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ARTICLE

The effect of reduced contrast sensitivity on colour vision testing

Lior Lipsky[1,2] · Hanya M. Qureshi[3] · Ronit Friling[2,4] · Dan D. Gaton[2,5] · Gilad Rabina[1,2] · Gad Dotan[2,4]

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Abstract

Objective To assess the effect of reduced contrast sensitivity on three commonly used colour vision tests in order to establish key discrepancies that may be relevant for clinical practice.

Methods A prospective non-interventional clinical study of colour vision testing using three commonly used devices: Ishihara and Hardy–Rand–Rittler (H-R-R) pseudoisocochromatic plate tests, and Farnsworth D-15 arrangement test performed under progressively reduced contrast sensitivity conditions achieved with a neutral density filter bar.

Results The Pelli–Robson contrast sensitivity (PRCS) at which 5% of the population should first experience a 10% reduction in colour vision testing from baseline was calculated for each of the three colour vision devices: Farnsworth D-15 test: 1.81 log contrast sensitivity (CS), H-R-R test: 1.69 log CS, and Ishihara test: 1.34 log CS. Single factor repeated measures analyses, conducted separately at each contrast sensitivity level, revealed no difference between the colour vision testing devices at PRCS ≥1.80 log CS ($P \geq 0.367$). However, in all PRCS ≤1.65 log CS, the differences were statistically significant (all $P \leq 0.004$), demonstrating a significantly lower percentage of errors in the Ishihara test compared with both the Farnsworth D-15 ($P < 0.023$) and H-R-R ($P < 0.035$) tests.

Conclusions At high contrast sensitivities, all colour vision tests function almost equally; however, at decreased levels of contrast sensitivity, H-R-R and Farnsworth D-15 are more greatly affected.

Introduction

Colour vision tests, especially the pseudoisochromatic colour plate tests, such as the Ishihara and Hardy–Rand–Rittler (H-R-R) tests, were originally developed in order to identify congenital colour vision deficiencies. However, they are also commonly used by clinicians to diagnose acquired ocular diseases [1, 2]. Clinicians often attribute errors in colour vision testing to optic nerve or macular disease, especially if test results indicate asymmetry between the eyes [3]. However, abnormal colour vision assessment does not necessarily imply true colour vision loss. For example, poor visual acuity and central visual field defects can induce inaccurate responses in colour vision tests [1, 4]. Furthermore, Zhao et al. [3] reported that abnormal colour vision testing demonstrated in optic neuropathy is more related to reduced contrast sensitivity, which is a measure of an individual's ability to differentiate between an object and its background, rather than truly reflecting genuine colour vision defect [5].

Consequently, this study aims to establish key clinical discrepancies in colour vision tests. Using neutral density filters, we assessed reduced contrast sensitivity's effect on three separate colour vision test results in healthy individuals.

Methods

We conducted a prospective clinical study on healthy volunteers at our Medical Centre. The study's protocol was approved by the institutional review board and its execution was aligned with the Declaration of Helsinki's tenets. Written informed consent was obtained from all subjects.

✉ Gad Dotan
gaddotan@hotmail.com

1 Ophthalmology Department, Tel Aviv Medical Center, Tel Aviv, Israel

2 Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel

3 Columbia College, Columbia University in the City of New York, New York, NY, USA

4 Ophthalmology Unit, Schneider Children's Medical Center of Israel, Petah Tikva, Israel

5 Ophthalmology Department, Rabin Medical Center of Israel, Petah Tikva, Israel

Subjects

All participants were adults (>18 years old) with a visual acuity ≥20/25 at 6 m and ≥Jaeger 1 at 30 cm in both eyes, wearing correction spectacles if needed. All had a baseline contrast sensitivity of 1.80 or better on the Pelli–Robson contrast sensitivity (PRCS) chart, normal slit-lamp biomicroscopy, and normal fundus examination. Individuals with any history of ocular disease, congenital colour vision deficiencies, less than perfect colour vision assessment in natural office lighting conditions, or inability to complete all parts of the study were excluded.

Study design

All examinations were conducted in the same office room, under identical lighting conditions of approximately 300 lux. Monocular assessments of visual acuity, PRCS, and colour vision were performed in the subject's dominant eye after occlusion of the non-dominant eye with an amblyopia eye patch. Assessments began using the darkest density filter (3.6 logarithm contrast sensitivity, log contrast sensitivity (CS)) of the neutral density filter bar (Richmond products INC., Albuquerque, NM, USA) and were repeated sequentially at progressively lower density filter levels (0.3 log CS intervals) until the lightest density filter (0.3 log CS) was reached. Testing was concluded earlier, if the subject achieved perfect scores on all three colour vision devices at a higher density filter level.

