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Evaluation of the Efficacy of Enchroma Filters for Correcting Color Vision Impairment

Nawaf M. Almutairi[1,2,*], Saad M. Aljohani[1], John Hayes[2], James Kundart[2], Muteb K. Alanazi[3], Karl Citek[2] and Naganathan Muthuramalingam[4]

[1]Department of Optometry, College of Applied Medical Sciences, Qassim University, Buraidah, Saudi Arabia.
[2]Pacific University, College of Optometry, Forest Grove, Oregon, USA.
[3]Optometry Department, College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia.
[4]Nifty Eye Care, Chennai, India.

Corresponding author: Nawaf M. Almutairi (e-mail: nm.almutari@qu.edu.sa).

Abstract **Objective:** This study examined the effectiveness of Enchroma Cx-14 filters on individuals with Red-Green color vision deficiency (CVD). **Methods:** ColorDx and the Farnsworth-Munsell (FM) 100-Hue test were used to assess subjective reactions to Enchroma. The ColorDx and FM, 100 Hue test error scores were computed and contrasted using Placebo (untinted glasses) and Enchroma CX-14, red, and green filters. **Results:** The findings demonstrated that while enchroma filters improved the mistake score in only two patients, they had no discernible impact on any CVD subject's performance. In one protan participant and all deutan individuals, colour discrimination was greatly enhanced by the red filter. Green filters and Enchroma did not raise mean error scores. **Conclusion:** Enchroma filters had limited effectiveness in improving color perception for individuals with Red-Green CVD.

Key Words enchroma Cx-14, color discrimination, abnormal color vision, Saudi Arabia

1. Introduction

In order to create successful therapies for colour vision deficit, it is essential to possess a comprehensive understanding of the physiology underlying both normal and impaired colour vision. The ability to see colour allows individuals to differentiate between surfaces that are uniformly lighted and have similar appearances [1]. The human visual spectrum has wavelengths ranging from around 380 nm to 700 nm. People who have normal colour vision have the ability to distinguish hundreds of various shades [2]. The perceptual organisation of human colour vision follows an oppositional pattern, whereby pairs of categories such as light and dark, red and green, and blue and yellow are present. Therefore, the perception of colour may be delineated within a three-dimensional spatial framework that is crossed by colour axes that conform to the previously indicated pairs of opponents [3]. Trichromatic vision refers to the cognitive capacity of individuals to differentiate between different spectral lighting conditions and a mixture of the three primary colour lights, namely blue, green, and red. The trichromatic theory of vision was suggested by Helmholtz about fifty years subsequent to its introduction by Thomas Young in 1807. According to this idea, the perception of colour is dependent on three processes, each of which is responsive to a certain segment of the electromagnetic spectrum [4], [5]. The perception of trichromatic colour is reliant upon three distinct categories of cones situated at the receptor level inside the retina. The cones in question are responsible for receiving inputs from the visible spectral areas, which are referred to as short (S), middle (M), and long (L) segments. These cones exhibit their highest sensitivity at around 426 nm, 530 nm, and 557 nm respective [6]. The perception of these wavelength spectrums is associated with the colours blue, green, and red, in sequential sequence. Therefore, the process of colour processing is dependent on the absorption of quantum photons by these photoreceptors. However, it is important to note that a single photoreceptor is unable to produce colour, even if photoreceptors may have a high level of sensitivity within their absorption range. Colorblindness is a disorder that affects persons universally when they are subjected to diffuse light settings. In such situations, the rods, which are the sole active class of photoreceptors, are inadequate to activate the cones due to insufficient light.

In the Lateral Geniculate Nucleus (LGN), the cone pho-

toreceptor signals undergo further processing via the color-opponent process. The LGN is composed of two distinct kinds of neurones. The first group is referred to as red-green colour opponent cells, which experience excitement when exposed to green light and inhibition when exposed to red light, or vice versa. The cells belonging to the opposing class are lit in a blue-yellow hue and exhibit a response to this stimulus. In contrast to the opposition system in the red-green channel, blue-yellow opponent cells get input from the S-cones and the combined input of the L and M-cones [7]. In layer 4Cbetain V1, the synapse cells facilitate the transmission of M and L inputs to the LGN via the Koniocellular route. Subsequently, the information is sent to cytochrome oxidase (CO) clumps located in layers 2 and 3 of visual cortex area 1 (V1).The inputs of V1 are finally sent to V2 and V4 [8], [9].

