating some of the peripheral rays through the optics of the visual system. This led to a revision of the glare light levels for each of the three levels tested in this study; glare levels were increased at each of the three levels over those used in the pilot study.

At the levels chosen for the full study, better stratification of the data between each of the three levels of glare was expected. The low-glare level was indeed enough to cause a decrease in CS at all spatial frequencies in both the mesopic and photopic conditions.

Table 1. Contrasts Comparing Glare Levels at Each Frequency Measurement

Mesopic	Contrast	95 % CI		p-value
(Low vs Baseline) @ 1.5	0.12	0.06	0.18	0.0001
(Low vs Baseline) @ 3	0.14	0.08	0.20	0.0000
(Low vs Baseline) @ 6	0.11	0.05	0.17	0.0002
(Low vs Baseline) @ 12	0.02	-0.04	0.08	0.5736
(Medium vs Baseline) @ 1.5	0.16	0.10	0.22	0.0000
(Medium vs Baseline) @ 3	0.16	0.10	0.22	0.0000
(Medium vs Baseline) @ 6	0.15	0.09	0.21	0.0000
(Medium vs Baseline) @ 12	0.05	-0.01	0.11	0.1227
(High vs Baseline) @ 1.5	0.35	0.29	0.41	0.0000
(High vs Baseline) @ 3	0.35	0.29	0.41	0.0000
(High vs Baseline) @ 6	0.32	0.26	0.38	0.0000
(High vs Baseline) @ 12	0.18	0.12	0.24	0.0000
(Medium vs Low) @ 1.5	0.04	-0.02	0.10	0.1857
(Medium vs Low) @ 3	0.02	-0.04	0.08	0.5974
(Medium vs Low) @ 6	0.03	-0.03	0.09	0.2578
(Medium vs Low) @ 12	0.03	-0.03	0.09	0.3267
(High vs Medium) @ 1.5	0.19	0.13	0.25	0.0000
(High vs Medium) @ 3	0.19	0.13	0.25	0.0000
(High vs Medium) @ 6	0.17	0.11	0.23	0.0000
(High vs Medium) @ 12	0.14	0.08	0.20	0.0000
Photopic	**Contrast**	**95 % CI**		**p-value**
(Low vs Baseline) @ 1.5	0.09	0.02	0.16	0.0124
(Low vs Baseline) @ 3	0.09	0.02	0.16	0.0146
(Low vs Baseline) @ 6	0.11	0.04	0.18	0.0021
(Low vs Baseline) @ 12	0.17	0.10	0.23	0.0000
(Low vs Baseline) @ 18	0.03	-0.04	0.10	0.4670
(Medium vs Baseline) @ 1.5	0.06	-0.01	0.13	0.0739
(Medium vs Baseline) @ 3	0.12	0.05	0.19	0.0007
(Medium vs Baseline) @ 6	0.13	0.07	0.20	0.0001
(Medium vs Baseline) @ 12	0.13	0.06	0.20	0.0002
(Medium vs Baseline) @ 18	0.02	-0.05	0.09	0.5830
(High vs Baseline) @ 1.5	0.31	0.24	0.38	0.0000
(High vs Baseline) @ 3	0.39	0.33	0.46	0.0000
(High vs Baseline) @ 6	0.37	0.30	0.44	0.0000
(High vs Baseline) @ 12	0.33	0.26	0.40	0.0000
(High vs Baseline) @ 18	0.21	0.14	0.28	0.0000
(Medium vs Low) @ 1.5	-0.03	-0.09	0.04	0.4754
(Medium vs Low) @ 3	0.03	-0.04	0.10	0.3367
(Medium vs Low) @ 6	0.03	-0.04	0.10	0.4619
(Medium vs Low) @ 12	-0.03	-0.10	0.04	0.3521
(Medium vs Low) @ 18	-0.01	-0.08	0.06	0.8584
(High vs Medium) @ 1.5	0.25	0.18	0.32	0.0000
(High vs Medium) @ 3	0.27	0.20	0.34	0.0000
(High vs Medium) @ 6	0.24	0.17	0.30	0.0000
(High vs Medium) @ 12	0.20	0.13	0.27	0.0000
(High vs Medium) @ 18	0.19	0.12	0.26	0.0000

