ORİJİNAL ARAŞTIRMA ORIGINAL RESEARCH

DOI: 10.5336/pediatr.2019-72628

Prevalence and Severity of Color Vision Deficiency Among Turkish Children

Türk Çocuklarında Renkli Görme Bozukluklarının Sıklık ve Ağırlığının Değerlendirilmesi

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ABSTRACT Objective: To determine the prevalence of color vision deficiency, ratio of deutan/protan and the distribution of the severity of color vision deficiency among Turkish children and to evaluate the usability the Color Assessment and Diagnosis (CAD) test in children. **Material and Methods:** A total of 1374 children (627 girls and 747 boys) of age 6-16 years were included in this study. The first 15 plates of the Ishihara test were used to evaluate to screen for color deficiency. Those who made three or more errors had their color vision examined using the CAD test to determine the type and severity of color vision deficiency. The prevalence of color vision deficiency in boys and girls, ratio of deutan and protan deficieny and the distribution of the severity of loss were calculated. The correlations of the CAD test result and number of mistakes on the Ishihara test with age were also evaluated. **Results:** Thirty seven boys (4.95%) and 3 girls (0.47%) made 3 or more errors and were categorized as having color vision deficiency. In total, 32 subjects completed the CAD test, 22 subjects (68.7%) were classified as deutan and 10 (31.2%) as protan with the ratio of 2.2:1. In terms of the CAD based color vision grading system for red-green deficiency 3 subjects (9.3%) were classed as color vision (CV) category 3, 5 subjects (15.6%) as CV category 4 and 24 subjects (75%) as CV category 5. There was no significant correlation between the CAD test result and number of mistakes on the Ishihara test with age (r=-0.075, p=0.684 and r=-0.191, p=0.295 respectively). **Conclusion:** The results reveal severe loss of red-green color vision in 75% of the children with color vision deficiency. The study also demonstrates that the CAD test can be used in children as young as six years.

Keywords: Color vision; color vision defects; child; color perception tests; Turkey

ÖZET Amaç: Türk çocuklarında renkli görme bozukluğunun prevalansı, dötan/protan oranı ve ağırlığına göre renkli görme bozukluğunun dağılımının saptanması ve Renk Değerlendirme ve Tanı testinin çocuklarda kullanılabilirliğini değerlendirmektir. **Gereç ve Yöntemler:** Yaşları 6 ile 16 arasında değişen 627'si kız 747'si erkek toplam 1374 çocuk çalışmaya dahil edildi. Renkli görme bozukluğunun taranmasında İshihara testinin ilk 15 plakası kullanıldı. Üç ve üzerinde hata yapanlar renkli görme bozukluğunun tipi ve ağırlığının tespit edilebilmesi için Renk Değerlendirme ve Tanı testi ile değerlendirildi. Kızlarda ve erkeklerdeki renkli görme bozukluğunun prevalansı, dötan/protan oranı ve ağırlığına göre renkli görme bozukluğunun dağılımı hesaplandı. Renk Değerlendirme ve Tanı testinin sonuçları ile İshihara testindeki hata sayısının yaş ile olan korelasyonu da değerlendirildi. **Bulgular:** İshihara testinde 3 ve üzerinde hata yapan 37 erkek (%4,95) ve 3 kız (%0,47) renkli görme bozukluğu olanlar grubunda değerlendirildi. Olgulardan 32 tanesi Renk Değerlendirme ve Tanı testini tamamlayabildi. Bu olgulardan 22 tanesi (%68,7) dötan, 10 tanesi (%31,2) protandı ve dötan/protan oranı 2,2:1 idi. Renk Değerlendirme ve Tanı testinin kırmızı-yeşil renkli görme bozukluğu ağırlık sınıflandırmasına göre olgulardan 3'ü (%9,3) renkli görme kategori 3, 5'i (%15,6) kategori 4 ve 24'ü (%75) kategori 5'e dahildi. Renk Değerlendirme ve Tanı testinin sonucu ve İshihara testindeki hata sayısı ile yaş arasında korelasyon tespit edilmedi (r=-0,075, p=0,684 ve r=-0,191, p=0,295 sırasıyla). **Sonuç:** Sonuçlar renkli görme bozukluğu olan çocukların %75'inin ağır kırmızı-yeşil renkli görme bozukluğuna sahip olduğunu göstermektedir. Çalışma aynı zamanda Renk Değerlendirme ve Tanı testi'nin çocuklarda 6 yaşından itibaren kullanılabilir olduğunu göstermektedir.

