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Detection of Congenital Color Vision Deficiency by Using Hardy-Rand-Rittler Pseudoisochromatic Test Plates

Konjenital Renk Görme Bozukluğunun Hardy-Rand-Rittler Psödoizokromatik Testi ile Tespiti

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ABSTRACT Objective: To screen, categorize and grade the severity of congenital color vision deficiency (CVD) by using Hardy-Rand-Rittler (HRR) pseudoisochromatic test plates and to detect the state of awareness of people about their abnormal color vision. **Material and Methods:** 2211 consecutive subjects aged between 15-45 years were recruited for the study. All patients underwent a color vision test by using HRR 4th edition pseudoisochromatic test plates. Both eyes were tested separately and the data of the right eyes were used for statistical analysis. The patients detected to have CVD were also asked if they were previously aware of their abnormal color vision. **Results:** Abnormal color vision was encountered in 59 out of 993 males (5.9%) and 4 out of 1218 females (0.3%). Congenital CVD cases were deutan in 47 (74.6%), protan in 11 (17.5%) and unclassified in 5 (7.9%) subjects. Five (7.9%) of the CVD subjects were classified as having mild, 21 (33.4%) having medium and 37 (58.7%) having strong color deficiency. Nineteen subjects (30.2%) were previously unaware of their abnormal color vision. The awareness of abnormal color vision was significantly associated with male gender and increased severity of the disease. **Conclusion:** HRR test may be used to detect, classify and grade severity of CVD. Approximately one third of the patients with CVD were previously unaware of their abnormal color vision. Female subjects and patients with mild CVD were more frequently unaware of their color vision problem.

Keywords: Color vision defects; color perception tests

ÖZET Amaç: Hardy-Rand-Rittler (HRR) psödoizokromatik testini kullanarak konjenital renk görme bozukluğu (RGB) taraması, sınıflandırılması ve ciddiyetinin araştırılması ile bozukluk tespit edilen hastaların bu konudaki farkındalıklarının tespiti amaçlanmıştır. **Gereç ve Yöntemler:** Çalışmaya 15-45 yaş arasında 2211 birey dahil edilmiştir. HRR 4. baskı psödoizokromatik testi kullanılarak renk görme muayenesi her iki göze ayrı ayrı uygulanmış ve sağ göz verileri istatistiksel analiz için kullanılmıştır. Konjenital RGB saptanan hastalara bu durum hakkındaki farkındalıkları da sorulmuştur. **Bulgular:** Çalışmaya dahil edilen 993 erkek hastadan 59'unda (%5,9) ve 1218 kadın hastadan 4'ünde (%0,3) konjenital RGB görülmüştür. Bu hastalardan 47'si (%74,6) dötan, 11'i (%17,5) protan idi ve 5 hastanın RGB tipi sınıflandırılamadı. Anormal renk görmesi olan hastaların 5'inde (%7,9) hafif, 21'inde (%33,4) orta ve 37'sinde (%58,7) ağır düzeyde RGB olduğu izlendi. Konjenital RGB tespit edilen hastalardan 19'u (%30,2) renk görme bozukluklarının farkında değildi. Anormal renk görme durumu farkındalığının erkek cinsiyet ve artmış hastalık şiddeti ile ilişkili olduğu görüldü. **Sonuç**: HRR testi RGB tespiti, sınıflanması ve ciddiyetinin derecelendirilmesi için kullanılabilir. RGB olan hastaların yaklaşık olarak üçte birinin bu durumun farkında olmadığı izlendi. Kadın cinsiyet ve hafif düzeyde hastalık şiddeti anormal renk görmenin farkına varmama ile ilişkili bulunmuştur.

