5-2005

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Abstract

Purpose: To evaluate a new approach for assessing small target contrast sensitivity and to demonstrate the effects of luminance and binocular viewing on visual acuity (VA) and contrast sensitivity (CS).

Methods: High and low contrast VA charts and two CS charts were used to measure VA and small-letter CS (20140 and 20150 Snellen equivalent) as a luminance and viewing status (monocular vs. binocular). A rear-illumination box provided chart luminance. All four charts were assessed with and without a mesopic filter in place under monocular and binocular conditions respectively.

Results: Reducing luminance produced a greater reduction in CS than VA. Also, reducing vision from binocular to monocular conditions produced a greater reduction in CS than VA.

Conclusions: The CS charts detect resolution loss that the VA charts miss. These CS charts under the same conditions may be useful to better quantify visual performance before and after refractive surgery. In addition, these CS charts may be useful for monitoring vision loss in corneal and macular edema, optic neuritis, and early cataracts.

Degree Type

Thesis

Degree Name

Master of Science in Vision Science

Committee Chair

Jeff Rabin

Subject Categories

Optometry

THE EFFECTS OF LUMINANCE AND BINOCULAR VIEWING ON VISUAL ACUITY AND CONTRAST SENSITIVITY

By

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A thesis submitted **to** the **faculty of** the
College ***of*** Optometry
Pacific **University**
Forest Grove, Oregon
for the degree of
Doctor of Optometry
May *2005*

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The Effects of Luminance and Binocular Viewing on Visual Acuity and Contrast Sensitivity

ABSTRACT

Purpose: To evaluate a new approach for assessing small target contrast sensitivity and to demonstrate the effects of luminance and binocular viewing on visual acuity (VA) and contrast sensitivity (CS).

Methods: High and low contrast VA charts and two CS charts were used to measure VA and small-letter CS (20140 and 20/50 Snellen equivalent) as a luminance and viewing status (monocular vs. binocular). A rear-illumination box provided chart luminance. All four charts were assessed with and without a mesopic filter in place under monocular and binocular conditions respectively.

Results: Reducing luminance produced a greater reduction in CS than VA. Also, reducing vision from binocular to monocular conditions produced a greater reduction in CS than VA.

Conclusions: The CS charts detect resolution loss that the VA charts miss. These CS charts under the same conditions may be useful to better quantify visual performance before and after refractive surgery. In addition, these CS charts may be useful for monitoring vision loss in corneal and macular edema, optic neuritis, and early cataracts.

ACKNOWLEDGEMENTS:

We would like to thank Dr. Jeff Rabin for his commitment to excellence as an educator, as well as a researcher. It war; our privilege working with such an intelligent and capable professor of optometry. We would also like to thank Precision Vision for making the CS charts, rear-illumination chart boxcs, and mesopic filters we used in our study. In addition, we appreciate all of the Pacific University students from the Class of *2005* and 2006 who participated in this study.

INTRODUCTION

Optimal visual acuity (VA) is a fundamental goal of vision care in clinical, as well as research settings. Refraction of the eye, detection, diagnosis and treatment of eye disease, and refractive surgery, share the common goal of achieving best VA. The effectiveness of VA is based on its sensitivity to defocus (i.e., blur). Blur causes a reduction in VA, and this reduction is proportional to the amount of blur. But blurring the retinal image also reduces the contrast of fine detail. Because, for small targets, sensitivity to contrast (i.e., contrast sensitivity; CS) changes much more rapidly than sensitivity to size (i.e., VA), a change in VA is associated with a much greater change in CS.