Anahtar Kelimeler: Renkli görme; renkli görme bozuklukları; çocuk; renk algılama testleri; Türkiye

Congenital color vision deficiency is one of the commonest functional disorders that results in reduced chromatic sensitivity and deviations from normal metamerism. The prevalence of red-green deficiency varies amongst different races and ethnic groups.[1]

Normal human color vision relies on signals derived from three classes of cone photopigments with

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Peer review under responsibility of Turkiye Klinikleri Journal of Pediatrics.

Received: 29 Nov 2019 ***Received in revised form:*** 19 Mar 2020 ***Accepted:*** 28 Apr 2020 ***Available online:*** 07 May 2020

well defined peak spectral responsivities in the short (S), middle (M) and long (L) wavelength regions of the visible spectrum. The corresponding cone photoreceptors are often decsribed as S-, M- and L-cones. Genetic mutations in cone pigment genes can shift the peak spectral responsivities of the M- and L-cones and this in turn results in differences in red-green color vision. X-linked recessive red-green color vision deficiency arises from mutation in red and/or green cone photopigments. When the M-cone pigment is absent and replaced by a variant L-cone pigment the subject is described as deutan. The presence of a normal M-cone and a variant M-cone pigment results in red-green defciency described as protan. Both classes result in either reduced or absent red-green chromatic sensivity.[2] In addition to reduced red-green color discrimination sensitivity, protan subjects also have reduced brightness sensitivity when presented with long wavelength lights such as ‘red’ traffic lights.[1]

People with color vision deficiency have difficulty in differentiating small color differences and can also exhibit different forms of metamerism which can cause color naming problems. Pilots, seafarers, train drivers, air traffic controllers, police officers and firefighters often require good color vision to ensure safe performance in color coded tasks. On the other hand color is used as teaching tool in schools. Children with color vision deficiency have problem in learning color names and this can often make children feel different and even inadequate.[3-5] Many children remain largely unaware of their color vision status either because of lack of or inadequate color vision screening. Early diagnosis of the class of color vision deficiency and a reliable indication of the severity of loss can help children to develop appropriate learning methods and can also guide them towards occupational careers where normal color vision is not an essential requirement. The purpose of our study was to investigate whether the severity of color vision loss can be measured in children as young as six years old using the Color Assessment and Diagnosis (CAD) test and to estimate the prevalence of moderate and severe color vision deficiency, ratio of deutan/protan and the distribution of the severity of color vision deficiency amongst Turkish children.

MATERIAL AND METHODS

The present study was approved by the Medical Ethical Committee of Istanbul Medipol University (date: 23/05/2019, number: 10840098-604.01.01-E.16349) and the work was carried out in accordance with the tenets in the Declaration of Helsinki. The parents of each child investigated provided written informed consent.

A total of 1374 children, aged 6-16 years, who attended the Ophthalmology Department at the Istanbul Medipol University were included in the study. Children with known or current evidence of ocular pathology (other than refractive errors), with history of long term use of medication, previous ocular surgery and those with chronic systemic diseases were excluded from the study. None of the subjects reported or complained about their color vision status at the time of admission to the hospital.

All children underwent a detailed ophthalmologic examination including a visual acuity testing with Snellen charts, cover test, intraocular pressure measurement, anterior segment and dilated fundus examination. Refractive error was estimated using cycloplegic refraction.