Considerable investigation has been undertaken about congenital colour vision deficit (CCVD), a condition that is generally recognised as the most widespread hereditary visual impairment. The most common type of CCVD is the red-green defect, which includes protanomaly, protanopia, deuteranomaly, and deuteranopia. Genetic disorders that affect the function of long-wavelength (L) or middle-wavelength (M) cone photoreceptors are frequently the cause of CCVD. The X chromosome codes for both green (chlorolabe) and red (erythrolabe) photopigments. Consequently, the incidence of red-green colour vision deficit is 0.5% among males and 0.5% among females, mostly due to the presence of two X-chromosomes in females compared to one in males [10].Typically, Europeans have the greatest occurrence of red-green CCVD, whereas Africans have the lowest occurrence [**?**]. Modifications in cone function, such as aberrant trichromacy and dichromacy, do not have an impact on visual acuity. Aberrant trichromacy refers to a deficit in opsin composition, whereas dichromacy refers to an absence of a particular class of cone photopigments. Chronic cardiovascular disease (CCVD) is often classified into three categories: protan, deutan, or tritan. It presents itself in two separate forms: anomalous trichromatic and dichromatic. The recognition of these classes has been established over the previous 25 years [14], [15].

Dichromacy is a colour vision defect that is less common and more severe in comparison to anomalous trichromacy.According to the source [16], the prevalence rates for protanopia and deuteranopia are 1.0% and 1.3% respectively.The anomaly arises due to the lack of either the M opsin gene (resulting in deuteranopia) or the L opsin gene (leading to propanopia) [16]. The lack of the matching cone axis leads to a reduction in the dimension of dichromat colour vision [17]. One example of a phenomenon that might lead to colour confusion along the red-green axis is protonopes. There is a hypothesis that suggests that the remaining photopigment has penetrated the missing photopigment. As an example, erythrolabe is used as a substitute for chlorolabe in the management of deuteranopia.

Similarly, chlorolabe is used as a substitute for erythrolabe in the treatment of protanopia. The term used to describe this method is the dichromacy replacement model [18]. The concept of unoccupied cones [19] introduces an alternate scenario when a portion of the cones lack any observable pigmentation.Protanopes have a limited ability to see and distinguish about twenty-one different wavelengths. In contrast, deuteranopes possess the ability to distinguish between 31 distinct wavelengths. The standard trichromat, however, has the capacity to distinguish about 150 wavelengths. The red-green dichromate is known to have a limited perception of two main colours within the visible spectrum [16].

Anomaly trichromacy is a genetic colour vision deficiency that involves a change in the sensitivity of one or more cone photopigments, similar to dichromacy. The preservation of normal L-photopigment is mostly seen in about 5% of males with deuteranomaly. In contrast, the M-photopigment is replaced by an atypical photopigment known as L', which has a spectrum sensitivity that is approximately comparable to that of the conventional L-photopigment [**?**]. In contrast, Protanomals, which make only 1% of the male population, have a functioning M-cone.The L-cone photopigment is substituted with an atypical M' photopigment [22]. In protanomals or deuteranomals, the degree of colour vision confusion is directly related to the displacement of peak sensitivity. Therefore, a greater displacement results in a more noticeable colour vision abnormality [23]. Anomaly trichromacy may result in a significant decline in colour differentiation, ranging from mild to severe. Many people with mild to moderate abnormal eye colour vision may not be aware of their issue until they have a colour vision test [24]. In contrast to dichromats, anomaly trichromats do not possess a neutral (white) point and have the ability to see colours beyond two fundamental hues within the visible spectrum [15]. Trichromats with abnormals On the anomaloscope, Rayleigh matches may be categorised as either protanomalous or deuteranomalous based on the matching range and the midpoint match. The inclusion of more red in protonomals results in a significant shift of their respective spectra towards the red region. Similarly, deuteranomals have a limited range of matching for their displacement to the green [25].

Acquired colour deficit often arises as a consequence of illnesses affecting the ocular and visual processes. According to epidemiological estimates, the prevalence of acquired colour vision deficit is believed to range from 5 to 15 percent of the population [11]. However, the frequency of this phenomenon was not determined by a comprehensive study, but rather based on prevailing public opinion [11]. A prevalence rate of 10.1% was calculated in a research done in Iran, with a sample of 5,102 persons aged 40 to 64, using the Farnsworth D-15 test. 66.1% of the studied individuals had a tritandefect, whereas the remaining ones had red-green faults [23].

Contrary to the opinions of some affected persons, red-green colour vision impairment is not regarded as a debilitating disorder. The existence of normal colour vision is a requirement for employment in certain jobs, such as those

