ORIGINAL ARTICLE

Effects of Contrast Sensitivity on Colour Vision Testing

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ABSTRACT

This study analyses how contrast sensitivity loss affects colour vision (CV) testing. Eleven participants were scored while cycling through randomly arranged pictures of CV tests with varying levels of contrast changes applied. Hardy-Rand-Rittler (HRR) scores declined significantly at each successive decrease in contrast level after the highest setting ($p < 0.004$). HRR scores were also lower than those for Ishihara and Farnsworth D-15 tests at two contrast settings ($p < 0.01$). Contrast changes had the greatest impact on HRR scores, indicating that this test may not be an accurate reflection of CV in patients with contrast sensitivity loss.

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Introduction

Colour vision (CV) testing is used conventionally by ophthalmologists to assess severity of CV loss by acquired or genetic disease processes or drug toxicities.^{1,2} Several different CV testing methods and apparatuses exist. The most common ones include pseudoisochromatic plates, such as the Ishihara and Hardy-Rand-Rittler (HRR) tests, and disc arrangement tests, such as the Farnsworth-Munsell 100 and Farnsworth D-15 (D15) hue discrimination tests.

Originally designed in 1917 as a quick assessment of congenital X-linked protan-deutan colour blindness, the full Ishihara colour test uses numbers arranged as colour dots of varying size, hue, and saturation. Later in 1955, the HRR test was developed to determine the extent and type of the colour defect. This test requires the identification of coloured shapes on a grey dotted background.³ Scored based on the number of symbols correctly identified, these tests are currently used as an initial analysis of patients' CV loss due to congenital defects, retinal diseases, or acquired colour deficiencies.⁴ Both of these pseudoisochromatic test booklets are inexpensive, durable, and readily available for use in the offices of eye care professionals.

Disc arrangement tests utilise caps of different hues and require the patient to sort them into a particular spectrum or group. These tests were

developed for occupational colour discrimination and can detect CV loss across all three axes. Numbers and shapes do not need to be discriminated, making the identification of these caps less reliant on visual acuity (VA).⁵ Arrangement testing allows for quantification of the severity of disease³ and may be more sensitive than pseudoisochromatic plates in detecting early visual dysfunction.^{3,6,7} However, a disadvantage is their time-consuming nature, thus limiting their use in the office setting.^{3,8}

Contrast sensitivity (CS), in addition to CV and VA, is an important vision parameter. CS measures an individual's ability to discern an object's lightness or darkness in comparison with its background.⁹ One may have high VA but poor contrast discrimination, which may affect activities of daily life such as motion detection and pattern recognition.¹⁰ Changes in CS can occur in patients with dry eye syndrome, retinal diseases, macular disorders, and glaucoma, among others.^{9,11}

CV tests have been explored in relation to low vision,^{5,7} colour blindness,¹² and cone dystrophies,³ but the effect of contrast vision loss on test results has not been extensively studied. In this study, we used a computer model for CS loss to determine its effect on CV testing scores for the Ishihara and HRR tests when compared with the gold standard colour vision D15 test.

Materials and methods

This Health Insurance Portability and Accountability Act (HIPPA)-compliant study was a prospective clinical investigation following the tenets of the Declaration of Helsinki, and all study procedures were approved by the institutional review board of the Johns Hopkins University. Participation was voluntary, and informed written consent was obtained prior to all study procedures.

Participants and setting

Subjects between the ages of 18 and 75 were recruited from the Wilmer Eye Institute and School of Medicine at the Johns Hopkins Hospital. Patients with ocular pathology, including those that affect colour or contrast vision, or binocular best-corrected visual acuity (VA) worse than 20/30 were excluded. All subjects underwent best-corrected logMAR VA assessment, Farnsworth D-15 CV and Pelli-Robson CS testing, and computer image discrimination testing.

Examination procedure

Measurement of distance VA with corrective lenses (if worn) was carried out using computerised logMAR VA charts in one clinic room at the Wilmer Eye Institute. Starting at the 20/30 line, testing proceeded sequentially to the line on which greater than or equal to half of the letters were properly read, for each eye separately, and then both eyes together.

CV was tested using the Farnsworth D-15 (D15) test (PV-16 quantitative colour vision test; Precision Vision, Lasalle, Illinois, USA). This test consists of 15 colour discs comprising the entire colour spectrum. Under simulated natural daylight conditions (OttLite 508 illumination; Tampa, Florida, USA), subjects were asked to arrange the discs in order according to the colour. Each correctly placed disc received 1 point. Subjects who did not place all discs in the correct order were ineligible for the study.