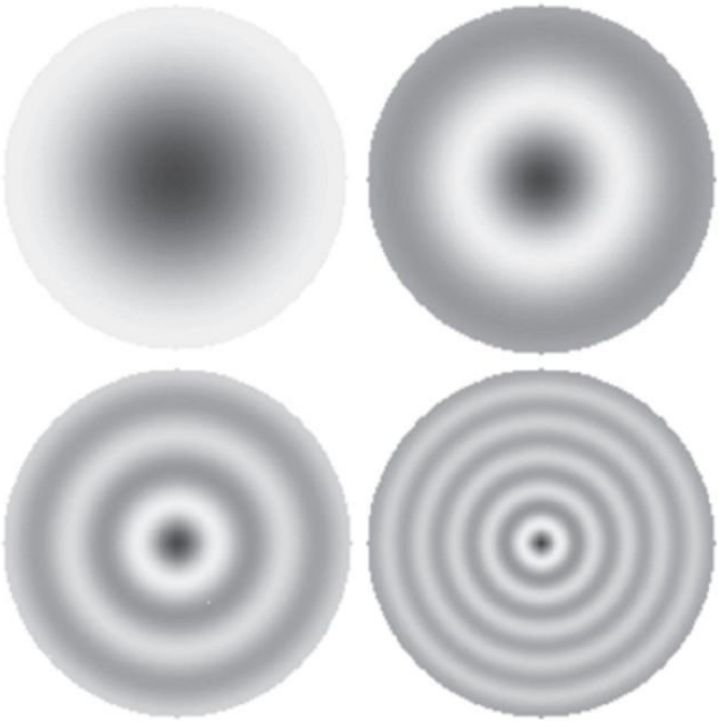

Figure 5. *Circular J0 or Bessel-function targets*

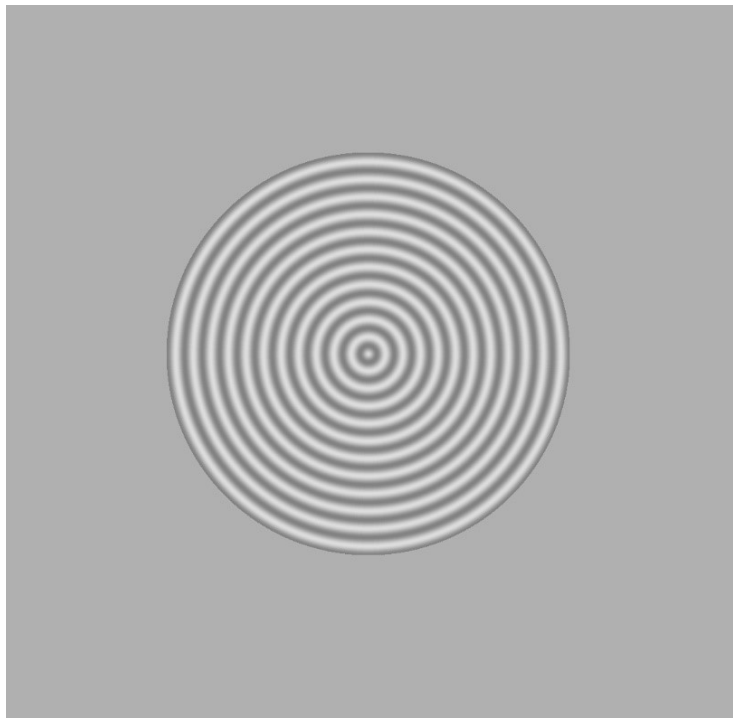

Figure 6. *Sinusoidal bull's-eye target on the screen as it appears to the test subject. The target shown here is the 12 cycles per degree target.*

The high-glare level was enough to create a significant difference from both the low- and medium-glare levels, again reducing CS from baseline and from either the low- or medium-glare levels. Low- and medium-glare levels were found both functionally and clinically interchangeable.