Color vision status was evaluated using the Ishihara test (24 plates edition). Refractive error of each subject was corrected and the test was performed under adequate daylight condition by an ophthalmologist. The plates were held at a distance of 50 cm and 5 s was given to each child to identify the numbers on each plate. The initial 15 numerical plates of the Ishihara 24-plate book were used to screen children and number of correct answers for each child was noted. Children who answered at least 13 out of 15 plates correctly were accepted as to have normal color vision. Children with 3 or more false answers were evaluated as defect in color vision and underwent the CAD test to determine the type and severity of color vision deficiency.

THE COLOR ASSESSMENT AND DIAGNOSIS (CAD) TEST

The CAD test (City Occupational Ltd, London, UK) measures the severity of red-green and yellow-blue color vision loss according to red-green and yellow-blue thresholds which are expressed in CAD units and diagnoses accurately the subject's class of color vision.[6] The CAD test was designed to isolate the use of color signals by burying the isoluminant color signal in dynamic luminance contrast noise to mask the detection of any residual luminance contrast signals.[7] The backgroud luminance is photopic, but the test is performed under low mesopic lighting with the eye of subject ~ 1.4 m away from the visual display. During the test, patients are instructed to keep their fixation around the centre of the square by looking at the centre black dot and to report the direction of colored target moving diagonally across a central square by pressing one of the four buttons on a bespoke keypad (top-left, top-right, bottom-left or bottom-right). The test was performed as a three-step procedure. First the learning test was adminsitred to teach the subject the experimental procedure and the use of the four response buttons. The 'definitive' CAD test was then used to measure the yellow-blue and then the red-green color thresholds. The program classifies the type of color vision and quantifies accurately the severity of loss in subjects with either congenital or acquired deficiencies. Typical reports generated by the program at the end of the test are shown in Figure 1.

The measured thresholds were then used to identify severity of loss using the Color Assessment and Diagnosis-based color grading system.[6] The grading system helps to categorize subjects with color vision deficiency according to the requirements of specific occupations. The grading system is summarized in Table 1.

SPSS statistical package for Windows 19 (SPSS for Windows, Chicago, IL, USA) was used for statistical analysis. The prevalence of color vision deficiency in boys and girls, ratio of deutan and protan deficieny and the distribution of the severity of loss were calculated. Kolmogorov-Smirnov test was used to control the normality between samples. Because the data are not normally distributed, the correlations of the CAD test result and number of mistakes on the Ishihara test with age were assessed with Spearman's correlation coefficient. The p value less than 0.05 was accepted as significant.

RESULTS

A total of 1374 children (627 girls and 747 boys) with mean age of 10.41 (range 6-16 years) ±2.92 years were included in the study. All subjects were of Caucasian ethnicity. Of the children, 1334 (97.09%) were able to identify at least 13 of 15 plates correctly and classified as to have normal color vision. A total of 37 boys (4.95%) and 3 girls (0.47%) had 3 or more mistakes and categorized as to have color vision deficiency. Except for one child, none of the subjects (97.5%) were aware of their color vision deficiency. Mean number of mistakes on the Ishihara test was 10.67±2.97. Figure 2 shows the percentage of errors for each plate of the Ishihara test. The CAD test administered to each of the 40 subjects identified as color deficient to evaluate the type and severity of color vision deficiency. Seven of these subjects failed to keep their appointments. With the exception of one subject, all children were cooperative and carried out

