The effects of optical defocus on visual acuity and contrast sensitivity

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Abstract
Background: Recent studies using the Small Letter Contrast Test (SLCT) suggest that small letter contrast sensitivity (CS) is more sensitive than visual acuity (VA) to optical defocus. With the advent of the new versions of the SLCT, we determined the effect of optical defocus on VA and CS and established normative values for these new charts.

Methods: High and low contrast VA and CS (20/40 and 20/50 letter size) were assessed in 25 subjects under decreasing amounts of spherical blur beginning at + 1.50 D to plano DS.

Results: At all levels of defocus 2:0.5 D, 20150 CS proved more sensitive than high and low contrast VA and 20/40 CS. At defocus of 0.38 D, 20/50 CS was more sensitive than high contrast VA and 20/40 CS, but not significantly different from low contrast VA and 20/40 SLCT.

Conclusions: CS with 20/50 letter size is a sensitive approach to quantify visual resolution in the contrast domain. Sensitivity to blur equals or exceeds that obtained with standard tests.

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THE EFFECTS OF OPTICAL DEFOCUS ON VISUAL ACUITY AND CONTRAST SENSITIVITY

By

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A thesis submitted to the faculty of the
College of Optometry
Pacific University
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In 2001, Lori Ann Kim graduated from Pacific University with a B.S. in Biology and B.A. in Japanese language. Following graduation from Pacific University College of Optometry, Lori looks forward to establishing a partnership practice in her home state of Hawai‘i.

Jessica Matsumoto is a fourth-year student at Pacific University College of Optometry. A native of Honolulu, Hawai‘i, she attended the University of Hawai‘i at Manoa and received a Bachelor of Arts in Biology in 2000. After completing her graduate education, Jessica hopes to establish her career in primary care optometry.
ABSTRACT

Background: Recent studies using the Small Letter Contrast Test (SLCT) suggest that small letter contrast sensitivity (CS) is more sensitive than visual acuity (VA) to optical defocus. With the advent of the new versions of the SLCT, we determined the effect of optical defocus on VA and CS and established normative values for these new charts. Methods: High and low contrast VA and CS (20/40 and 20/50 letter size) were assessed in 25 subjects under decreasing amounts of spherical blur beginning at +1.50 D to plano DS. Results: At all levels of defocus ≥0.5 D, 20/50 CS proved more sensitive than high and low contrast VA and 20/40 CS. At defocus of 0.38 D, 20/50 CS was more sensitive than high contrast VA and 20/40 CS, but not significantly different from low contrast VA and 20/40 SLCT. Conclusions: CS with 20/50 letter size is a sensitive approach to quantify visual resolution in the contrast domain. Sensitivity to blur equals or exceeds that obtained with standard tests.

Key words: visual acuity, contrast sensitivity, vision testing, optical defocus, letter chart
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INTRODUCTION

With the advent of supplemental techniques for refractive surgery, new methods of measuring best-corrected visual acuity (VA) and contrast sensitivity (CS) are desired to produce optimal visual potential for the patient. The same methods can be applied to visual outcomes, post-cataract extraction, and implantation of an intraocular lens. In a study conducted by Nio et al., VA, CS, and depth of focus were assessed post-cataract surgery. The CS functions of pseudophakic and age-matched phakic subjects were compared. Wavefront aberrometry is gaining much popularity among ophthalmologists and optometrists who are involved with laser-assisted in situ keratomileusis (LASIK) and photorefractive keratectomy (PRK). Wavefront technology aims to correct higher-order aberrations, such as coma, secondary astigmatism and spherical aberrations. A more accurate assessment of VA and CS will supplement such techniques, as to provide the patient with optimal post-surgical vision.