New Tests and Significance

CS testing has yet to become routine in the eye and vision care field. When clinicians look to include new testing protocols, they should make themselves aware of the various factors that can affect the measurements. Without estimates for the significance of changes of the kind reported here, they have no basis on which to decide whether or not a patient's test score has truly changed.[10] The primary aim of this study was to provide both the researcher and the clinician with normal values and values of significant change. With the current level of glare set to our medium level, the clinician and researcher know to expect a 0.1 log unit decrease in CS at each spatial frequency in both the mesopic and photopic conditions. Should a patient or subject show larger changes than this in response to glare, this would be a clear indication that CS is negatively affected and needs further investigation. In order to establish the significant level of change, it was important to have many steps of CS levels in the testing paradigm, with fine gradations between steps. The present study results thus show very small standard deviations. Narrow standard deviations facilitate the definition of finer significant changes in the levels of CS recorded. A study outcome of refined measurement of CS provides both the researcher and the clinician with support for the expected 0.1 log change in CS as normal with medium glare.

Not all Bull's-Eye Targets are the Same

The term "bull's-eye" has been used to describe two different types of circular targets used in CS testing. The first are radial frequency stimuli, defined in polar coordinates, where the spatial frequency varies along the radius and is modulated by spherical Bessel functions (J0). They are referred to in the literature as J0 targets (cylindrical Bessel functions), bull's-eye, or circular gratings. Contrary to sine-wave

gratings, radial frequency stimuli are circularly symmetric and have a fixed center.[11] Examples of the J0 targets can be seen in Figure 5.

The second type of target that is known as a sinusoidal bull's-eye target is the Holladay target (Figure 6). A characteristic of the Holladay version of the bull's-eye CS target is that it is more similar to linear sine-wave gratings in that the amount of contrast is the same across the entire target. The J0 type target uses highest contrast in the center and drops off towards the periphery.

Kelly and Magnuski conducted substantial work determining contrast thresholds primarily using the J0 targets. Contrast thresholds for circular J0 targets and rectilinear sine-wave gratings behave quite differently as functions of spatial frequency.[12] The J0 pattern has its highest contrast in the center, and the contrast gets less and less as you move to the outside part. This is totally unlike the Holladay bull's-eye in that anywhere you look, the contrast ratio is the same. Each pattern is detected at threshold, not in terms of its spatial contrast, but rather in terms of the component of maximum amplitude in its two-dimensional Fourier transform.[12]

The original reasons given for using the J0 pattern were simply that as visual stimuli, circularly symmetric patterns seem more natural, and the J0 target in particular provides a center of fixation, while rectilinear gratings do not. Results showed that there was a significant difference between CS as measured by J0 targets and by rectilinear sine-wave gratings. Following comparison with a Holladay-type target, Kelly and Magnuski found that the Holladay type functioned more similarly to linear sine wave gratings than did the J0 pattern.

An earlier barrier to using circular targets is that they are more difficult to generate accurately than rectilinear ones. Eventually, a suitable simulator was constructed. This was back in the 1970s when monitors that could render these types of targets were severely limited as compared to what can be produced with today's monitors and software.

Conclusions

Results presented here demonstrate that the use of the sinusoidal bull's-eye target for measuring CSF does follow the expected CS curves. Additionally, we identified the specific level of glare that causes CS to drop by 0.1 log unit for each spatial frequency under both mesopic and photopic conditions. Using the different levels of glare helped to define the parameters through which glare affects CS in normal healthy subjects.

These curves provide the basis for considering adding the use of the bull's-eye target with glare to determine how well different contact lenses, ophthalmic lenses, and IOLs perform under glare conditions. Additionally, the CS findings defined may lead to development of clinical testing protocols for aiding in the diagnosis of conditions such as cataract, macular degeneration, and epi-retinal membranes. Future testing with these specific populations and comparisons of performance on this test with linear CS targets should be done.

The M&S CTS system provides significant improvement over existing CS testing methods that project a fixed 8-target display with minimal luminance control. The M&S CTS system provides precision luminance with no floor or ceiling to the display targets, allowing for much greater sensitivity and a broader range of CS testing results.

Acknowledgements

Thank you to Jan Gryczynski, PhD, founding partner COG Analytics, Potomac, MD, for his assistance with the statistics.