Anahtar Kelimeler: Renkli görme bozuklukları; renk algılama testleri

Normal human color vision is trichromatic and based on the presence of long (L), middle (M) and short (S) wavelength sensitive cones.[1] Color vision deficiency (CVD) can be acquired, but is mostly congenital. Its prevalence may be as high as 8% in males and 0.5% in females

depending on the ethnicity of the investigated population.[2] The most common form of congenital color vision deficiency is associated with the inability to discriminate

Red and green wavelengths, and inherited as X-linked recessive.[1] It is characterized by absence of either the L-cone function (protan defects) or M-cone function (deutan defects). On the other hand, congenital blue CVD involving the S-cones (tritan defects) is extremely rare and inherited in autosomal dominant fashion. It has also been shown that acquired tritan defects are more common when compared to any other types of acquired CVD, although congenital tritan defects are rare.[3,4]

Although Ishihara color plate test is the most popular and widely used one, there are many other tests clinically in use to diagnose CVD including Hardy-Rand-Rittler (HRR) pseudoisochromatic test, Farnsworth-Munsell 100-Hue test, Farn sworth D-15 test, Medmont C-100 test and Nagel anomaloscope.[5] The HRR pseudoisochromatic test was first published by the American Optical Company in 1954.[6,7] Richmond Products published the 4th edition in 2002, the colors of which have been re-engineered for better performance.[8] Compared to Ishihara, HRR provides more information, since it includes plates to detect tritan CVD, besides protan and deutan defects and has a carefully designed set of plates to differentiate protan, deutan and tritan deficiencies and grade their severity.

The aim of the present study was to screen, categorize and grade the severity of congenital CVD in the outpatient clinic of a tertiary eye hospital by using Richmond HRR 4th edition test plates and to detect the state of awareness of people about their abnormal color vision.

MATERIAL AND METHODS

The study was designed as a cross-sectional study and was undertaken at the outpatient clinic of a single tertiary eye hospital. It was carried out upon approval of the Institutional Review Board. Only patients who fulfilled the selection criteria and gave written informed consent in line with the Declaration of Helsinki were included in the study. Patients were recruited between January 2015 and July 2015. After obtaining detailed medical history, all patients underwent a monocular color vision test by using HRR 4th edition pseudoisochromatic test plates (Figure 1) prior to standard ophthalmological examination including best corrected Snellen visual acuity (BCVA) testing, slit-lamp examination, tonometry and dilated fundus examination with a 90-diopter lens. The patients with acquired CVD and the ones having a BCVA less than 20/20 were excluded. In order to eliminate confounding factors that could affect the color vision test performance, the patients with accompanying ocular diseases such as glaucoma, cataract, ocular surface disorders, retinal diseases, amblyopia, strabismus, any type of refractive errors greater than or equal to 6 D, and those with a previous history of ocular surgery or trauma, optic nerve or central nervous system disorders were also excluded.

The HRR test is composed of 24 test plates each displaying either one or two geometric symbols, which can be a cross, a circle or a triangle. The symbols are made up of colored dots on a background of neutral grey dots. The patient is asked to name the shape of each symbol they see, and indicate its location, which can be in one of four quadrants of each plate. There are 4 non-scored

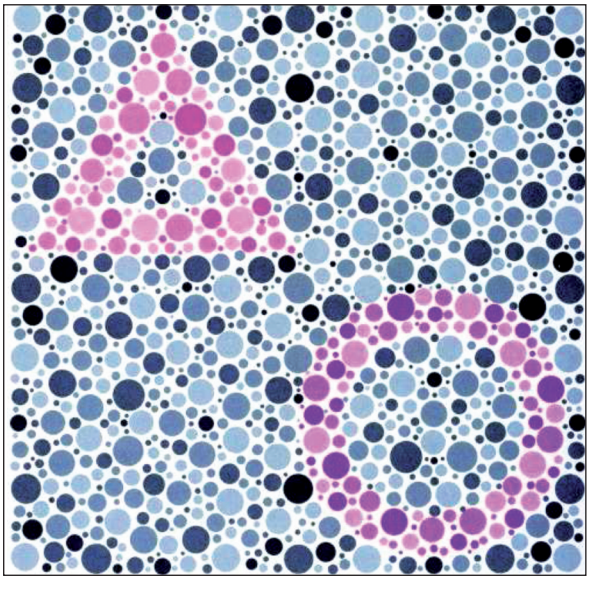

FIGURE 1: A plate from handy-rand-rittler pseudoisochromatic test.