Rabin and Wicks (1996) developed the Small Letter Contrast Test (SLCT) and compared the SLCT results to those of standard VA (Bailey-Lovie) and CS (Pelli-Robson) tests. Their study presents evidence on the reliability, sensitivity, and usefulness of the SLCT and suggests that small letter CS is more sensitive than VA to optical defocus. The SLCT can be used to identify individuals who require optimal VA, such as refractive surgery patients or pseudophakic patients. Earlier forms of the SLCT used letters with a 20/25 demand. In the new version of the SLCT provided by Precision Vision, Incorporated, larger letters (20/40-20/50 demand) are used in order to accommodate a larger testing population (those who have potential acuities better than 20/40). Our study provides normative values of the new improved version of the SLCT and evaluates the effects of optical defocus on various levels of VA and small letter CS in visually normal subjects.
METHODS

Testing subjects were selected from the Pacific University College of Optometry student body. The required age range was between 20-40 years, and best-corrected VA was at least 20/20. Candidates with hyperopia greater than 4.00 DS, myopia greater than 7.00 DS and cylinder greater than 3.00 DC were excluded from the subject pool.

Each subject was refracted to best-corrected VA, using a standard phoropter at a distance of 4 meters. Performance on the improved SLCT was compared to that obtained with standard high contrast VA charts (black letters, white background) as well as low contrast VA charts, calibrated for the same distance of 4 m (13.1 ft), both provided by Precision Vision, Incorporated. Subjects were tested with darkened room illumination, monocularly (right eye) using the following test charts: (1) high-contrast (~96%) chart, presented before back-lit illumination, (2) low-contrast (~5%) chart presented before back-lit illumination, (3) prototype SLCT with a letter size demand of 20/50, and (4) prototype SLCT with a letter size demand of 20/40. (The purpose of back-lit illumination was to standardize illumination levels for testing conditions.) For each of the above charts, the subject was then asked to identify letters at the top of the chart and proceed downward until he/she could no longer recognize letters. The subject was encouraged to make a best guess, as the letters became more challenging to identify. The procedure was repeated with each of the four chart targets, each time the blur was reduced by 0.25 DS. The last cycle of testing ended with the subject identifying letters with a plano lens before his/her right eye. It is at this condition (plano DS) that normative data for the prototype 20/40 and 20/50 VA charts were determined. Each subject was recalled approximately 7-21 days post-initial assessment. At this subsequent assessment, baseline VA and CS with their best correction could be re-measured. The purpose of this visit was to establish repeatability in the
subject pool. In accord with the Declaration of Helsinki, informed consent was obtained from all subjects after protocol review by our institutional review board.

<table>
<thead>
<tr>
<th>High contrast (96%) VA</th>
<th>Low contrast (5%) VA</th>
<th>20/50 CS test (prototype)</th>
<th>20/40 CS test (prototype)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DHN</td>
<td>DHN</td>
<td>1 VKCNH1</td>
<td>1 SVDN1</td>
</tr>
<tr>
<td>VZSR</td>
<td>VZSR</td>
<td>2 RDNSK2</td>
<td>2 OKSVZ2</td>
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<td>OSDVZ</td>
<td>OSDVZ</td>
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<td>3 EROSDY3</td>
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<td>NOZCD</td>
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<td>4 DNY7</td>
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<td>RDNCSK</td>
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<tr>
<td>NOZCD</td>
<td>NOZCD</td>
<td>7 DORN7</td>
<td>7 DORN7</td>
</tr>
</tbody>
</table>
RESULTS