References

1. Snellen H. Probebuchstaben zur Bestimmung der Sehschärfe. Utrecht : Van de Weijer, 1862.

2. Richman J, Spaeth GL, Wirostko B. Contrast sensitivity basics and a critique of currently available tests. J Cataract Refract Surg 2013;39:1100-6. http://bit.ly/2XE6avM

3. Hong YT, Kim SW, Kim EK, Kim T. Contrast sensitivity measurement with 2 contrast sensitivity tests in normal eyes and eyes with cataract. J Cararact Refract Surg 2010;36:547-52. http://bit.ly/2XJPR08

4. Lesmes LA, Lu ZL, Baek J, Albright TD. Bayesian adaptive estimation of the contrast sensitivity function: The quick CSF method. J Vis 2010;10(3):17.1-21. http://bit.ly/2XFGeQg

5. Hohberger B, Laemmer R, Adler W, Juenemann AGM, Horn FK. Measuring contrast sensitivity in normal subjects with OPTEC® 6500: Influence of age and glare. Graefes Arch Clin Exp Ophthalmol 2007;245:1805-14. http://bit.ly/2XAEc3Z

6. MacRae S, Holladay JT, Glasser A, Calogero D, Hilmantel G, et al. Consensus statement on contrast sensitivity. Food and Drug Administration. s.l. : Ophthalmology 2017;124:139-41.

7. Ginsburg AP. Contrast sensitivity: Determining the visual quality and function of cataract, intraocular lenses and refractive surgery. Curr Opin Ophthalmol 2006;7:19-26. http://bit.ly/2XNMEwZ

8. Holladay JT. Astigmatic axis independent sparial frequency and contrast sensitivity target and method. US 7,354,155 B2 USA, April 8, 2008. http://bit.ly/2XJQ2Zm

9. Elliott DB, Bullimore MA. Assessing the reliability, discriminative ability, and validity of disability glare tests. Invest Ophthalmol Vis Sci 1993;34:108-19. http://bit.ly/2XG8P87

10. Reeves BC, Wood JM, Hill AR. Reliability of high- and low-contrast letter charts. Ophthal Physiol Opt 13;1993:17-26. http://bit.ly/2XHEzts

11. Santos NA, Oliveira AB, Nogueira R, Simas M. Mesopic radial frequency contrast sensitivity function for young and older adults. Brazilian J Med Biol Res 2006;39:791-4. http://bit.ly/2XHELca

12. Kelly DH, Magnuski HS. Pattern detection and the two-dimensional Fourier transform: Circular targets. Vis Res 1975; 15:911-5. http://bit.ly/2XNmDxO

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Harris PA, German Z, Roberts L. Normal values for mesopic and photopic contrast sensitivity function with and without glare using a sinusoidal bull's-eye target. Optom Vis Perf 2019;7(3):138-48.

Appendix A

Test Protocol Description

1. A training phase is conducted to familiarize the patient with the targets. In the case of the bull's-eye gratings, a grating and a blank disk are alternately displayed so that the patient learns to differentiate these targets.
2. The high-frequency cut-off is determined. This will provide an equivalent acuity at the end of the exam. Starting at 18 cycles per degree at 99% contrast, the patient is presented with increasingly higher spatial frequency targets (e.g., 24, 30, 38 cpd) until they record an incorrect answer. The last correct spatial frequency is then verified.
3. For 18, 12, 6, 3, and 1.5 cycles per degree, contrast testing begins at 0.3 log units above the normative results. If this is not visible, it moves to 0.3 log unit steps of contrast. With the first correct answer, the test moves down 0.3 log units until an incorrect response is recorded. The test then moves up 0.2 log units, works back down in 0.1 log unit steps if correct, and goes up another 0.2 if incorrect. It continues reducing contrast in 0.1 log steps until a miss or a repeat of the best answer occurs. The system averages the two best at the next incorrect or reports the final answer if correct twice on the same log unit of contrast.
4. Throughout the exam, randomly interspersed gray disks are shown in order to prevent guessing (false positives). At the conclusion of the exam, the report will include a reliability index that shows the number of gray disks presented and the number that the patient identified. It also provides a percentage. A low score may indicate the need to educate the patient and to have them retake the exam.
5. The exam beeps, adding a beep at each spatial frequency so that the clinician can hear that the patient is still progressing. At completion, the Windows 'Ta Da' is played to let the clinician know that the test is completed.
6. The report will provide the raw data as well as a percentage of normal based on normative values. It also provides an elapsed time and reliability index. For each cycle/degree, the percent of contrast and its corresponding log units are printed.
7. Finally, the report presents the high-frequency cut-off and its equivalent acuity level.