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Ishihara Electronic Color Blindness Test: An Evaluation Study

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Purpose: Evaluation of computer based color deficiency test.
Materials and Methods: Two hundred and sixty seven volunteers have been checked using both traditional Ishihara plates and a computer diagnosis program using LCD monitors.
Results: The prevalence of red green color vision deficiency (RG-CVD) was 8.75% of male participants, no female participants were diagnosed, both in the paper based test, and in the computer based test. Computer based test gave 100% sensitivity and 98.78% specificity.
Conclusion: Presenting the computer based color deficiency test software on LCD screen can be used for screening of color vision deficiency with nearly similar sensitivity and specificity to the Ishihara test with the advantage reducing the cost through decreasing required resources over time, and decreasing the time to analyze the results.

Keywords: Color blindness; color vision deficiency; color vision screening.

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1. INTRODUCTION

Color vision is provided by three types of photoreceptors; sensitive to blue, green, and red wavelengths of the visible spectrum [1]. Color vision deficiency (CVD) could be congenital or acquired; the acquired form reflects a problem that occurred anywhere along the visual pathway from the photoreceptors to the cortex [2]. While congenital color deficiency is due to a genetic disorder where the color deficient person could miss one, some pigments, where anomalous trichromats are the most common, and they have an anomalous pigment in either the red or green cone [3].

Up to 8% of the world's male population exhibits a type of CVD. This is made up of 1% red-blind (protanope) and 1.1% green-blind (deuteranope) dichromats and of 1% red-insensitive (protanomolous) and 4.9% green-insensitive (deuteranomolous) trichromats. Only 0.4% of women have any sort of color vision deficiency. More than 80% of CVD subjects have one form of anomalous trichromacy, which demonstrates a milder and variable severity than those with dichromacy [4].

Due to abnormal cone characteristics, people with CVD may have great difficulty with color discrimination that affects their social life and careers [5].

Different methods are used for diagnosing color vision deficiency including; Anomaloscope, arrangement tests, and Pseudoisochromatic plates which are the most popular and easy applicable screening test [4]. Different test books have significant variations, and the pigment technology, and age of the test could affect the result of the test [6].

Ishihara color test is most often used to screen for congenital and acquired red green deficiencies, and the characteristics of the responses may change with the severity of the defect [7].

Computer software programs had been previously used to test different visual functions such as; visual acuity, stereo vision, visual field, and color vision [8-12].

This study was conducted to evaluate the use of computer software for CVD screening as compared to the results of Ishihara test.

2. METHODOLOGY AND VOLUNTEERS

A prospective non randomized controlled study was conducted in the period from January 2012 to June 2013, where 267 volunteers from the Menofia University Campus students were examined for red green color vision deficiency (RG-CVD). Announcements were made using posters in different places of the campus besides electronic announcement in different internet social groups. The announcements highlight the aim of this screening test, how, and where the volunteer would be examined.

2.1 Collection of Volunteers' Data

The Volunteers were asked to fill a registration form containing personal information; age, gender, residence, telephone number. Volunteers with vision disorders, other than requiring spectacles or contact lenses to correct refractive errors, were excluded. This study was approved by the clinical research committee of the Menoufia University Hospital and it followed the tenets of the Declaration of Helsinki. An informed consent were signed by all volunteers. These data with the results of examination of volunteers on the first 21 plates of the 36 Ishihara test and the computer based test were documented in a spread sheet of SPSS software program version 16.

2.2 Paper-Based Ishihara Test

To get the best results on color vision testing, the examined person should wear his/her vision correction whether spectacles or contact lenses. Any add-on materials in the vision correction aid that could alter color perception should be prohibited. The examiner (who was previously assessed and classified as having normal color vision) has to check these points carefully before starting the test.

Brand new Ishihara 38 plates were used for screening. A full CVD test has been performed using the first 21 numerical plates. As noted in the instruction sheet of this brand [13], examinations were done in ordinary day light (opened windows in the examination room in a non cloudy morning in the middle east area, with a sufficient white fluorescent lambs for room lighting), with no direct sun exposure, plates were held 75 cm from the volunteer and tilted so that the plane of the paper is at right angle to the line of vision, the numerals seen on the plates were

stated within 3 seconds, and recorded by the examiner.