Contrast sensitivity testing

Contrast sensitivity was assessed using the Pelli–Robson chart at the manufacturer's specified testing distance of 1 m. The chart is comprised of Sloan letters arranged in 16 groups of 3 letters, decreasing by 0.15 log unit for each triplet. Subjects had to identify 2 of the 3 letters correctly to get credit for each triplet, with the faintest one seen indicating the score of the tested eye (log CS).

Visual acuity testing

Visual acuity was determined at a distance of 1 m using the Early Treatment Diabetic Retinopathy Study (ETDRS) chart and was recorded as the logarithm of the minimum angle of resolution (logMAR).

Colour vision testing

Colour vision testing was performed using the Ishihara pseudoisocochromatic plate test (38 plates version, 2014 edition, Kanehara & Co., Ltd, Tokyo Japan), H-R-R pseudoisochromatic plate test (4th edition; Richmond Products INC., Albuquerque, NM, USA), and Farnsworth D-15 test (Richomond Products INC., Albuquerque, NM, USA).

Pseudoisochromatic plate testing was done at a distance of 30 cm, while holding the book at a perpendicular angle to the visual axis in accordance with the manufacturer's instructions. The score of the Ishihara and H-R-R tests was set as the number of plates correctly identified out of the first 12 and 20 screening plates, respectively. For the one digit/figure plates, one point was given if the subject correctly identified the number/shape and zero points were given if the subject did not see or could not identify the number/shape. For the two digits/figures plates, one point was given for correct identification of both numerals/shapes, half a point was given for identification of one numeral/shape, and zero points were given if none were seen or identified. This scoring method followed a commonly performed clinical practice as described by Zhao et al. [3]. The Farnsworth D-15 arrangement test consists of one reference colour disc and 15 moveable discs, which the subject was asked to arrange according to hue on a black-coloured surface. A maximum score of 15 was awarded if all discs were correctly positioned, while one point was deducted for every misplaced disc.

Statistics

Statistical analysis was performed using Prism 7 statistical software (GraphPad Software Inc., San Diego, CA). All statistical tests were non-parametric and two-tailed with statistical significance defined at an alpha level below 5%. Spearman's correlation coefficients between contrast sensitivity and all colour vision tests were calculated and compared. Participant scores on each contrast sensitivity level were calculated per colour vision test. Scores were then converted to percentages of the maximum scores for each test. Using a method described by McCulley et al. [4], we recorded the contrast sensitivity at which there was a 10% reduction in colour vision test score from baseline for all participants. The mean of these scores was calculated followed by deduction of two standard deviations to determine the contrast sensitivity at which 5% of the population should first experience a reduction in colour vision testing. The Friedman test of single factor repeated measures analysis and post hoc Dunn's multiple comparison test were performed repeatedly at each contrast sensitivity level to compare colour vision testing devices and analyse differences between each pair.

Results

Twenty healthy subjects with normal baseline colour vision (10 males, 10 females, mean age 33 ± 7 years, range,