demonstration plates in which the symbols can be seen by all observers. One of these plates has no symbol so that the patients understand that a symbol might not be seen in some plates. Following the demonstration plates, there are 20 plates. Of the first 6 screening plates, 2 are for tritan defects and 4 for the protan-deutan defects. These are followed by 14 diagnostic plates designed to differentiate the type of CVD and grade severity. Screening plates are very desaturated and the saturation progressively increases in plates grading severity. The saturation of the neutral colors increases progre ssively, in different plates, so that the color difference between the symbol and the grey background increases as the patient proceeds through the plates.

The 4th edition of Richmond HRR test was given to 2211 consecutive subjects aged between 15-45 years who attended the outpatient clinic with complaints concerning refraction disorders, vitreous floaters, mild dry-eye or with non-specific ocular complaints. The test was performed and analyzed by the same examiner (MAS) in the same room under standard illumination conditions (basic daylight fluorescent tubes). The plates were held approximately 60 cm away from the patient at a perpendicular angle to the line of sight. Three standard questions including 'how many colored symbols do you see here?' 'what are they?' and 'where are they?' were asked to all subjects. They were given 3 seconds to respond to each plate and each missed symbol was counted as an error. No revision of the patient's opinion was allowed during testing. If all 6 symbols on the screening plates were seen, the patient was named to have normal color vision and no more testing was done. A patient who made errors on the screening plates assumed to have CVD and subsequent diagnostic test plates were asked in the same manner.

A patient is a "protan" if the total number of symbols recognized in the protan column is greater than the deutan column; a 'deutan' if the symbols recognized is greater in the deutan column; and 'unclassified to the type of red-green deficiency' if the number of recognized symbols are equal in both columns. Patients having CVD were graded as mild, medium or strong, depending on whether they see or do not see the symbols on the more saturated plates. There are 10 grading plates for the protan/deutan defects: those who made errors only in the 5 least saturated plates were graded as mild, those who made an error in the next 3 most saturated plates were graded as medium, and patients who made errors in the last 2 plates with the most saturated colors were graded as strong. Both eyes were tested separately and the data of the right eyes were used for statistical analysis. The patients detected to have CVD were also asked if they were previously aware of their abnormal color vision in order to ascertain state of awareness.

SPSS 21.0 software for Windows (SPSS, Inc., Chicago, IL, USA) was used for statistical analyses. The Shapiro-Wilk test was used for testing the normality of each variable. Descriptive statistics were expressed as frequency and percentage for categorical variables whereas quantitative data were expressed as mean±standard deviation for normally distributed variables and median (minimum-maximum) for non-normally distributed data. Chi-square test was used for comparison of variables. Pearson's correlation coefficient was used to determine the correlation between two quantitative variables. $P<0.05$ was considered statistically significant.

RESULTS

The mean age of 2211 subjects [993 (44.9%) males, 1218 (55.1%) females] was 29.7±10.4 (15-45) years. Of these, 63 (2.8%) were diagnosed to have congenital CVD. Abnormal color vision was encountered in 59 out of 993 males (5.9%) and 4 out of 1218 females (0.3%) ($p<0.001$).

Congenital CVD cases were deutan in 47 (74.6%), protan in 11 (17.5%) and unclassified in 5 (7.9%) subjects. All 4 females with abnormal color vision were deutan. None of the subjects in our study made errors in tritan plates. Five (7.9%) of the CVD subjects were classified as having mild, 21 (33.4%) having medium and 37 (58.7%) having strong color deficiency. Severity of ab-

normal color vision was similar in both sexes (p=0.425). (Table 1)

Out of the 6 symbols to be recognized in the protan-deutan screening plates, the mean number of errors made was 4.8±0.9.[2-6] Out of the 18 symbols to be recognized in the protan-deutan diagnostic plates, the mean number of errors made was 7.7±3.6.[2-15] The number of errors made in screening and diagnostic plates were positively correlated with severity of the disease (p<0.001, r=0.561 for screening plates; p<0.001, r=0.770 for diagnostic plates).