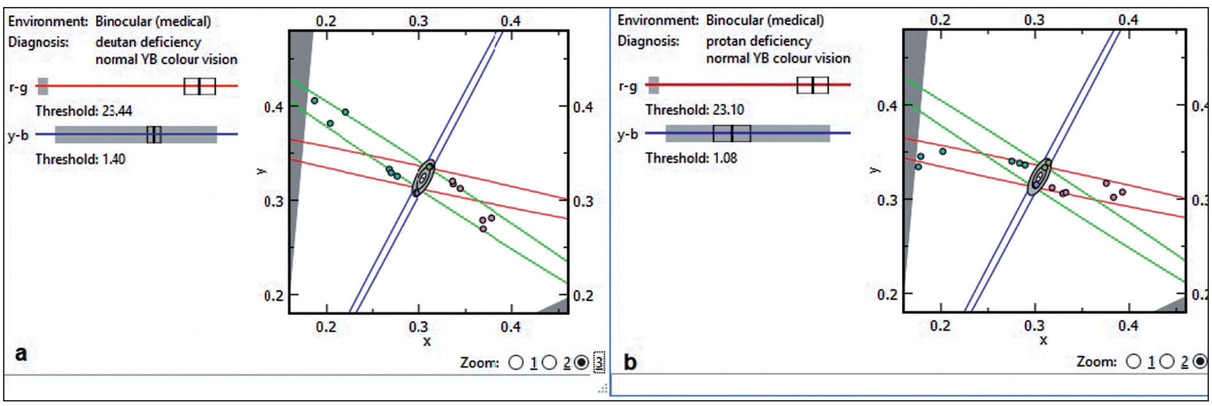

FIGURE 1: Color reports of deutan (a) and protan (b) subject generated at the end of the Color Assessment and Diagnosis test.

TABLE 1: Color vision grading system.[6]

Category	Name	Description
CV 0	'Supernormal' CV	normal trichromats with RG CAD thresholds below the mean value for the corresponding age
CV 1	'Normal' trichromatic CV	RG CAD thresholds below the upper normal limits that have been established for healthy aging
CV 2	'Functionally normal' CV	CAD threshold ≤2.35 CAD units
CV 3	'Safe' CV	2.35<RG thresholds ≤4 CAD units
CV 4	'Poor' RG CV	4<RG thresholds ≤12 CAD units
CV 5	'Severe' RG color deficiency	RG thresholds >12 CAD units

CV: Color Vision, RG: Red-Green, CAD: Color Assessment and Diagnosis.

the full the CAD test. Mean age of the children who completed the CAD test was 10.3 (range 6-16) ± 2.8 years. They had no problems in understanding the test procedure. In total, 32 children completed the CAD test and 22 of them (68.7%) were classified as deutan and 10 of them (31.2%) as protan (a ratio of 2.2 to 1).

When evaluated according to the color vision grading system, 3 subjects (9.3%) were classed as color vision(CV) category 3, 5 subjects (15.6%) as CV category 4 and 24 subjects (75%) as CV category 5. The distribution of color vision deficiency subjects according to type and category in color vision grading system for each gender is summarized in Table 2.

There was no significant correlation between the CAD test result and number of mistakes on the Ishihara test with age (r=-0.075, p=0.684 and r=-0.191, p=0.295 respectively).

DISCUSSION

In the present study, prevalence of color vision deficiency was 4.9 % for boys and 0.4 % for girls. Also, the ratio of deutans to protans was 2.2 to 1 (22/10) and 75% of subjects were classed as CV category 5 which means severe loss of red-green color vision.

Red-green color vision deficiency has X-linked recessive inheritance and so is much more common in males compared to females worldwide. Depending on the presence of variant red-green color pigments encoding genes or the complete absence of one class of pigment genes, the severity of color vision deficiency varies from close to normal color vision to total lack of red-green color discrimination. Prevalence of color vision deficiency shows variation due to difference in ethnicity, geographical area, but can