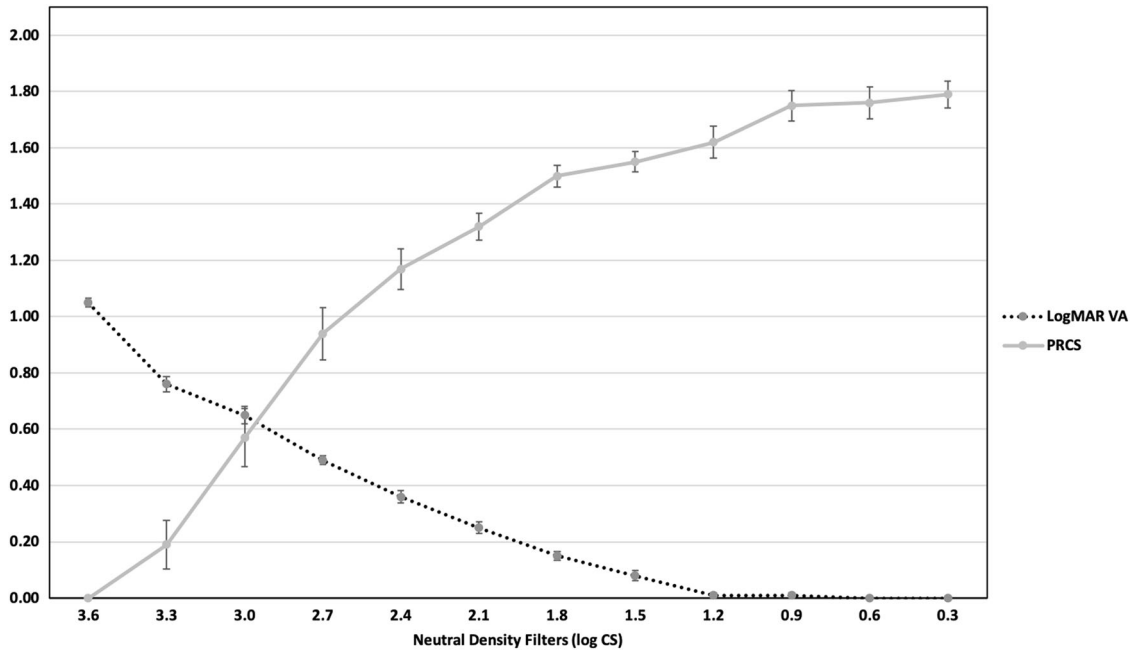

Fig. 1 Effect of neutral density filters on Pelli–Robson contrast sensitivity (PRCS) and logarithm of the minimum angle of resolution (logMAR) visual acuity. Log CS logarithm of contrast sensitivity

Table 1 Spearman's correlation coefficient of Pelli–Robson contrast sensitivity (PRCS) with three colour vision test scores

	Correlation coefficient (r)	P value
Ishihara	0.983	<0.001
Hardy–Rand–Rittler (H-R-R)	0.996	<0.001
D-15	0.983	<0.001

20–53 years) underwent monocular colour vision assessment (13 right eyes and 7 left eyes) while using a neutral density filter bar, which progressively decreased contrast sensitivity and visual acuity (Fig. 1). There was a strong and highly significant correlation between contrast sensitivity and colour vision test score for all three tests (Table 1); however, no test had a significantly stronger correlation with contrast sensitivity than the others ($P = 0.769$).

The PRCS at which 5% of the population should first experience a 10% reduction in colour vision testing from baseline was calculated for each of the colour vision devices: Farnsworth D-15 test: 1.81 log CS, H-R-R test: 1.69 log CS, and Ishihara test: 1.34 log CS (Fig. 2).

Friedman's test of single factor repeated measures analysis conducted separately at each contrast sensitivity level revealed no difference between the colour vision testing devices at PRCS ≥1.80 log CS ($P \geq 0.234$). However, in all PRCS ≤1.65 log CS, the differences were statistically significant (all $P \leq 0.008$). Additionally, post hoc Dunn's multiple comparison test found that the Ishihara test had a significantly lower percentage of errors compared with both Farnsworth D-15 ($P < 0.023$) and H-R-R ($P < 0.035$). There was no significant difference in the percentage of errors between the H-R-R and Farnsworth D-15 tests ($P > 0.171$).

Discussion

Abnormal colour vision assessment can be the result of congenital colour vision defects, reduced visual acuity, or central visual field defect [1, 4]. However, according to our study it can also be caused by diminished contrast sensitivity.

In 2007, McCulley et al. [4] reported that colour vision testing is diminished in visual acuities below 20/100, with a greater effect of reduced visual acuity on the Ishihara test compared with the H-R-R and Farnsworth D-15 tests. In our study, we demonstrated that these tests are also affected by reduced contrast sensitivity, but in reverse order of dependency, with contrast sensitivities below 1.80 log CS resulting in greater inaccuracies in the H-R-R and Farnsworth D-15 testing compared with the Ishihara plate test. Using neutral density filters, we observed a decrease in colour vision testing even when the visual acuity was higher than necessary to affect colour vision testing according to McCulley et al. [4], demonstrating that reduction in contrast sensitivity and illumination independently affect colour vision performance (Table 2).

The design of pseudoisochromatic colour plate tests is based on hiding the numbers or figures in the background

