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Efficacy of ChromaGen lenses in enhancing color perception in color vision deficiency: a critical evaluation

Mehmet Sait Günerigök[1], Özgür Bülent Timuçin[2], Ahmet Tuncer Özmen[3]

[1]*Department of Opthalmology, Medikalpark Bursa Hospital, Bursa, Turkiye*
[2]*Department of Opthalmology, Van Training and Research Hospital, Health Sciences University, Van, Turkiye*
[3]*Department of Ophthalmology, Faculty of Medicine, Uludağ University, Bursa, Turkiye*

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Corresponding Author: Özgür Bülent Timuçin, bulenttimucin@gmail.com

ABSTRACT

Aims: Despite advancements in color vision correction, evidence supporting the efficacy of ChromaGen haploscopic filter systems in improving color perception remains limited. This study primarily investigates the performance of ChromaGen lenses (CL).

Methods: The study included 27 volunteers diagnosed with color vision deficiency (CVD). An anomaloscope was used to detect color vision defects. Participants underwent color vision tests (Ishihara and panel D15) both with and without CL. The results were statistically analyzed.

Results: All participants were male, aged 21 to 57. Among them, 12 (44%) had protan defect (10 protanopes, 2 protanomalies) and 15 (56%) had deutan defect (12 deuteranopes, 3 deuteranomalies). Without CL, protan defect participants read 2.0±1.0 pages on the Ishihara test, while deutan defect participants read 3.0±1.9 pages. With CL, protan defect participants read 4.5±2.2 pages and deutan defect participants read 14.2±0.9 pages, showing statistically significant improvement ($p<0.05$). The difference between protan and deutan groups was also statistically significant ($p<0.05$). In the panel D15 test, without the use of CL 81% of individuals with protanopia and deuteranopia made significant errors, whereas participants with protanomaly and deuteranomaly performed well. No significant improvement was noted with CL in the panel D15 results. Twenty-three participants preferred magenta and four preferred pink CL. Fifteen participants expressed interest in using CL solely to pass the Ishihara test.

Conclusion: This study concludes that commercially available ChromaGen filters do not provide clinically significant evidence of improved subjective color perception. Therefore, recommending these devices to the CVD population for color perception may not be highly beneficial. However, ChromaGen lenses may be used by some CVD patients to pass the Ishihara test.

Keywords: Color vision deficiency, ChromaGen lenses, anomaloscope, Ishihara test, panel D15 test, color vision correction, haploscopic filter systems

INTRODUCTION

Color vision deficiency (CVD) presents significant challenges in daily life particularly affecting tasks that require accurate color discrimination. Patients with CVD encounter important vocational limitations in various industries. Unfortunately, the options available to assist individuals with CVD are limited. Despite several recent innovations,[1-6] there remains a notable lack of clinical evaluations and interventional studies assessing the efficacy of these devices. Existing research is sparse and often confined to case reports, highlighting a critical gap in our understanding of their potential benefits.[7]

ChromaGen lenses (Chromagen Ltd, Chester, UK) represent a recent advancement in contact lens technology. These lenses have shown promise in enhancing color perception for individuals with red-green color vision impairments.[1,8] This study aims to explore the effectiveness of ChromaGen lenses (CL) particularly in improving color vision scores and subjective visual experiences to provide deeper insights into their role as a viable solution for managing CVD. Through a comprehensive review of current literature and clinical observations we seek to establish a foundational understanding of how CL can be integrated into therapeutic practices for patients with color vision deficiency.

METHODS

This prospective study was conducted at the ophthalmology department of a single tertiary hospital, adhering to the Declaration of Helsinki throughout the study, and was approved by the Bursa Uludağ University Clinical Researches

Ethics Committee (Date: 11.09.2007, Decision No: 2007–14/43). After providing verbal information about the study, written informed consent was obtained from all participants.

Volunteers with CVD were included in the study, while individuals with corrected visual acuity less than 2/10 in one eye or 12/20 for both eyes combined, as well as those with night blindness, diplopia, paralytic strabismus, visual field defects, cataracts, macular degeneration, retinopathy or monochromatic and achromatic vision were excluded. Detailed histories, including age, gender, occupation and age of diagnosis were recorded. Comprehensive eye examinations and color vision tests were conducted and participants' experiences with color vision in daily and professional life were documented.