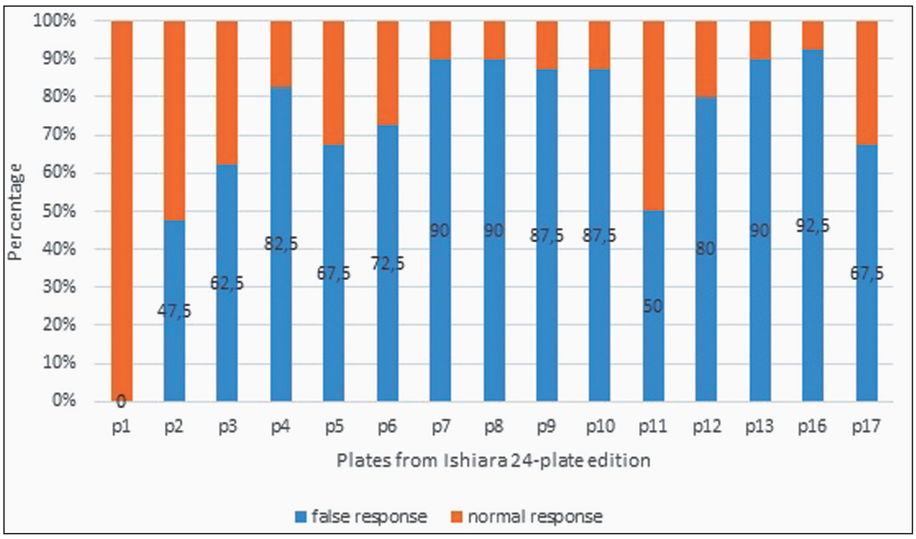

FIGURE 2: Responses of children with color vision deficiency in Ishihara test. Plate 1 was introductory plate, plates 2-7 were transformation plates, plates 8-13 were vanishing plates, and plates 16-17 were classification plates.

TABLE 2: Distribution of the color vision deficiency subjects according to type and category in color vision grading system for each gender.

	Number (prevalence rate, %)		
	Total (n=1374)	Male (n=747)	Female (n=627)
No. of subjects with color vision deficiency	40 (2.9%)	37 (4.9%)	3 (0.4%)
No. of subject evaluated With CAD test	32 (2.3%)	30 (4.0%)	2 (0.3%)
Type			
Deutan	22 (1.6 %)	22 (2.9%)	0 (0%)
Protan	10 (0.7%)	8 (1.0%)	2 (0.3%)
Category			
CV 3	3 (0.2%)	3 (0.4%)	0
CV 4	5 (0.3%)	5 (0.6%)	0
CV 5	24 (1.7%)	22 (2.9%)	2 (0.3%)

No: Number, CAD: Color Assessment and Diagnosis, CV 3: Category 3 in color vision grading system, CV4: Category 4 in color vision grading system, CV5: Category 5 in color vision grading system.

also reflect the limitations of the diagnostic tests employed. It has been known that color vision deficiency affects 8% of males and 0.4 % of females in Caucasian population.[1,8] The prevalence of deuteranomaly was predicted as 5 % and prevalences of protanomaly, protanopia and deutranopia were 1% for each.[8] Prevalence studies with children from different countries show different results in the literature. In a study from Turkey, the prevalence of color vision deficiency was found to be 7.3% in young males which is higher than our result.[9] Our findings may underestimate somewhat the prevelance of color vision deficiency in male subjects simply because it is well established that the Ishihara 24 plates tests with 2 or fewer errors as a pass on the first 15 plates can also pass ~ 6% of deutans and ~ 1.4% of protans.[6] If one applies this correction, the percentage of color vision deficiency boys is our study is expected to be just over 5%. The common practice is to accept two errors as a pass to ensure that almost all normal trichromats pass the test. Other studies in children from Tahran and Jourdan found that 8.1% and 8.7% of males had color vision deficiency, respectively.[10,11] Prevalence of color vision deficiency was 5.6% for non-Hispanic White boys in Multi-ethnic Pediatric Eye Disease Study and 5.3% for Singaporean boys in the study of Chia et al.[12,13] These results are very similar to what we found in our study. Prevalence of color vision deficiency in Arab boys was found to be only 2.9% and only marginally larger at 3.6% in Ethiopian boys.[14,15] Prevalence for girls was between 0-0.6% and did not change significantly between studies.[10-13,15] With the exception of the study of Citirik et al., deutan deficiency was more common than protan with ratios between 1.3 to 3.9.[9,10-15] Deutan to protan ratio was 0.5 and clearly unexpected in the study of Citirik et al.[9] The deutan to protan ratio was 2.2 in agreement with data from other studies. Although these ehnic differences are likely to be real, these estimates may have been affected by the poor accuracy of the tests employed.