2.3 Computer-Based Ishihara Test

The first 21 plates of a brand new Ishihara color vision deficiency examination plates were scanned using HP Deskjet 1050 J410 all in one scanner with 600 dpi resolution, no adjustments or modifications of the scanned images were made. The test program has been written in Matlab code and converted to an executable program. The test has been performed on Acer Veriton M 290 PC (Intel Core i3 Processor, 4GB-Ram).

The test starts when the volunteer pushes the Start button of the first screen, where the first plate appears to the volunteer with the instructions of using the test. After submitting the first answer (all cases should answer it correctly), next plate is displayed one after another for 3 seconds only after which the image disappears and he records the numeral in the specified place, then he switches to the next plate. Fig. 1 shows a screenshot of the program. At the end of the 21 plates, the program summarizes the test presenting which answer is correct and which is not, final score and the final diagnosis decision according to the instructions sheet.

2.4 Screen Adjustment

The test has been performed on Acer Professional 24" Widescreen LCD Monitor with 1920 x 1080 Full HD resolution. To achieve an approximate accurate color reproduction, the following screen adjustments were made; the monitor was kept half an hour in operation. Monitor resolution was set to max. Color calibration process has been performed to insure the quality of the presented colors on the screen. The sufficient specs for this test were: Color temperature 6500° K, Color intensities of red, green, and blue respectively to 50%. Set in the "Control Panel" mode "true color" and "16 million colors".

2.5 Statistical Analysis

Validation of screening tests for CVD had been approached [12], which was guided by simplicity, acceptance, and reliability of the procedure; this validation was mainly focused on analysis of sensitivity, and specificity of the test [11].

Sensitivity is defined as the proportion of volunteers classified as having CVD among those with Ishihara plates proven CVD. While specificity is the proportion of volunteers classified as not having CVD among those in whom the disease was excluded by Ishihara plates.

Sensitivity and Specificity were calculated to the results of the computer based test using the paper based test results as a reference.

Screening inefficiency (SI) for each plate was used by Crone, which measures the quality of the discriminating ability of the each plate [11],

$$SI = \sum (\text{false positive answers}) + \sum (\text{false negative answers}) \text{ divided by} \sum (\text{answers}) \quad \text{Eq. (1)}$$

Student *t* test was used to calculate the statistical difference between numerical variables, while the *Chi* square test was used for categorical variables.

3. RESULTS

The study included 267 volunteer, 240 males (89.9%), and 27 females (10.1%) with an age range from 19 to 23 years, with a mean 20.7 years, and standard deviation 1.34 years.

Using the paper based test, twenty one volunteers were diagnosed as having RG-CVD, all were males, with a percent 8.75% of male participants, and 246 volunteers were diagnosed as normal, no female volunteers were diagnosed as RG-CVD as shown in Table 1.

Table 1. Results of the paper based test

Diagnosis	Number of plates answered correctly	Number of volunteers	Total number of volunteers
RG-CVD	4	3	21
	6	3	
	8	3	
	10	9	
	13	3	
Normal	19	3	246
	20	18	
	21	225	

Volunteers were diagnosed as normal if they were able to read 17 or more plates correctly, and diagnosed as RG-CVD if they were able to read 13 or less plates only correctly.

Using the computer based test, also 21 volunteers were diagnosed as RG-CVD, and all were males, with a percent 8.75% of male participants, and 243 volunteers were diagnosed as normal, and three volunteers answered 16 plates correctly, so they were not classified as RG-CVD nor normal, no female volunteers were diagnosed as having RG-CVD as shown in Table 2.

The same number of volunteers were diagnosed as red green CVD by both tests, with 100% sensitivity of the computer based test compared to the paper based test, and 243 volunteers were diagnosed as normal in computer based test, when compared to the 246 volunteers diagnosed as normal by the paper based test gave a 98.78% specificity for the computer based test. Table 3 shows that the results of the computer based test was the same as that of the paper based test in 150 volunteers, where all volunteers answered the same number of plates in a correct way.

Table 2. Results of computer based test

Diagnosis	Number of plates answered correctly	Number of volunteers	Total number of volunteers
RD-CVD	6	3	21
	8	3	
	12	3	
	13	12	
Not diagnosed	16	3	3
Normal	17	15	243
	18	6	
	19	24	
	20	57	
	21	141	

In 102 volunteers the numbers of correct plates answered by the volunteers were more in paper based test than in computer based test, where; in 54 volunteers there were one more correct answer, in 24 volunteers there were 2 more correct answers, in 6 volunteers there were 3 more correct answers, in 12 volunteer there were 4 more correct answers, and in 6 volunteer there were 5 more correct answers, however these differences in the number of correct answers did not affect the end result of the computer based test whether the volunteer is a RG-CVD or not (Table 3).