Color vision was assessed using the Anomaloscope, Ishihara and panel D15 tests. The Anomaloscope was initially employed to confirm the diagnosis and subtype of color blindness through Rayleigh matching. Rayleigh color matching data were collected on CVD participants using an Oculus HMC Anomaloscope. Participants were categorized into Protan and Deutan groups.

The Ishihara test (published in 1978) were administered without CL first, followed by a repeat of the tests with CL. Errors were assessed with natural vision, and results were recorded after repeating the tests with CL to evaluate their effectiveness. Fifteen Ishihara plates were held 75 cm from the subjects. All subjects were asked to identify the symbols on plates 2-15, responding without more than a three-second delay. The first plate was excluded from evaluation as it was designed for both normal vision and all types of CVD. The number of recognized symbols on the 15 consecutive plates was noted for each participants.

Panel D15 test were administered without CL first, followed by a repeat of the tests with CL. Panel D15 errors were assessed with natural vision and results were recorded after repeating the tests with CL to evaluate their effectiveness. The panel D-15 hue Test consists of 15 color caps selected from various parts of a color circle contained in a box. There is one fixed reference color cap that is blue. The participant is asked to arrange the 15 color caps in the order of perceived similarity, starting from the reference cap. Once the test is completed the box is closed and turned upside down. The numbers on the back of the color caps are then checked to evaluate how the participant arranged them.

Standard plano CL with a 6 mm pupil diameter and an 8.6 mm base curve were utilized. Refractive errors were corrected with glasses. Initially participants performed the Ishihara test with one eye using a ChromaGen filter to determine the dominant eye. Filters were then applied to the non-dominant eye and adjustments were made based on performance improvements. The same filter was applied to the dominant eye and participants explored colorful environments for one hour to assess subjective changes in color perception. None of the patients in the study were previous contact lens wearers. The Ishihara and panel D15 tests were repeated with the selected CL and results were recorded. Participants were subsequently asked about their interest in purchasing and using the lenses regularly.

Statistical Analysis

Statistical analysis was performed using SPSS 13.0. Differences in Ishihara test results with and without ChromaGen lenses for all patients (protan and deutan) were evaluated using the Wilcoxon test. Comparisons between the two groups were conducted using the Mann-Whitney U test, with statistical significance set at $p<0.05$.

RESULTS

All participants were male, aged between 21 and 57 with an average age of 30.55. Of the 27 participants 25 had previously been diagnosed with color blindness at other healthcare institutions. The anomaloscope test identified 10 protanopes, 2 protanomalous individuals, 12 deuteranopes and 3 deuteranomalous individuals. The significant errors made by all participants in the Ishihara test confirmed red-green color blindness but did not distinguish the type of blindness. Participants with deutan deficiency read between 1 and 8 of the 15 Ishihara plates in the first stage while participants with protan deficiency read between 1 and 4 plates. Protanopic and deuteranopic individuals made significant errors in the panel D15 test. However protanomalous and deuteranomalous participants performed well (Table 1). With CL deuteranopic individuals read between 12 and 15 plates (Table 2, Figure 1), while participants with protan deficiency read between 2 and 9 plates (Table 3, Figure 2).