In our study 19 (30.2%) subjects were previously unaware of their abnormal color vision. The awareness of abnormal color vision was significantly associated with male gender (p=0.043) and increased severity of the disease (p=0.039). The mean age of subjects who were aware of abnormal color vision was 30.4±9.5 years, whereas the mean age of the subjects who were unaware of the condition was 22.0±9.0 years, the difference being statistically insignificant (p=0.184) (Table 2) .

TABLE 2: State of awareness of patients about their abnormal colour vision.

		Aware of CVD (n=44)	Unaware of CVD (n=19)	p*
Gender	Male	43 (72.9%)	16 (27.1%)	
	Female	1 (25.0%)	3 (75.0%)	**0.043****
Type of CVD	Protan	8 (72.7%)	3 (27.3%)	
	Deutan	33 (70.2%)	14 (29.8%)	0.871
	Unclassified	3 (60.0%)	2 (40.0%)	
Severity of CVD	Mild	1 (20.0%)	4 (80.0%)	
	Medium	16 (76.2%)	5 (23.8%)	**0.039****
	Strong	27 (73.0%)	10 (27.0%)	

Results are denoted as 'number (percent)' of subjects, * Chi-square test, ** p<0.005 statistically significant, CVD: Color vision deficiency.

DISCUSSION

An ideal color vision test should accurately detect, categorize and grade severity of CVD. There are many tests for assessing color vision. Some of them, such as the 'gold-standard' anomaloscope and Farnsworth-Munsell 100-Hue test, are complicated and time consuming to be clinically practical.[5] The most widely used tests are pseudoisochromatic plates. The widely used Ishihara test is a simple and rapidly performed test, however, it only allows identification of red-green defects, but does not test blue CVD.[9] One other advantage of HRR to Ishihara is the presence of symbols instead of numbers. So, the risk of memorizing the answers to enable them to pass the test is kept minimal. It can also be performed upside down to confound those who are clever enough to memorize the answers. Another advantage of HRR plates is its ease for testing small children who can name geometric shapes before they can read Ishihara numbers. The HRR pseudoisochromatic test is easily administered and scored to accurately assess the type and the severity of the CVD. The HRR 4th edition pseu doisochromatic plates have proved to be superior to the Ishihara plates in detecting congenital dyschromatopsia.[8,10] Cole et al. found a sensitivity of 1.00 and a specificity of 0.975 when the criterion for failing is two or more errors with the screening plates.[10] They stated that those with red-green color vision deficiency were correctly classified as protan or deutan in 86%, unclassified in 11%, and incorrectly classified in 3% and concluded that the test was as good as the Ishihara test for detection of red-green color vision deficiencies, but unlike Ishihara, also has plates for detection of tritan defects. The HRR 4th edition test has also been found to be superior to the Ishihara test in detecting acquired dyschromatopsia due to optic neu-

TABLE 1: Distribution of the type and severity of colour vision deficiency in both sexes.

		Male (n=59)	Female (n=4)	Total (n=63)
Deutan	Mild	3	1	4
	Medium	16	1	17
	Strong	24	2	26
Protan	Mild	1	0	1
	Medium	3	0	3
	Strong	7	0	7
Unclassified	Mild	0	0	0
	Medium	1	0	1
	Strong	4	0	4

Results are denoted as 'number' of subjects.

ropathy.[11] As acquired CVD may be a combination of red, green and blue defects, the HRR test would probably detect more cases when compared to Ishihara test plates.[11]