In 15 volunteers, the number of correct plates answered were more in computer based test, out of them; twelve participants answered 1 more correct plate, and 3 participants answered 2 more correct plates, these differences in the number of correct answers did not affect the end result of the computer based test whether the volunteer is a RG-CVD or not (Table 3).

The mean and the standard deviation of the screening inefficiency for the paper and the computer based test were 0.04±0.02, and 0.05±0.02 respectively with no significant difference between both tests (P=0.092) (Table 4).

On comparing the results of both tests according to categorization into normal, and RG-CVD, we found that the same number of volunteers were diagnosed as RG-CVD, and 247 volunteer were diagnosed as normal by the paper test and only 243 were diagnosed as normal with the computer based test, without significant difference between both tests (P=0.0912) as shown in Table 4.

Comparing all answers to the whole set of plates, the paper based test resulted in 5376 correct answers , and 231 false answers , and in the computer based test there were 5310 correct answers, and 297 wrong answers with a significant difference between both tests (P=0.004) (Table 4).

Table 3. Difference between both tests regarding the number of correct answers in each test

Two test difference	Number of difference	Number of volunteers	Total number of volunteers
Number of correct answers more in the computer based test	1	12	15
	2	3	
Number of correct answers more in the paper based test	1	84	102
	2	24	
	3	6	
	4	12	
	5	6	
No difference			150

Table 4. Difference between both tests regarding the screening inefficiency, the categorization into normal or RG-CVD, and the total number of answers in each test

Variable		Paper based test	Computer based test	P value
Screening inefficiency	Mean	0.04	0.05	0.092
	STD	0.02	0.02	
Categorization into	Normal	247	243	0.0912
	RG-CVD	21	21	
Total number of answers	Correct	5376	5310	0.004
	Wrong	231	297	

4. DISCUSSION

Different tests had been used for screening of color vision deficiency; Cavanagh et al. [10] mentioned that at least two approaches are accepted to detect color anomaly, Ishihara plates and the American optical pseudoisochromatic plates. Long and Tuck mentioned that other methods can be used, such as Nagel anomaloscope or the Fransworth-Munsell 100-Hue test [14].

Pseudoisochromatic plates are the most popular and easily applicable for screening of color vision deficiency [4]. Several experiments have shown a high reliability of Ishihara test to detect RG-CVD [15-18]; however the printing technology, and the age of the test could affect the end result of the test [6].

Integration of tests of human sensory functions to computer can improve the quality of the results, reduces the required resources, and decrease the time to analyze the results [19,20].

There have been a number of attempts to develop methods of color testing based on computer software; Pardo et al. [21,22] have presented a system of characterizing red–green color vision anomalies by simulating the Pickford–Nicholson type anomaloscope on a cathode ray tubes (CRT) monitor. Toufeeq in 2004 has described an inexpensive computer based test for detection of color defect [23], also, Miyahara et al., developed a computerized system to diagnose red green color defects using Cathode Ray Tube (CRT) screen [24].

In 2007, Kuchenbecker et al. [25] has developed a German-language web-based color vision test with 25 pseudoisochromatic color plates based on the color plates of Velhagen and Broschmann and of Ishihara.

These entire computer based tests for examination of color vision deficiency used CRT screens, with some technical restrictions, that not all perceivable colors can be adequately presented on a CRT monitor [26].

Derefeldt and Hedin [27] investigated the spectral emission of colors on CRT monitors, and showed that certain shades of orange yellow and blue green colors cannot be represented on a monitor using CRT technology, this lead to the assumption that the spectral emission of Ishihara plates on a CRT monitor will be different from the spectral emission of the reflected day light on the paper plates.

In 2004; Pardo et al. [28] conducted a comparative study of the color gamuts that can be generated by three of the TFT-LCD, as well as of their variations in the chromaticity of the primary stimuli and of the white point as a function of viewing angle, and came to a conclusion that these monitors are valid for color vision research and diagnosis.

In this study, all participants were examined using the paper based test, and the computer based test with plates presented on LCD monitor, the prevalence of RG-CVD was 8.75% of male participants, no female participants were diagnosed, both in the paper based test, and in the computer based test, which is similar to that of Modarres et al. [29] (8.18% of male participants), and Buckalew et al. [30] (8% of male participants).