Table 1. Anomaloscope, Ishihara, and panel D 15 test results

Patient number	Diagnosis in anomaloscope test	Pages correctly read in Ishihara test	Panel D15 results
1	Protanopia	4/15	Abnormal
2	Protanopia	1/15	Abnormal
3	Protanopia	3/15	Abnormal
4	Protanopia	2/15	Abnormal
5	Protanopia	1/15	Abnormal
6	Protanopia	3/15	Abnormal
7	Protanopia	1/15	Abnormal
8	Protanopia	1/15	Abnormal
9	Protanopia	1/15	Abnormal
10	Protanopia	2/15	Abnormal
11	Protanomaly	3/15	Normal
12	Protanomaly	3/15	Normal
13	Deuteranopia	2/15	Abnormal
14	Deuteranopia	3/15	Abnormal
15	Deuteranopia	3/15	Abnormal
16	Deuteranopia	3/15	Abnormal
17	Deuteranopia	1/15	Abnormal
18	Deuteranopia	5/15	Abnormal
19	Deuteranopia	1/15	Abnormal
20	Deuteranopia	2/15	Abnormal
21	Deuteranopia	2/15	Abnormal
22	Deuteranopia	2/15	Abnormal
23	Deuteranopia	2/15	Abnormal
24	Deuteranopia	2/15	Abnormal
25	Deuteranomaly	6/15	Normal
26	Deuteranomaly	4/15	Normal
27	Deuteranomaly	8/15	Normal

Table 2. Ishihara test results and error amounts before and after the application of ChromaGen lens in patients with deutan defect

ID	Anomaloscope results without ChromaGen lens	Ishihara results without ChromaGen lens	Ishihara error amount without ChromaGen lens	Ishihara results with ChromaGen lens	Ishihara error amount with ChromaGen lens
1	Deuteranopia	2/15	13	14/15	1
2	Deuteranopia	3/15	12	15/15	0
3	Deuteranopia	3/15	12	14/15	1
4	Deuteranopia	3/15	12	15/15	0
5	Deuteranopia	1/15	14	15/15	0
6	Deuteranopia	5/15	10	14/15	1
7	Deuteranopia	1/15	14	14/15	1
8	Deuteranopia	2/15	13	13/15	2
9	Deuteranopia	2/15	13	12/15	3
10	Deuteranopia	2/15	13	15/15	0
11	Deuteranopia	2/15	13	13/15	2
12	Deuteranopia	2/15	13	14/15	1
13	Deuteranomali	6/15	9	15/15	0
14	Deuteranomali	4/15	11	15/15	0
15	Deuteranomali	8/15	7	15/15	0

Table 3. Ishihara test results and error amounts for patients with protan defect before and after applying ChromaGen lens

Patient number	Anomaloscope results	Ishihara results without ChromaGen lens	Ishihara errors without ChromaGen lens	Ishihara results with ChromaGen lens	Ishihara errors with ChromaGen lens
1	Protanopia	4/15	11	8/15	7
2	Protanopia	1/15	14	2/15	13
3	Protanopia	3/15	12	5/15	10
4	Protanopia	2/15	13	2/15	13
5	Protanopia	1/15	14	5/15	10
6	Protanopia	3/15	12	9/15	6
7	Protanopia	1/15	14	4/15	11
8	Protanopia	1/15	14	3/15	12
9	Protanopia	1/15	14	2/15	13
10	Protanopia	2/15	13	4/15	11
11	Protanomaly	3/15	12	5/15	10
12	Protanomaly	3/15	12	5/15	10

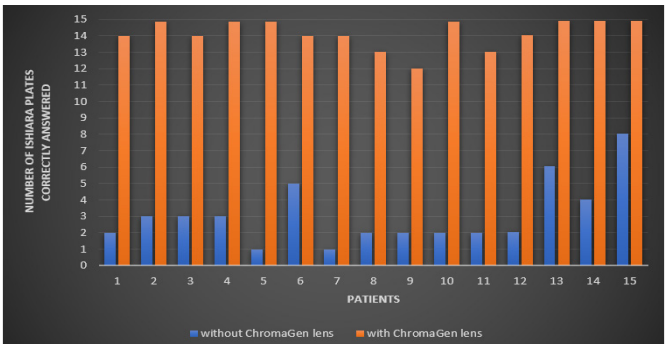

Figure 1. The number of pages correctly identified by participitants with Deutan defect in the first and second stages of the Ishihara test (p<0.05)

