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Contrast sensitivity of patients with congenital color vision deficiency

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Abstract
Purpose To investigate the static and dynamic contrast sensitivity (CS) of patients with congenital red-green color vision deficiency (CVD) and to compare these values with those of healthy control subjects.
Methods The study included 25 subjects with congenital CVD (10 with strong protan defect and 15 with strong deutan defect) and 20 age- and gender-matched healthy subjects. Following detailed ophthalmological examination, monocular static and dynamic CS measurements were taken with the Monpack3 device (Metrovision, Perenchies, France) on all subjects. The data from the right eyes of all the subjects were used for statistical analysis.
Results The mean age of the groups was similar (deutan group: 25.3 ± 11.3 years, protan group: 27.1 ± 12.2 years, control group: 26.7 ± 8.8 years, $p = 0.98$). The mean static and dynamic CS values in the protan and deutan groups were higher compared to those of the healthy control subjects, but not at a statistically significant level (all $p > 0.017$).
Conclusion The static and dynamic CS values of patients with congenital red-green CVD were similar to those of healthy control subjects.

Keywords Color vision deficiency · Static contrast sensitivity · Dynamic contrast sensitivity · Color blindness

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Introduction

Congenital color vision deficiency (CVD) is seen in 8% of males and 0.5% of females. Signals related to six complementary color tones (red-green, blue-yellow and black-white) come from three different cones, providing normal color vision. All three types of cone photoreceptors must be healthy for normal color vision. Loss of function in any type of cone photopigment causes congenital CVD [1]. Blue congenital CVD involving the small (S) wavelength-sensitive cone is extremely rare and inherited in an autosomal dominant fashion [2]. The most common form of congenital CVD is associated with the inability to discriminate red-green and is inherited as X-linked recessive [3]. It is characterized by the absence of either the long (L) or medium (M) wavelength-sensitive cone functions.

According to recent studies, congenital CVD can alter some visual functions beyond color vision [4, 5]. Jagle et al. [4] reported that visual acuity (VA) is better

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than normal in some congenital CVD cases according to their genotypes. This was reported to be because of a decrease in chromatic noise, which in turn decreases retinal image defocus and blurring [4]. Normally, the difference between L and M cone peak absorbance is nearly 30 nm, and this small difference causes 0.20-diopter shift in focus [6]. Sharpe et al. [5] revealed that dichromats are better than normal at tasks involving high temporal frequency stimuli. In summary, some authors have argued that in CVD, some visual functions are better than normal.

The aim of this study was to investigate static and dynamic contrast sensitivity (CS) in subjects with congenital red-green CVD and to compare these values with those of age- and gender-matched healthy control subjects.

Methods

This prospective study was carried out at the Ophthalmology Clinic of Ulucanlar Eye Research and Training Hospital with approval granted by the local research ethics committee. The aim and method of the study were explained to patients in detail, and informed consent was obtained from each participant. All procedures were performed in accordance with the ethical standards of the Declaration of Helsinki for human subjects.

Study subjects

This cross-sectional study included 25 young male subjects (16–39 years) with congenital red-green CVD (10 with protan defect and 15 with deutan defect) who were admitted to our clinic in 2016 for routine eye examination. A control group was formed of 20 age-matched healthy males (17–36 years). Subjects with a history of ocular surgery, presence of ocular disease such as strabismus, nystagmus, glaucoma, retinal pathology, a systemic disease such as diabetes mellitus and hypertension or drug use such as digoxin for cardiac insufficiency and erectile dysfunction medications were excluded from the study. All the subjects underwent a standard ophthalmic examination including slit-lamp examination, tonometry and dilated fundus examination, and all subjects were screened for glaucoma. All subjects had 20/20 best-corrected VA without any refractive error. (Refraction error was investigated without cycloplegia.) Only the data of the right eyes of the subjects were included for statistical analysis.

Color vision

The Hardy–Rand–Rittler (HRR) 4th edition test plates (Richmond Products Inc, Albuquerque, New Mexico, USA) were used for description of the presence, type and extent of congenital CVD. Since there can be different types of CVD in each eye of a patient, both eyes were tested separately. The test was performed in the same room under standard illumination conditions (basic daylight fluorescent tubes). The HRR test is composed of 24 test plates each displaying either one or two geometric symbols (except plate 4), which can be a cross, a circle or a triangle. First, four non-scored demonstration plates can be seen by all observers. Of the next six screening plates, two are for tritan defect and four are for protan–deutan defects. These are followed by 14 diagnostic plates designed to differentiate the type and extent of congenital protan–deutan defects. The plates were held approximately 60 cm away from the patient at a perpendicular angle to the line of sight. All the subjects were asked three standard questions of "how many colored symbols do you see here?", "What are they?" and "Where are they?". They were given 3 s to respond to each plate.