After VA and CV testing, subjects were shown 212 images on a computer monitor (Dell P2314H) at a distance of 42 inches with luminance in the range of 0 to 4 candelas/m². The images fell into five categories: 23 images were Hardy-Rand-Rittler (HRR) pseudoisochromatic plates (4th edition;

Richmond Products Inc., Albuquerque, New Mexico, USA), 17 were Ishihara pseudoisochromatic plates (1997 version; Kanehara & Co., Ltd., Tokyo, Japan), 10 were D15 discs, 2 were Pelli-Robson (PR) CS charts, and 1 was an Early Treatment Diabetic Retinopathy Study (ETDRS) VA chart.

These images were taken of the physical versions of each of the above testing plates or charts, captured at a distance of 6 inches using a digital single-lens reflex camera (Canon T5i). Each image was then adjusted to three different levels of contrast corresponding to the number of letters able to be read on a PR chart: high: 1.80 log units (1.6% contrast loss), medium: 1.50 log units (3.2% contrast loss), and Low: 1.05 log units (8.9% contrast loss).^{9,13} These adjustments were made using ImageJ software (version 1.46r; Wayne Rasband, National Institutes of Health, Bethesda, MD, USA), giving a total of four variants of each image (one unadjusted and three contrast adjusted). For the D15 test, the discs were arranged in a clockwise manner with the pilot disc on the left side. Pictures were taken of the discs arranged in the proper order as well of those in an incorrect order, i.e., some discs were switched around. All 212 images were randomised and presented in the same order to each subject. For PR charts, participants were asked to read as many letters as they could, and the faintest triplet for which at least two of three letters were correctly identified indicated the log contrast sensitivity score of the tested eyes. For the ETDRS chart, VA was determined by the lowest line on which at least half of the letters were read.

For the Ishihara plates, a score of 2 points was given for correctly identifying single-digit or double-digit plates. One point was given if only one digit was identified on a two-digit plate, and 0 points were given if numbers were not identified on both one-digit and two-digit plates. For HRR plates, 2 points were awarded for correctly identifying the shape and quadrant for both one-shape and two-shape plates. Zero points were given for incorrect shape identification on either plate type. One point was given for correctly identifying only one shape in the two-shape plates. For D15 discs, 1 point was given if the subject was successfully able to determine if the disc order was correct or incorrect; otherwise, zero points were given.

Statistics

All analyses were performed using Stata Statistical Software, release 14.1 (StataCorp LP, College Station, TX, USA). The Wilcoxon signed-rank test was used to assess differences between task scores, comparing each of the three CV tests at each of the three contrast levels. Differences within a particular CV test were also assessed for each contrast level compared with baseline scores. Statistical significance was adjusted using the Bonferroni method to account for multiple comparisons, indicated in each table.

Results

A total of 13 participants were tested in this study. Of these, two had baseline Ishihara scores that were less than 70% of the total possible score and were therefore excluded from further analyses, leaving an eligible study population of 11.

Nine (81.8%) participants were male, three (27.3%) were white, six (54.5%) were Asian, and two (18.2%) were of Middle Eastern descent (Table 1). The mean ($\pm$ SD, range) age was 28.6 ($\pm$ 14.71, 22–72) years. Two (18.2%) subjects presented without corrective lenses, whereas the others wore either glasses or contact lenses. Median visual acuity in each eye was 20/20. Mean Pelli-Robson score was 1.95 at baseline.

With no contrast adjustment, participants' median (% correct, range) scores were 34 (99.2%, 33–34), 45 (97.8%, 42–46), and 10 (100%, 10–10) for the Ishihara, HRR, and D15 pictures, respectively (Table 2). Mean PR scores for baseline, high, medium, and low contrast were 1.95, 1.82, 1.49, and 1.04, respectively ($p = 0.004$ for all). There was no significant difference between the percent of Ishihara or D15 pictures answered correctly as compared with their respective baselines for either the high or medium contrast settings (Table 3). At the lowest contrast setting, however, scores were significantly lower than baseline for both Ishihara and D15 ($p = 0.007$ and $p = 0.003$, respectively). For HRR pictures, both the medium and low contrast settings were lower than baseline ($p = 0.003$). HRR scores were also lower between each successive decrease in contrast level after the high setting ($p = 0.003$). HRR scores were significantly lower than both Ishihara and D15

Table 1. Demographic data of subjects.

Characteristic	Subjects
Mean age in years (SD)	28.6 (14.7)
Sex, <i>n</i> (%)	
Male	9 (81.2)
Female	2 (18.2)
Race, <i>n</i> (%)	
White	3 (27.3)
Asian	6 (54.5)
Middle Eastern	2 (18.2)

Table 2. Median scores (range) for colour vision tests.