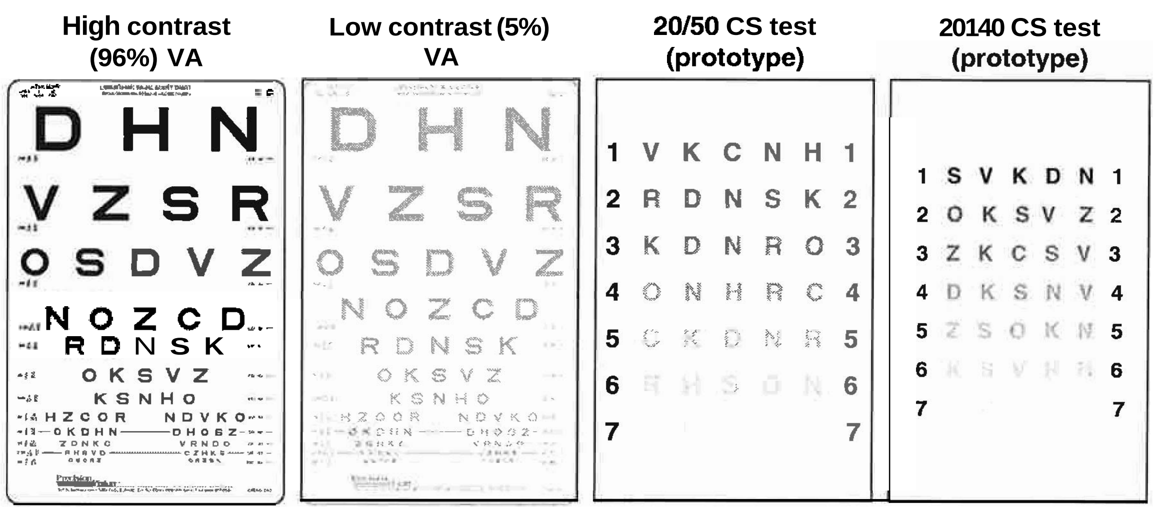
The greater change in CS compared to VA suggests that small letter CS may provide a more sensitive index of blur. In previous studies, it was found that small letter CS is more sensitive than VA to small changes in the luminance of the stimulus, vision with two eyes vs. one, and for identifying visual differences among pilot trainees.'"' To make this approach available for general use, a hard-copy letter chart version was developed (the Small Letter Contrast Test, or SLCT).[7] After limited distribution, this test was unavailable commercially, making it problematic to achieve widespread use. There continues, nevertheless, to be a considerable demand for this approach, exemplified in a recent textbook on refractive surgery, which describes the SLCT as meeting "many of these test requirements" for the ideal visual performance test.[8] Moreover, recent advances in laser eye surgery and optical wavefront sensing offer the prospect of achieving levels of vision well above normal levels (i.e., "super-vision"), by correction of higher order optical imperfections. While potential improvements in VA will be modest (2X) and are limited by the packing density of the retinal receptors, the potential for improved small target CS is much greater, on the order of 7-10X. Yet no clinical tests exist to quantify this degree of super-vision.

The purpose of this study is to evaluate an improved version of small letter contrast sensitivity. In conjunction with Precision Vision, Incorporated (www.precision-vision.com), a prototype small letter contrast test has been developed. Unlike the original SLCT, the improved version uses larger letters (20140 and 20150 as compared to smaller 20125 letters), in order to be applicable to a larger number of patients (those with vision of 20140 or better). In addition, the test includes an extended range of contrast to better quantify vision, particularly in cases of "super-normal" vision. Unlike the original SLCT, the new version includes a fluorescent light box for rear-illumination, which will better standardize illumination levels. Also included are neutral density mesopic filters, which fit into the light box to display the chart under reduced luminance levels. Normative values and repeatability will be determined for the new test, and effects of illumination and binocularity will be assessed in visually normal subjects. Results will be compared to comparable measures of high and low contrast VA.

METHODS

This methods section will cover the project overview, the experiment process, and the analysis. This research was conducted by the authors under the direct supervision of Dr. Jeff Rabin, the principal investigator. Figure 1 shows the test prototype provided by Precision Vision, Inc., includes two letter charts: one comprised of 20140 letters, and the other consisting of 20150 letters. The charts are printed on translucent material affixed to plexi-glass, making it possible to provide standardized rear-illumination. Each chart has 7 rows of letters with five letters per row. Contrast decreases, by row, in approximately 0.3 logarithmic steps, from 100% (row 1) down to 1.25% (row 7). The charts are calibrated for a viewing distance of 4 m (13.1 feet). Chart luminance, provided by the rear-illumination box, is 100 cd/m^2. In addition to these prototypical charts, Precision Vision has provided standard high contrast VA charts (black letters, white background) as well as low contrast VA charts, calibrated for the same test conditions.

Figure 1:



In addition, this experiment examined the effects of luminance and binocularity on VA and CS performance. Following refraction to best VA (at least 20/20), the illumination box was positioned 4 m in front of the subject under dim room conditions. The mesopic filter (attenuated light by a factor of approximately 50X) was placed in the illumination box, and the subject was asked to adapt to the uniform dim field for 5 minutes. The high contrast VA chart was placed in the illumination box, the left eye was occluded, and the subject was asked to read down the left column of letters as far as possible. The examiner then directed the patient to the row located three rows above the smallest legible letter, and asked the patient to read the letters aloud from left to right, and proceeding downward, row by row. The subject was asked to provide their best guess of any letters they are unsure of, and to continue reading aloud until they could longer see the letters. An examiner kept track of letters read correctly, by use of a score sheet, and drawing a diagonal line through letters read incorrectly. The high contrast VA chart then was removed and replaced with the low contrast (5%) chart, and the same procedure was used for testing low contrast acuity. Small letter CS was then tested using the 20150 prototype test, followed by CS using the 20140 chart. The occluder then was removed from the left eye, and the same procedure was repeated with both eyes exposed (binocular viewing). After all four charts were assessed with the mesopic filter in place under monocular and binocular conditions, the filter was removed and the measures repeated under normal luminance conditions. The luminance conditions were presented from lowest (mesopic filter) to highest (normal luminance) to minimize learning effects, since letter recognition improves with increasing luminance. Each subject was asked to return 7-21 days after the initial visit so that VA and CS with best correction could be quickly re-measured to assess the repeatability of each test

All subjects were recruited from the College of Optometry student body. Recruitment was limited to subjects with ages ranging from 20-40 years old, with corrected visual acuity of at least 20120 in the tested eye(s), and no history of eye disease. Subjects with myopia >7D, astigmatism >3D, and/or hyperopia >4D were asked not to participate, since these refractive errors often are associated with sub-normal acuity.

RESULTS

Figure 2 shows mean (±2SE; n=25) VA (in log MAR) and CS (in log CS) plotted against letter chart luminance (100 and 1 cd/m^2). Monocular and binocular mean values are shown for high and low contrast VA, and for both 20150 and 20140 CS tests. As in many previous studies of VA, a decrease in luminance (from 100 to 1 cd/m^2), contrast (from 96% to 5%), and the transition from binocular to monocular viewing resulted in a decrease in performance. Three-way repeated measures ANOVA revealed significant effects of luminance (F=975), contrast (F=2382), and viewing condition (bin. vs. mon., F=249) on VA ($p<0.0001$). However, the effect of luminance and binocular viewing had larger effects on CS as compared to VA. This is evident in the slope of VA and CS versus luminance; a steeper slope is evident for CS. Moreover, the separation between monocular and binocular functions is more pronounced for CS as compared to VA. Two-way repeated measures ANOVA showed significant effects of luminance, viewing condition, and letter size on CS ($p<0.001$).

Figure 2:

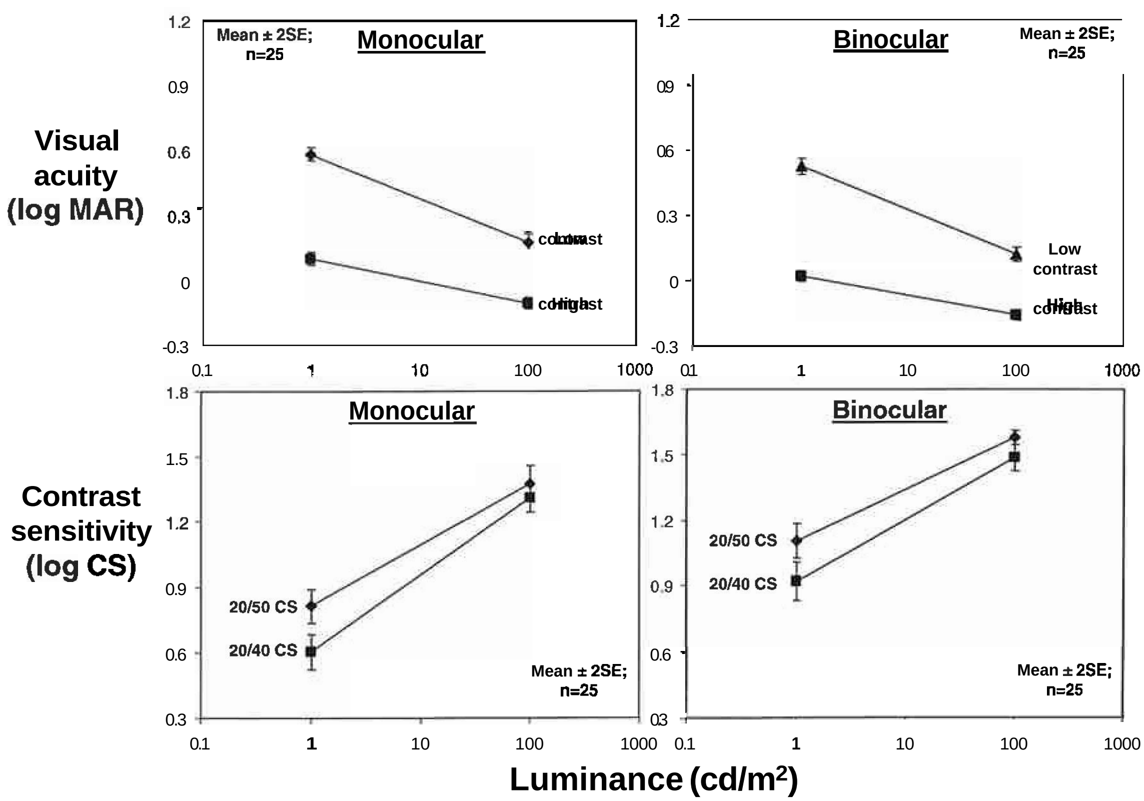
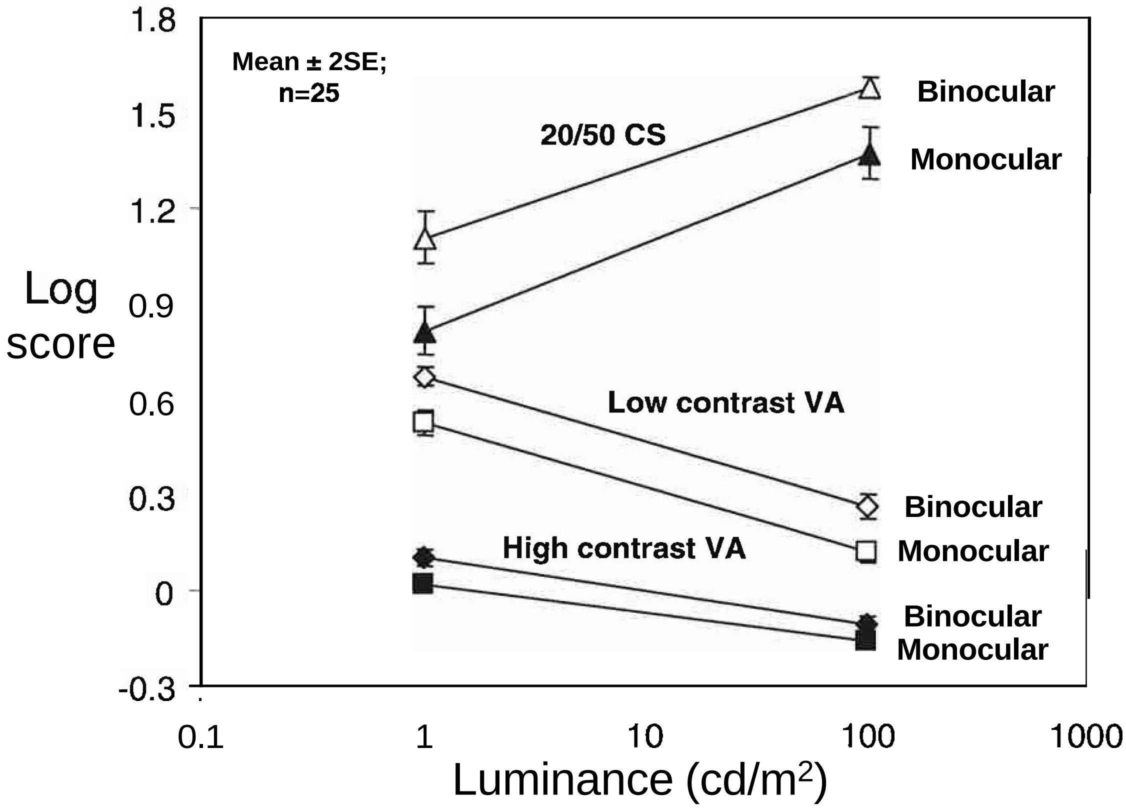


Figure 3 shows mean (±2SE; n=25) log score plotted against luminance to better illustrate differences between VA and 20150 CS, as well as the magnitude of the effects for monocular versus binocular viewing. Whereas high contrast VA shows minimal difference between monocular and binocular viewing, and a comparatively small effect of luminance, both 20150 CS and low contrast VA show greater effects of viewing condition and luminance, with 20150 CS showing the largest effect (i.e., steepest slope and greatest separation between functions).