Contrast sensitivity

CS measurement was taken at 200 cm distance, under 80 cd/m^2 standard photopic conditions using the vertical sinusoidal grating method with the Monpack3 device (Metrovision, Perenchies, France) at low (0.8 and 1.6 cpd), medium (3.2 and 6.4 cpd) and high (12.8 and 25.6 cpd) spatial frequencies. The test was performed by using the static and dynamic test programs of an optoelectronic stimulator, as monocular. The increase in contrast on the stimulator was applied progressively in steps of 0.25 dB of contrast. Each measure was repeated several times to evaluate the reproducibility of the responses. The final graph was recorded to indicate all the responses obtained for each spatial frequency in cpd and at different contrasts in dB (Fig. 1). For statistical analysis, the measurements of CS were converted to logarithmic values as logCS.

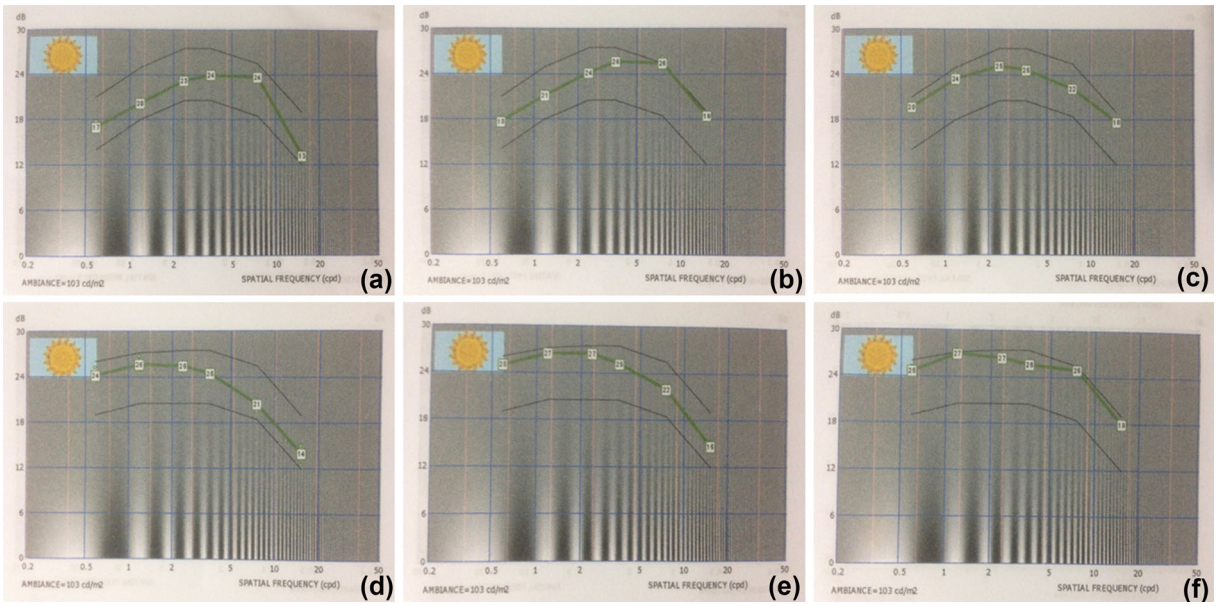

Fig. 1 The final graph which is recorded to indicate all the responses obtained for each spatial frequency in cpd and at different contrasts in dB. **a** Static contrast sensitivity measurement of a patient from deutan group, **b** static contrast sensitivity measurement of a patient from protan group, **c** static contrast sensitivity measurement of a healthy subject from control group, **d** dynamic contrast sensitivity measurement of a patient from deutan group, **e** dynamic contrast sensitivity measurement of a patient from protan group, **f** dynamic contrast sensitivity measurement of a healthy subject from control group

Statistical analysis

Statistical analyses were applied using Statistical Package for the Social Sciences (SPSS) version 22.0 software (IBM Corp, New York, USA). The conformity of numerical data to normal distribution was evaluated using the Kolmogorov–Smirnov test. The nonparametric Kruskal–Wallis test was used to compare three independent samples because the numerical data did not conform to normal distribution. After Bonferroni correction, a p value of ≤ 0.017 was considered statistically significant. Power and Sample Size (PASS) calculation software version 11 was used to make the sample size and power calculations.