Cole et al. reported 100 CVD patients tested with HRR 4th edition plates and classified them as having mild deficiency in 31%, medium deficiency in 43%, and strong deficiency in 26%.[10] In preschool boys, most congenital CVD cases were either deutan (51%) or protan (34%). Of them, 32% were classified as mild, 15% as moderate, and 41% as severe.[12] In the literature, large variations are found in type and severity of CVD related to the cross sectioning of the population tested.[12] It is questionable that the subjects in our study do represent a true cross-section of the color deficient population in our country, which creates a major limitation for our study. Congenital CVD is rare among females. The prevalence was reported as 0.35% among 7467 female subjects tested for congenital CVD.[13] In the multi-ethnic pediatric eye disease study, the prevalence of CVD in preschool girls was 0.0% to 0.5% for all ethnicities.[12] In our study, the prevalence was 0.3% among 1218 female subjects tested for congenital CVD. Categorization of severity as medium or strong may depend on a single error being made in the medium or strong groups of diagnostic plates and errors may not have been made in all of the preceding less saturated plates. Total errors in HRR would be a better measure of severity.[10] Nevertheless, total errors made on screening and diagnostic plates were correlated with the severity grading in our study population.

Good visual acuity is needed to perform the test reliably.[14,15] HRR plates are more likely to detect CVD, particularly when BCVA is 20/25 or better.[11] However, McCulley et al. investigated the effect of decrease in visual acuity on clinical color vision testing, and stated that testing with HRR plates is accurate up to logMAR 1.10 (20/252).[14] Nevertheless, the subjects with a BCVA less than 20/20 were excluded from our study. The HRR plates are designed to be given under lighting that is close to illuminant C.[5] The manufacturer recommends an intensity of illumination between 10 and 60 foot-candles or 'Richmond Products Daylight Illuminator'. Although there are some studies stating that lighting is not as critical as is often thought,one important limitation of our study is the illumination.[16,17] All tests were done in the same room under standard illumination conditions (basic daylight fluorescent tubes) but the lighting was not tested for suitability for the manufacturer standards.

Congenital CVD is one of the inherited disorders of the vision. Those with CVD are at a distinct disadvantage when performing certain visual tasks: for this reason, they have traditionally been barred from pursuing certain occupations.[2,5] The high prevalence of congenital CVD necessitates early diagnosis, since these individuals cannot accurately make color discrimination which will impact their future professional performance. However, the subjects with mildly defective red-green color vision may not be aware of it until they are tested. Almost one third of the adults with abnormal color vision do not know they have CVD.[5] This is unfortunate because patients who know they have abnormal color vision are better able to find adaptive strategies and will be able to avoid disappointments in their career choice. As most male subjects undergo color vision testing during medical examinations prior to enlisting for compulsory military service in our country, males are highly aware of congenital CVD. In our study 30.2% of all subjects with abnormal color vision were previously unaware of their condition. Female subjects and those with mild CVD were less aware of their abnormal color vision in our study population.

CONCLUSION

Richmond HRR 4th edition test which was found to be a reliable tool for detection of CVD, revealed a 5.9% frequency of congenital CVD in males and 0.3% in females in a tertiary eye hospital. HRR test may be used to screen, classify and grade severity of CVD, albeit its complexity in interpretation. Approximately one third of the patients with CVD were unaware of their abnormal color vision. Female subjects and patients with mild CVD were more frequently unaware of their color vision problem.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Mehmet Ali Şekeroğlu;* ***Design:*** *Mehmet Ali Şekeroğlu;* ***Control/Supervision:*** *Pelin Yılmazbaş;* ***Data Collection and/or Processing:*** *Mehmet Ali Şekeroğlu, Mert Şimşek;* ***Analysis and/or Interpretation:*** *Mehmet Ali Şekeroğlu, Mustafa Alpaslan Anayol;* ***Literature Review:*** *Mehmet Ali Şekeroğlu, Başak Bostancı, Sibel Doğuizi;* ***Writing the Article:*** *Mehmet Ali Şekeroğlu;* ***Critical Review:*** *Pelin Yılmazbaş;* ***References and Fundings:*** *Başak Bostancı, Sibel Doğuizi;* ***Materials:*** *Mehmet Ali Şekeroğlu, Mert Şimşek.*

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