Computer based test gave 100% sensitivity and 98.78% specificity, which makes the use of computer based test convenient for screening RG-CVD without losing any positive cases, or misdiagnosing negative cases as RG-CVD, there were three cases that fall in the zone between normal, and RG-CVD, where volunteers did not fulfill the criteria to be normal, or RG-CVD with the computer based test.

Comparing the number of volunteers diagnosed as normal or RG-CVD by both tests, resulted in statistically insignificant difference, so, the computer based test could be used in screening of RG-CVD.

Comparing the total correct and wrong answers in both tests resulted in a significant difference, however this did not affect the reliability of the computer based test, as the total number of correct and wrong answers did not diagnose RG-CVD from normal, where it depends on the number of correct and wrong answers in all plates for each, not all participants.

Some plates are better detectable than others, this assumption was confirmed by Haskett and Hovis [31] where they found that plate number 7 is the one most misread by participants, also in this study, plates number 9, and 10 were the most misread (21 mistake in each test), for that, screening inefficiency was calculated for each plate independently, and the mean and the standard deviation values for all plates were calculated, and compared, which resulted in statistically insignificant difference between both tests, so both tests can be used for screening of RG-CVD without significant difference in the mean result of the discriminating ability of these plates.

5. CONCLUSION

Presenting the computer based color deficiency test software on LCD screen can be used for screening of color vision deficiency with nearly similar sensitivity and specificity to the Ishihara test with the advantage reducing the cost through decreasing required resources over time, and decreasing the time to analyze the results.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDICES

A. Figures

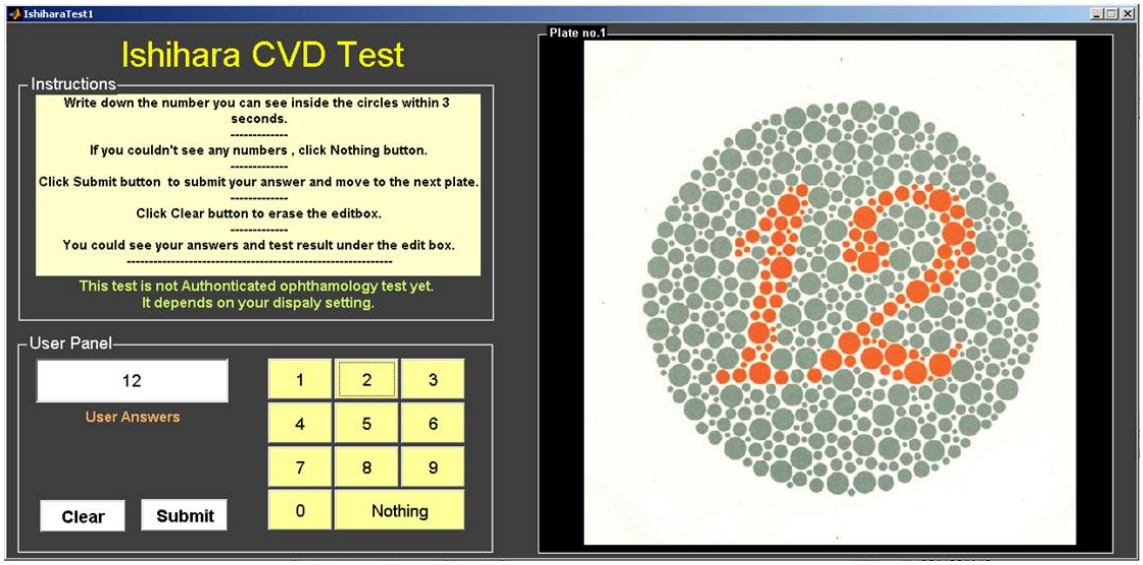

Fig. 1. Computer-based ishihara test

2a

2b

Fig. 2a and b. Contrast / brigtness screen adjustment test

Fig. 3. Color screen adjustment test.

B. Equations

Equation (1): Screening inefficiency.

C- Appendix

For actual reproduction of the test, the following target could be used to judge whether the monitor used is adjusted for best viewing. Set contrast to maximum and the brightness so that you can identify by black 11 degrees in the graphics in Fig. 2.a and 7 degrees (2 of white, 3 for gray and 2 for black) as in Fig. 2.b. Also, you should see red, green and blue graphics in Fig. 3 each of 2 different colors. If this is not the case, your settings are not correct, or your monitor is not suitable for accurate color reproduction.

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