Results

The data from the right eyes of 45 young male Caucasian subjects (15 deutan, 10 protan, 20 control subjects) were evaluated in this study. All the patient group subjects were found to have strong congenital red-green CVD, according to the HRR test. There was no statistically significant difference between the groups in terms of mean age (deutan group: 25.3 ± 11.3 years, protan group: 27.1 ± 12.2 years, control group: 26.7 ± 8.8 years, $p = 0.98$).

The monocular static and dynamic CS values of the protan and deutan groups were slightly higher than those of the control group in all spatial frequencies. However, after the analysis with the Kruskal–Wallis test, there was no statistically significant difference between the groups (all $p > 0.017$). We found that we needed to enroll at least 10 eyes for each group in the study as a result of a priori power analysis via PASS 11. In our study, we enrolled 15 eyes for deutan group, 10 eyes for protan group and 20 eyes for control group and found the power of our study accordingly as 84.2%. The monocular static and dynamic CS values of all the groups are shown in detail and compared with each other in Table 1.

Discussion

Congenital CVD is an inherited disorder which causes some disadvantages when performing certain visual tasks. However, some previous studies have shown that some visual functions including CS and VA were better than normal in congenital CVD [4–7]. The aim

Table 1 Measurements of monocular static and dynamic contrast sensitivity

	Static contrast sensitivity				Dynamic contrast sensitivity			
	Deutan	Protan	Control	*p* value	Deutan	Protan	Control	*p* value
0.8 cpd	1.262 ± 0.05 (1.18–1.30)	1.261 ± 0.05 (1.18–1.30)	1.248 ± 0.05 (1.15–1.34)	0.54	1.373 ± 0.03 (1.28–1.41)	1.375 ± 0.04 (1.28–1.41)	1.363 ± 0.04 (1.28–1.40)	0.60
1.6 cpd	1.332 ± 0.04 (1.23–1.40)	1.329 ± 0.05 (1.23–1.36)	1.315 ± 0.04 (1.23–1.36)	0.59	1.415 ± 0.02 (1.38–1.45)	1.400 ± 0.03 (1.34–1.43)	1.398 ± 0.04 (1.32–1.45)	0.42
3.2 cpd	1.362 ± 0.03 (1.30–1.41)	1.357 ± 0.05 (1.23–1.40)	1.343 ± 0.04 (1.26–1.40)	0.47	1.407 ± 0.02 (1.34–1.43)	1.405 ± 0.03 (1.34–1.43)	1.394 ± 0.04 (1.30–1.43)	0.84
6.4 cpd	1.363 ± 0.04 (1.30–1.41)	1.371 ± 0.04 (1.30–1.41)	1.348 ± 0.05 (1.20–1.41)	0.64	1.398 ± 0.03 (1.34–1.43)	1.391 ± 0.04 (1.32–1.43)	1.385 ± 0.05 (1.30–1.43)	0.82
12.8 cpd	1.333 ± 0.05 (1.23–1.41)	1.315 ± 0.07 (1.23–1.41)	1.243 ± 0.24 (0.48–1.38)	0.36	1.352 ± 0.08 (1.15–1.43)	1.332 ± 0.07 (1.23–1.43)	1.341 ± 0.06 (1.20–1.41)	0.66
25.6 cpd	1.106 ± 0.17 (0.70–1.26)	1.033 ± 0.19 (0.70–1.28)	1.092 ± 0.21 (0.60–1.26)	0.70	1.106 ± 1.17 (0.70–1.26)	1.033 ± 0.20 (0.70–1.28)	1.091 ± 0.21 (0.60–1.26)	0.70

cpd cycles per degree

$p < 0.017$ was denoted as statistical significance

of the present study was to investigate whether the CS values were altered or not. The results of the study showed a positive change in static and dynamic CS measurements in congenital red-green CVD, but these changes were not statistically significant.

Janaky et al. [7] argued that both protan and deutan defects exhibit enhanced static and dynamic CS over a wide range of spatial frequencies, and this enhancement was statistically significant at some spatial frequencies. However, there are many methodological differences between that study and the current study. Janaky et al. separated congenital CVD subjects as dichromats or anomalous trichromats by anomaloscopy and enrolled only dichromats. In the current study, subjects were separated using HRR and this test described patients according to the extent of the deficiency as mild, medium, or strong and only patients with strong congenital CVD were included in the study. Currently, there are no reports that being dichromat and strong deutan/protan defects are completely equal. Another important point is the technical differences in the measurement of CS, such as different luminance conditions, reference spatial frequencies, test distance, etc. In statistical analyses, CS values were used as logCS in the current study. Using logarithmic values in VA and CS is a common convention for standardization, which also affects the results of statistical analyses [8].