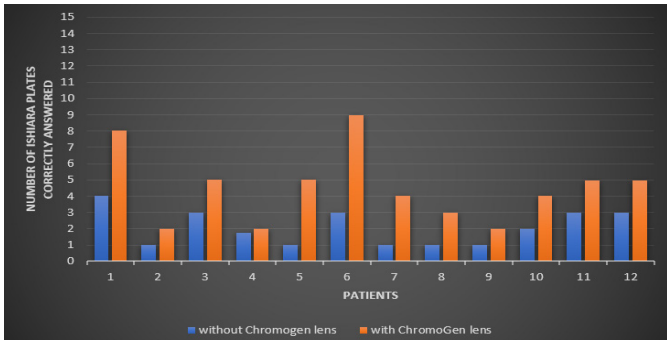

Figure 2. The number of plates correctly identified by participitants with Protan defect in the first and second stages of the Ishihara test (p<0.05)

Under natural conditions the average number of plates read correctly in the Ishihara test was 2.7±1.6 and the average number of errors was 12.3±1.6. With CL the average number of plates read increased to 9.8±5.1 and the number of errors decreased to 5.1±5.1. The difference between the tests conducted with and without CL was statistically significant (p<0.05).

Participants with protan deficiency read 2.0±1.0 plates without CL while participants with deutan deficiency read 3.0±1.9 plates. With CL, participants with protan deficiency read 4.5±2.2 plates and participants with deutan deficiency read 14.2±0.9 plates. The increase in the number of plates read and the decrease in the number of errors were statistically significant for both groups (p<0.05). No improvement was observed in the panel D15 test results with CL.

Twenty-three participants preferred magenta lenses while four participants chose pink lenses. While magenta lenses were not noticeable from the outside pink lenses were clearly visible. Participants reported experiencing difficulties in professional activities involving colors but did not encounter any issues in daily life other than naming colors. Although CL caused colors to appear brighter and also made the surroundings appear darker and pinkish. This situation was found to be disturbing by the participants. Fifteen

participants considered purchasing the lenses but only four participants thought about using the lenses to improve color perception. The others only wanted the lenses to pass the Ishihara test.

DISCUSSION

Color vision deficiency (CVD) impacts about 8% of the population. Among individuals with CVD, 6% exhibit trichromat anomalies, while 2% are classified as dichromats.[9] In this study, 22 participants were identified as dichromats, and 5 were classified as having trichromat anomalies. Due to the small sample size and the more pronounced color perception issues experienced by dichromat individuals[10] in professional life, we believe that our volunteer group does not reflect the prevalence rates of CVD in the general population.

In this study, the use of ChromaGen lenses (CL) increased the average number of correctly recognized Ishihara cards. Similarly, previous studies have shown that the addition of CL increases the number of correctly recognized cards.[11,12] However, in some individuals with CVD, this increase was limited. Those with limited increase had a protan defect and their CVD was found to be severe. In our study, participants with protan or deutan defects were unable to succeed in the Ishihara test without CL. However, after the application of CL, those with protan defects were able to read between 2 and 9 cards. Among the 14 participants with deutan defects, 93% were able to read 13 or more cards with CL, while 7% could read 12 cards. Participants with protan defects were unable to achieve success with CL, while 93% of those with deutan defects succeeded with the lenses.

The Ishihara test is typically used for screening. It is inadequate for determining the type and severity of color vision deficiency. For a more advanced evaluation of color vision deficiency, tests like panel D-15 and FM-100 are more useful. In this study, the effectiveness of CL was evaluated using the panel D15 test. Participants diagnosed with deuteranomaly and protanomaly (5 individuals) succeeded in the panel D15 test without CL, while those diagnosed with deuteranopia and protanopia did not succeed. Our finding that CL does not affect panel D15 test results is consistent with the findings of Swarbrick and colleagues.[1] Many studies have reported significant improvements in color perception with CL. However, Swarbrick et al.[1] found no clinical improvement in the lantern test. They reported that 78% of the test group succeeded in the Ishihara test with CL; error rates in all patients with deutan defects fell to 2 or below, and about half of the participants with protan defects achieved the same success. The ineffectiveness of CL in the lantern and panel D15 tests suggests that these lenses do not aid in color recognition and naming, indicating their unsuitability for professions where safety is critical.