Ishihara test is the most commonly used screening test because of its high sensitivity and specificity in detecting color vision deficiency. Further, it is easy to use and widely available.[16] But Ishihara test has some disadvantages. It is difficult to use the test to achieve both high sensitivity and specificity and the percentage of color vision deficiency subjects tends to be underestimated when 2 or even more errors are allowed as a pass in order to pass all normal trichromats. Another disadvantage is that it does not test for yellow-blue deficiency and cannot be used to estimate reliably the severity of color vision loss. The classification of protan and deutan subjects is also poor with many subjects ending up either misclassifed or indeterminate.[16] Knowledge of the severity of color vision loss has become important since recent studies have shown that those with mild loss of red-green color can work in some color demanding occupations and can perform color-related tasks as well as normal trichromats.[17] For example, Class 1 medical certificate requirements for pilots are determined by the civil aviation authority in Turkey. According to this regulation, candidates are not allowed to get a class 1 pilot certificate at values above 6 CAD units in deutans and 12 CAD units in protans that means CV category 4 and 5 are not allowed.[18]

According to the maritime medical requirements regulation, candidates who make mistake in Ishihara are asked to evaluate with Anomaloscope or Lantern tests.[19] Anomaloscope test is the gold standart for colour vision deficiency but it is difficult to perform especialy for children and experienced technician is required.[20] Because of the presence of different kinds of lantern tests with variable size and brightness and pass / fail criteria are different for each country, its usage is limited in the world.[21] Thanks to its easy application in children, the CAD test can also predict colour vision deficiency level according to maritime medical requirements. Raising awareness of young people on this issue before university choices is important for their career planning.

To the best of our knowledge, this study is the first to atempt to quantify accurately the severity of color vision deficiency for children.

Colors are used to enhance teaching and children with color vision deficiency will not benefit from the use of such color coded material. There is little doubt that when unaware of their color vision deficiency, school children with color vision deficiency can be disadvantaged in education when compared to those with normal color vision.[3-5] If children are aware of their color vision deficit, they can learn and develop effective adaptive behaviours, such as using enhanced color saturation or other spatial cues to deal with any potential limitations. Career choice advice can also be made more specific. These are the main reasons why accurate screening for color vision deficiency and assessment of the severity of color vision loss should be carried out early during educational development. Color vision test is not carried out routinely as part of normal ophthalmic examination and as a result the majority of color vision deficiency subjects remain undetected. In the present study only one child with color vision deficiency was aware of his condition. Although the Ishihara test does not have high sensitivity and specificity, it is nevertheless easy to administer in children, as has been demonstrated in our study. Equally important, the CAD test can also be administered in those children who fail Ishihara test in order to determine the class of color deficiency and to estimate the severity of loss. We didn't find a correlation between the CAD test result and number of mistakes on the Ishihara test with age. The result showed the reliability of the mentioned tests in young children.

One of the limitations of this study was that our sample was not population-based and included children who visited the hospital for other reasons. Ideally, all children should have examined with the CAD test, but the time and effort needed made this option impractical. Despite these limitations, this study gives valuable information about prevalence and classification of color vision deficiency in children and may well be the first study to attempt to assess accurately the severity of red-green color vision loss in children with color vision deficiency.

CONCLUSION

In conclusion, color vision deficiency is a common disorder of vision with the prevalence in Turkey of just over 5% for boys and 0.4 % for girls. The children were unaware of their color vision deficiency. Given the potential impact on learning and academic achievement, color vision assessment in all children should ideally be carried out at the time of their first ophthalmologic examination. This would make it possible to advise those identified with color vision deficiency on career choice and best strategies to cope with their deficiency.

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

All authors contributed equally while this study preparing.

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