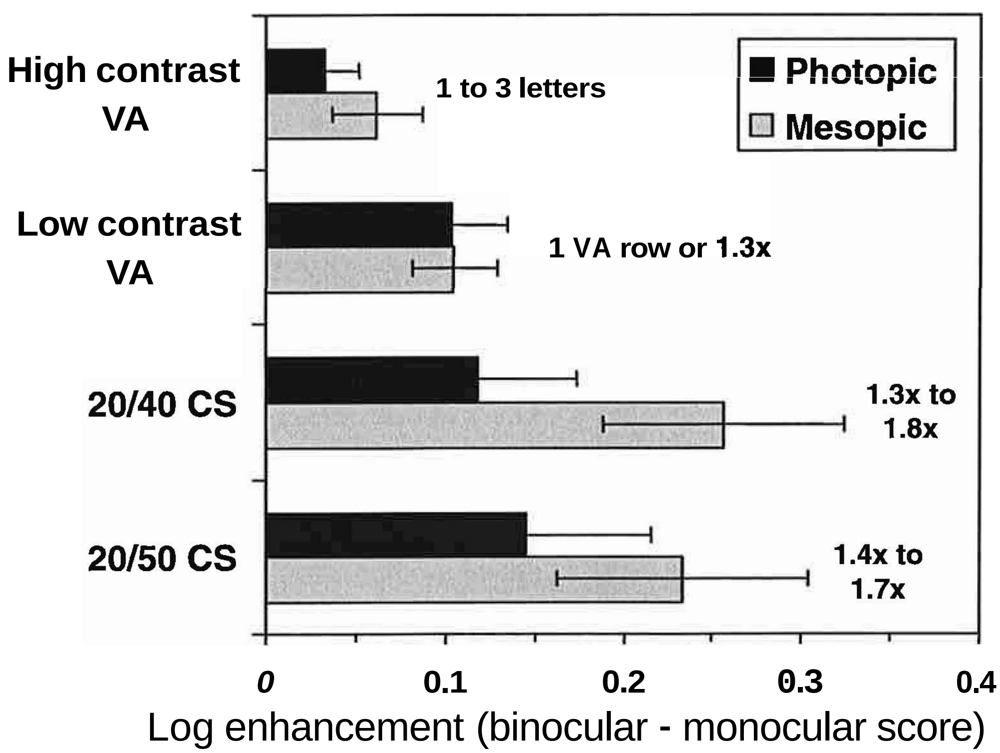
Figure 3:



To further explore effects of luminance and viewing condition of visual performance, the degree of enhancement was determined for each vision test. While binocular enhancement typically is expressed as a percentage or ratio (binocular/monocular performance), the ratio of two logarithmic values is equivalent to the difference between log scores. Hence enhancement is conveniently determined as the difference between binocular and monocular scores. However, simply computing the difference does not take into account the variability of the measurement. A larger effect does not necessarily imply greater sensitivity if the variability is also greater. To standardize effects of test-retest variability, we computed the absolute value of the difference between monocular scores for each subject, collected approximately two weeks apart. We then computed the median difference across subjects for each vision test. The median difference, expressed in log units, was 0.02 for high contrast VA, 0.04 for low contrast VA, and 0.06 for both

20140 and 20150 CS. This indicates that, on average, repeatability is one letter for high contrast VA, two letters for low contrast VA, and one letter for CS. These values were subtracted from the binocular enhancement for each subject, to gain a more realistic estimate of the degree of enhancement for each test condition. Figure 4 shows mean (±2SE; n=25) binocular enhancement, with values corrected for test-retest repeatability. As documented in previous studies, high contrast shows only slight enhancement, while larger effect is evident in the contrast domain, as well as for low contrast VA. Interestingly, the greatest effect was observed for CS under mesopic viewing conditions. This is a novel finding suggesting a significant gain in performance under low luminance conditions when using two eyes as compared to one. This result has practical implications for night vision performance and enhancement with monocular and binocular displays.

Figure 4:



DISCUSSION

In the wake of newer refractive surgeries where 'supervision' is purported, there remains to be a readily available means to measure the subtle variability in visual performance (i.e. visual acuity). It has been shown in previous studies that high spatial frequency CS as a function of optical defocus falls off more dramatically than the standard VA variant. Using this fact, small letter CS testing (20125) was used in the past to illustrate this salient point, but the SLCT failed to gain any clinical ubiquity. Many conditions with subtle resolution decrements may be detected, diagnosed, and monitored more effectively with an efficient and clinically available CS chart that can capture this subtle variability in resolution.

This study used a clinically more appropriate letter test-size (20150 and 20140) and revealed that, controlling for optical defocus, luminance and binocularity may be manipulated to vary the established CS vs. VA relationship, with the interesting finding that binocular enhancement was greatest under mesopic conditions. Studies should use this relationship with a clinically useful tool, such as the 20150 CS chart; to explore the applicable conditions and procedures utilized in a clinical setting where the initial presentation or outcome reflects a subtle visual resolution.

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