Limitations

ChromaGen lenses offer a wider range of colors and intensities compared to other contact lens models designed for individuals with color vision deficiency (CVD). Studies report that participants using CL tend to prefer magenta, pink or purple lenses.[8] Similarly, in our study, 23 participants preferred magenta lenses, while 4 chose pink lenses. This suggests that the range of usable colors in the ChromaGen filter system is limited.

In our study, 14 out of 15 participants with deutan defects (93%) succeeded in the Ishihara test with CL. However, we believe this success is artificial. The success of color vision deficient patients in the Ishihara test can be explained by ChromaGen filters altering the color dots on the cards, allowing some participants to see hidden numbers or shapes. Indeed, similar studies have reported this effect as artificial. The fact that our participants with deutan defects succeeded in the Ishihara test with CL but did not achieve success in the panel D15 test indicates that CL has no effect on color perception.

CONCLUSION

While CL enable individuals with CVD to pass the Ishihara test, they do not alter color perception. More than half of the participants (15/27) reported that the sole purpose of using CL was to pass the Ishihara test. Our study anticipates that the use of assistive devices like CL during CVD assessment may raise certain ethical and legal issues. In summary:

- **Legal definition of color blindness:** Current legal regulations do not clearly define how color blindness should be assessed. This situation creates legal uncertainty when an individual passes the Ishihara test with CL but is still classified as color blind (Figure 3).

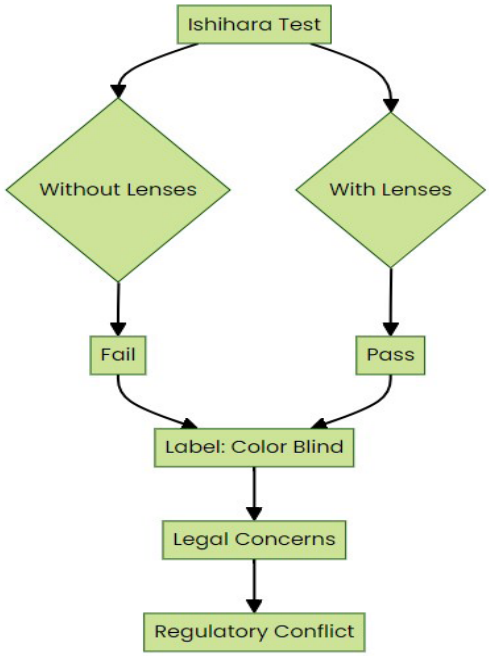

Figure 3. ChromaGen lenses with Ishihara test pathway: challenges and legal implications

- **Principle of legal certainty:** The absence of a clear legal provision on how the Ishihara test should not be passed may make it seem contrary to the principle of legal certainty, which requires laws to be applied in a clear and consistent manner.
- **Equality in assessment:** The use of CL creates disparities in how color vision deficiencies are assessed. Without clear legal provisions on the method of assessment, the use of CL could lead to unfair advantages or disadvantages in professions requiring specific color vision standards.
- **Lack of standardized guidelines:** Insufficient legal guidelines regarding the use of CL in assessments may lead to inconsistent practices among healthcare providers.

- **Ethical considerations:** The ethical implications of labeling individuals as "color blind" based on their performance with or without CL may raise questions about fairness and the integrity of the assessment process.
- **Impact on employment and licensing:** Misclassification due to the use of CL could affect employment opportunities or licensing in professions requiring specific color vision standards, potentially leading to legal challenges related to discrimination.
- **Absence of legal precedents:** The lack of established legal precedents regarding the use of CL in color vision assessments may lead to uncertainty for practitioners, patients and legal authorities.

Addressing these conflicts may require updates to regulations and clearer definitions regarding the assessment of color vision with CL. Therefore, based on our study data, we recommend adding the phrase "without corrective optical devices for color blindness" to all legal texts that stipulate the condition of "not having color blindness" to address these significant issues effectively.

ETHICAL DECLARATIONS

Ethics Committee Approval

The study was carried out with the permission of the Bursa Uludağ University Clinical Researches Ethics Committee (Date: 11.09.2007, Decision No: 2007–14/43).

Informed Consent

All patients signed and free and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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