There are various factors that could affect CS values. The current study investigated the effect of congenital CVD on CS within a homogenous group of subjects. In this study, all were young male Caucasian patients and were age-matched between groups. Age is one of the most important factors which can affect CS ability. A decrease in lutein and zeaxanthin pigments in macula, age-related changes in crystalline lens and senile miosis are considered as probable reasons [9]. Woo et al. [10, 11] proposed that the CS ability is not completely the same in all ethnicities, because the difference in ethnicity determines macular pigment densities and this can affect CS. The current study included a large and homogeneous sample, all of which had a strong protan–deutan defect according to HRR, which can be considered to have increased the validity of this study.

There are some limitations to this study. First, the subjects were not separated in terms of genotype. Congenital red-green CVD is associated with disturbances in the X-linked opsin gene array, which contains the genes for encoding the L and M cone pigments. Forty-four percentage of patients are true reduction dichromats, with only one gene in the array, which encodes for either the single-gene protanopes or single-gene deuteranopes. Fifty-six percentage of patients have at least two genes in the array, all of which encode for either the multi-gene protanopes or multi-gene deuteranopes [5]. Jagle et al. [4] reported

that VA in patients with congenital CVD was similar to that of normal subjects, but when the results were investigated in terms of patients' genotype, the multigene dichromats were found to be better than normal. The second important limitation of this study is that the dominant eyes of subjects were not detected and only the right eyes were included for the statistical analysis. Some studies have argued that the dominant eye shows functional laterality due to dominance of one of the cerebral hemispheres. There have been reports that the dominant eye is superior to the non-dominant eye in VA and CS [12, 13]. The importance of this study is to clearly show that CS is not increased in congenital red-green CVD. The current study differs from other similar studies in terms of methodological improvements and the evaluation of a large homogeneous sample with congenital red-green CVD.

In conclusion, monocular static and dynamic CS slightly increase in congenital red-green CVD, but this difference is not statistically significant.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

References

1. Simunovic MP (2010) Color vision deficiency. Eye (Lond) 24:747–755
2. Foote KG, Neitz M, Neitz J (2014) Comparison of the Richmond HRR 4th edition and Farsworth Munsell 100-Hue test for quantitative assessment of tritan color deficiencies. J Opt Soc Am A Opt Image Sci Vis. 31:186–188
3. Ceyhan D, Yasar T (2011) Color vision and health committee procedures. Turk J Ophthalmol 41:35–42
4. Jägle H, de Luca E, Serey L, Bach M, Sharpe LT (2006) Visual acuity and X-linked color blindness. Graefes Arch Clin Exp Ophthalmol 244:447–453
5. Sharpe LT, de Luca E, Hansen T, Jägle H, Gegenfurtner KR (2006) Advantages and disadvantages of human dichromacy. J Vis 6:213–223
6. Schlaer S (1937) The relation between visual acuity and illumination. J Gen Physiol 21:165–188
7. Janáky M, Borbély J, Benedek G, Kocsis BP, Braunitzer G (2014) Achromatic luminance contrast sensitivity in X-linked color-deficient observers: an addition to the debate. Vis Neurosci 3:99–103
8. West SK, Rubin GS, Broman AT, Munoz B, Bandeen-Roche K, Turano K (2002) How does visual impairment affect performance on tasks of everyday life? The SEE project. Salisbury eye evaluation. Arch Ophthalmol 120:774–780
9. Koçtekin B, Gündoğan NÜ, Altıntaş AG, Yazıcı AC (2013) Relation of eye dominancy with color vision discrimination performance ability in normal subjects. Int J Ophthalmol 6:733–738
10. Woo GC, Lee MH (2002) Are ethnic differences in the F-M 100 scores related to macular pigmentation? Clin Exp Optom 85:372–377
11. Kaimbo DW, Spileers W, Missotten L (1994) The Farnsworth-Munsell 100 Hue test in the Bantu population. Preliminary results. J Fr Ophthalmol 17:664–667
12. Gündoğan NÜ, Şahin FI, Gedik Ş, Pekdogan Ö, Akova Y (2007) Color vision deficiency of three sisters in the same family. Int J Ophthalmol. 7:909–913
13. McManus IC, Porac C, Bryden MP, Boucher R (1999) Eye-dominance, writing hand, and throwing hand. Laterality 4:173–192