Test	Baseline	High	Medium	Low
Ishihara (max 34)	34 (33–34)	34 (31–34)	34 (32–34)	31 (15–34)
HRR (max 46)	45 (42–46)	44 (42–46)	41 (30–44)	27 (12–33)
D15 (max 10)	10 (10–10)	10 (9–10)	10 (8–10)	7 (6–9)

Table 3. p values of comparison between contrast settings for each colour vision test.

Settings	Ishihara	HRR	D15
Baseline-High	0.8343	0.0471	0.0833
Baseline-Medium	0.8342	0.0032*	0.084
Baseline-Low	0.0074*	0.0033*	0.0028*
High-Medium	0.9583	0.0032*	0.9464
High-Low	0.0048*	0.0033*	0.003*
Medium-Low	0.0067*	0.0033*	0.0029*

*Statistically significant with a p value of <0.008 .

Table 4. p values of comparisons between colour vision tests for each contrast setting.

Tests	High	Medium	Low
Ishihara-HRR	0.4707	0.0033*	0.0033*
Ishihara-D15	0.3225	0.4610	0.1305
HRR-D15	1.00	0.0044*	0.0087*

*Statistically significant with a p value of <0.017 .

scores (Figure 1) at both medium and low contrast settings ($p < 0.01$; Table 4).

Discussion

Contrast sensitivity is an important visual parameter that determines the ability of an individual to distinguish between comparatively brighter and dimmer areas of an image. It is usually measured as a CS function that plots the minimum contrast an observer requires to distinguish between sine wave gratings of varying spatial frequencies.¹³ A simpler method is the use of a PR chart that contains letters arranged in triplets of decreasing contrast.¹³

In the present study, we have shown that modeled CS loss had the most significant impact on HRR

Figure 1. Percentage difference in accuracy based on contrast level. At low and medium contrast levels, accuracy decreased significantly in HRR compared to Ishihara or D15 testing.

scores, corroborating previous research that showed a positive correlation between HRR and PR CS scores in optic neuropathy patients.⁶ This previous study also showed a positive correlation between Ishihara and PR scores, which was not readily revealed in our study. When compared with both Ishihara and D15 in our study, HRR showed a larger than expected decrease in scores in both the medium and low contrast settings. Therefore, HRR scores may not be an accurate reflection of CV in patients with CS loss. The D15 test, which was used as our gold standard CV test, also showed a score decrease between the baseline and lowest contrast setting. At this low setting, the contrast decrease may resemble the effects of fogging on reducing visual acuity, which directly affects the results of CV tests.⁵

Pseudoisochromatic plates require an observer to identify shapes (HRR) or numbers (Ishihara) arranged as coloured dots of varying size, hue, and saturation against a similarly styled background.^{3,5} Due to the variances in spectral sensitivity of these tests, there exist differences in luminous reflectances between the figure and background,¹⁴ causing colour perception to be altered.¹⁵ These properties may in

part contribute to the undesirable and often overlooked contrast-related effects of pseudoisochromatic plate CV testing. However, the distinguishing feature of HRR testing leading to its difference from Ishihara as observed by our study is not clear.

In addition to increasing age, CS is decreased in various ocular pathologies, including macular degeneration, retinal diseases, and dry eye.^{9,11,16} Other diseases, such as optic neuropathies, traditionally rely on abnormal pseudoisochromatic plate testing as evidence for clinical suspicion. One study reported that HRR testing is more likely than Ishihara to detect a deficit in CV in patients with non-glaucomatous optic neuropathy.¹⁷ However, CS loss may actually appear concurrent with or even precede clinically detectable CV loss symptoms in these cases.^{18,19} Our finding that HRR is impacted by CS loss may explain HRR's advantage over Ishihara in these diseases. HRR testing may be used as a surrogate for detecting reduced CS in these patients.⁶ This is in part due to the time-consuming and variable nature of conventional clinical CS testing.⁹

Some study limitations include our relatively small study population and the use of the Farnsworth D-15 test as our standard CV test instead of the Farnsworth-Munsell 100 test. Although the Farnsworth-Munsell 100 is more sensitive in detecting acquired CV deficiency, it has a higher rate of false positives for CV loss.^{6,9} D15 has been shown to be a sufficient surrogate test.⁸ In this study, we used a computer model for CS loss. Future studies in patients with ocular pathology, such as dry eye, that decreases CS without effects on CV, will allow a direct examination of the impact of CS loss on the results of pseudoisochromatic plates.

In this study, we sought to determine the effect of CS loss through a computer model on CV testing scores of pseudoisochromatic plates. Our findings show that HRR scores may be significantly affected by CS loss. Clinicians should be cautious when interpreting results from HRR tests, especially in patients with disorders that are known to affect contrast sensitivity.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the article.

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