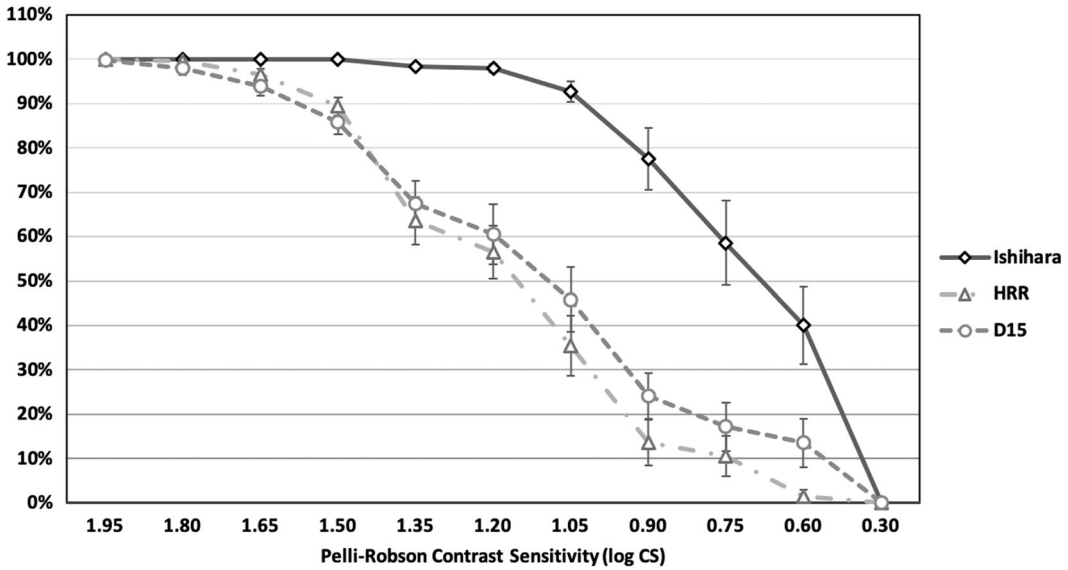

Fig. 2 Comparison of three colour vision testing devices (Ishihara colour plate test, represented by diamonds; Hardy–Rand–Rittler (H-R-R) colour plate test, represented triangles; and Farensworth D-15 arrangement test, represented by circles) at decreasing levels of contrast sensitivity. Pelli–Robson contrast sensitivity (*x*-axis) is plotted against colour vision testing results (*y*-axis), which are presented as the percentage of correct responses at each contrast sensitivity level relative to the maximum score for each test

Table 2 Comparison of the logMAR visual acuity and PRCS causing a 10% reduction from baseline colour vision testing in 5% of the population

	LogMAR[a]	PRCS
Ishihara	0.72	1.34
H-R-R	1.10	1.69
D-15	1.40	1.81

LogMAR logarithm of the minimum angle of resolution, *PRCS* Pelli–Robson contrast sensitivity, *H-R-R* Hardy–Rand–Rittler

[a]According to McCulley et al. [4]

and were developed in order to detect congenital colour vision defects; however, their efficiency for detecting acquired colour vision defects is limited, possibly by the unintended introduction of contrast-related elements [1–3]. Since the amount of contrast needed to distinguish between an object and its background is highly dependent on the object's size, larger objects typically need less contrast difference to be seen [5]. Consequently, the fact that the Ishihara numerals are larger than the H-R-R symbols and the Farnsworth D-15 discs may partially explain the lower error rate induced by reduced contrast sensitivity on the Ishihara test when compared with the other two tests.

Loss of contrast sensitivity may be the result of many ocular disorders including optic neuropathies, maculopathies, media opacities, amblyopia, and dry eye syndrome [1, 6–9]. Recently, Zhao et al. [3] noted that pseudoisocochromatic colour vision testing can be used as a measure of contrast sensitivity in patients with acquired optic neuropathy. Almog and Nemet [1] further suggested that loss of contrast sensitivity is responsible for errors encountered in Ishihara colour testing in patients with macular disease, media opacities, and amblyopia. Wyszecki and Stiles [10] reported that that spectral transmittance by the ocular media, specifically the lens and macular pigments, accounts for light loss before reaching the photoreceptors. Additionally, they found differences in bleaching responses of different visual pigments under increasing lighting conditions, with the blue visual pigments bleaching at lower illumination levels compared with the red and green visual pigments. Our study provides additional evidence that colour vision is affected by reduced contrast sensitivity and dim lighting conditions, which are not the recommended settings under which these tests should be typically performed; however, further studies are needed to establish differences in effect between the three visual pigments.

We limited our study to three commonly used colour vision tests, demonstrating that at high contrast sensitivities, these tests function almost equally. However, at lower levels of contrast sensitivity, more errors are noticeable in the H-R-R and Farnsworth D-15 tests than in the Ishihara test. Other less widely available colour vision tests, including the City University of London CAD test, which is not light dependent, were not included in this study. Consequently, our findings are limited only to the colour vision tests performed. More studies are needed to analyse the influence of contrast sensitivity on other colour vision tests as well.

Summary

What was known before

- Colour vision testing is affected by reduced visual acuity and central visual field defect.

What this study adds

- Colour vision testing is also affected by diminished contrast sensitivity.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

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