Figure 2 shows mean (±2SE) VA (in log MAR) and CS (in log CS) plotted against optical defocus. Values are shown for high and low contrast VA, and for both 20/50 and 20/40 prototype CS tests. In each case log MAR and log CS decrease linearly with increasing defocus ($r^2>0.96$ for each function; best fit linear regression lines shown; values for >1D defocus omitted from regression for low contrast VA because most subjects were unable to visualize the chart at this level of blur). However, the slope of the decrease is greater in the contrast domain. While high and low contrast VA decrease 0.12 log MAR and 0.15 log MAR per 0.25 D, respectively; both 20/40 and 20/50 CS decrease at a rate of 0.28 log units per 0.25 D. From a clinical perspective, it should be noted that both VA and CS decrease approximately one row of letters per 0.25 D of defocus. This is because VA changes 0.1 log units per row (on most log MAR acuity charts), while CS changes 0.3 log units per row on the prototype CS charts.
Notwithstanding the greater effect of defocus on CS as compared to VA, the two measurements assess separate dimensions of spatial vision. VA is a size threshold while CS is a contrast threshold, making direct comparisons between the two measures problematic. Moreover, the greater effect of defocus on CS does not ensure greater test sensitivity, since variability of this measurement is also greater. The essential factor in determining sensitivity is the change in performance relative to variability. In order to standardize measurements with respect to variability, all values were converted to Z-scores; which is the difference between each score and the mean value under optimal conditions, divided by the standard deviation (SD) of the measurement. This transformation expresses all scores as the number of SDs from the mean, allowing for direct comparison between the results of separate tests. Figure 3 shows VA and CS plotted against optical defocus, with all values expressed as SDs from mean performance. For both VA and CS, the number of SDs below optimal performance increases linearly with optical defocus ($r^2 > 0.96$). The slope of each function, which is the SDs per diopter of defocus, is indicative of test sensitivity. Notwithstanding this correction for variability, 20/50 CS shows superior sensitivity (2.6 SDs per 0.25 D), as compared to high (1.8 SDs per 0.25 D) and low contrast VA (1.7 SDs per 0.25 D); and 20/40 CS (2 SDs per 0.25 D). At all levels of defocus $\geq 0.5$ D, Z-scores for 20/50 CS were significantly greater than those for high and low contrast VA and 20/40 CS (paired 2-tailed t-tests; $p<0.01$). At defocus of 0.38 D, Z-scores for 20/50 CS exceeded those for high contrast VA ($p < 0.001$); but were not significantly different from Z-scores for low contrast VA ($p = 0.68$) and 20/40 CS ($p = 0.16$).

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*The SDs utilized in this computation are based on a total of 45 visually normal subjects (pooled from this study with 20 subjects enrolled in a concurrent study).*
**DISCUSSION**

Visual acuity makes up only a small portion, the higher resolution domain, of our vision. VA allows one to resolve fine detail but does not adequately measure a person’s ability to resolve objects in a reduced contrast. As shown in previous studies, CS can be more sensitive than standard VA tests to defocus. Our findings confirm previous results and also show that 20/50 CS provides the greater sensitivity to defocus than high and low contrast VA and 20/40 CS.

Elliott and Situ (1998) investigated the effectiveness of VA versus letter contrast sensitivity in early cataract. They showed that small letter CS is a more sensitive assessment of early cataract than VA and large CS. The Small Letter Contrast Test (SLCT) shows greater
sensitivity than VA to decreases in vision secondary also to keratoconus, corneal infiltrates, edema, and amblyopia. Like the original SLCT, the 20/50 CS test may play an important adjunctive role to VA in measuring and monitoring optical defocus in the afore mentioned patients and people suffering from central vision loss (e.g., corneal and macular edema, diabetic retinopathy, optic neuritis). In patients who have undergone laser refractive surgery, defocus and optical aberrations primarily affect higher spatial frequencies; therefore, CS tests such as the 20/50 test may play a significant role in evaluating visual discrimination in these patients.

The 20/50 CS test may also be useful to observe visual changes over time in patients progressing through vision therapy and to evaluate individuals for careers requiring exceptional visual qualifications such as aviation. Grimson et al. (2002) found that the SLCT shows potential as an adjunctive test in establishing a standard visual screening for military pilots.

Unlike the original SLCT, the improved version uses larger letters (20/50 as compared to smaller 20/25 letters) and thus is more applicable to a larger number of patients (those with vision of 20/40 or better). Although VA and CS test different aspects of spatial vision, CS may play an important adjunct role to VA. Future testing with the 20/50 CS may provide useful information during clinical practice and patient management.
REFERENCES