involving commercial driver's licences, police officers, pilots, or firemen.For the last two centuries, efforts have been undertaken to address colour vision deficit; nevertheless, a widely acknowledged remedy has not yet been established. Only a small number of choices, of the many that have been tried, have shown an impact. In 1817, Seebeck introduced the concept of using colour filters as a strategy for addressing colour vision insufficiency [26]. Following this, colour filters have attracted significant attention from scholars.Coloured filters enhance the capacity to distinguish between various shades, tones, and degrees of brightness by selectively absorbing certain wavelengths. The X-Chrom lenses, a kind of red contact lenses worn over one eye, were introduced by Zeltzer in 1971 [27]. According to reference [28], the X-Chrom lens employs a long-pass filter to intensify the blackness of yellow-green objects, while simultaneously amplifying the redness and slight darkness of orange objects. According to the findings, the efficacy of the treatment was shown to be lower with dichromats and higher with anomalous trichromats [29]. Barry et al. conducted an examination on a cohort of sixteen individuals with colour anomalies. The examination included the use of X-Chrom lenses, AO HRR pseudoisochromatic plates, and Farnsworth-Munsell 100-Hue tests. The findings of their study revealed a significant decrease in the AO pseudoisochromatic error score, whereas no significant reduction was seen in the 100-Hue test outcomes. The JLS lens, akin to the X-Chrom lens, is a kind of aqua (blue-green) lens that is used for the correction of colour vision deficit by being worn over one eye. The JLS lens was assessed by Schlanger on a cohort of twenty-five individuals who exhibited colour deficiency. A success rate of 62% was seen in seventeen out of twenty-four individuals, indicating progress [30]. According to his conclusion, a significant improvement in subjective colour perception necessitates a difference in the perceived brightness between the two eyes.

ChromaGen, an English optician, was designed by David Harris in 1996. It provided several advantages over previous lenses [31], [32]. ChiraGen soft contact lenses are offered in a variety of colours and provide enhanced comfort compared to X-Chrom lenses. The participants are given guidelines to choose their favourite filter or filters from a range of colours that include the visible spectrum, running from red to violet. Furthermore, it should be noted that the tinting of lenses is limited to the pupil size, resulting in enhanced cosmesis as compared to lenses with complete tinting [33]. Swarbrick et al. assessed the effectiveness of ChromaGen on fourteen individuals with colour deficiency using the Farnsworth D-15, Ishihara, and Farnsworth Lantern. The tests were administered to participants three times: first, during the delivery of lenses, and then again after a two-week trial during which the participants used the lenses. Visual analogue scales were used to record the subjective reactions on a daily basis. Their findings showed that ChromaGen considerably decreased the Ishihara test error rate, especially among deutan people. Moreover, a noteworthy reduction in errors identified on the D-15 assessment was seen.On the other hand, the degradation of the lens did not provide any noteworthy impact on the efficacy of the Farnsworth Lantern test. Patients reported a subjective improvement in their sense of colour. Although certain colour tests showed enhancement, participants reported visual impairment in low-light environments as a result of the dark-colored glasses. According to the research, although the lenses improved improve colour discrimination, they did not provide precise colour perception. The implications of this have significant consequences in terms of prescribing these lenses for persons who want to pursue jobs that need consistent colour vision.

The Enchroma lens is a modern filter application. A variety of hue intensities are offered for enchroma filters, ranging from light-blue for interior applications to dark grey for outdoor settings.Enchroma filters use a "Multi-notch filter" technology, as stated by the manufacturer, to selectively exclude certain areas of the visible spectrum [34]. Analysing the peak sensitivity response curve for proton anomaly and deuteranomaly wavelengths is used to establish the intended wavelength, which are essential components of anomalous trichromacy. During a proton anomaly, the L-cone's maximal sensitivity changes to that of the M-cone. This leads to a convergence in sensitivity between the two categories of cones, which makes it difficult to distinguish the absorbed spectra. As a result, Enchroma exploits this overlap by eliminating the unwanted wavelengths that overlap, resulting in a minor difference in the wavelength sensitivities of the M and L-cones. The evaluation of the mechanism of Enchroma wavelength spectrum change has not been conducted in a clinical investigation. Enchroma use written and videoed testimonials from patients on its official website as a means of promoting its goods.

The aim of this study was to assess the performance of Enchroma filters on the analysis of anomalous dichromats and trichromats. A hypothesis was formulated suggesting that persons with atypical colour vision will not encounter any alterations in colour perception when use Enchroma glasses. We conducted an investigation to see whether Enchroma filters would enhance the colour perception of persons with abnormal colour vision in comparison to commercially available conventional filters. This was done using standard clinical colour vision tests.

1.

2. Methods

A. Subjects

Two separate universities employed a randomised cross-over design. The first phase of the study was conducted at the Visual Performance Institute of Pacific University College of Optometry, while the subsequent phase took place at Qassim University, College of Applied Medical Sciences, Department of Optometry Eye Clinics, situated in Buraydah City, Saudi Arabia. Approval for the study was given by both the Institutional Review Boards of Pacific University and Qassim University. A total of 10 people, consisting of 9 men and 1 female, with genetic red-green colour vision

deficit, were recruited from Pacific (n=2) and Qassim (n=8) universities. The participants' ages ranged from 19 to 52. All participants had a minimum highest corrected visual acuity of 20/20.The moderate deutans consisted of two severe protans and six severe deutans. The informed consent form, which had received approval from the Qassim University Institutional Review Board, was signed by all participants. The research followed the guidelines specified in the Declaration of Helsinki.

Participants who met the specified criteria showed impairments in both red and green colours at all degrees of severity. Participants were required to be a minimum of 18 years old and in optimal ocular condition.Each individual in the study got a comprehensive ocular examination and exhibited a minimum corrected visual acuity of 20/25 in both eyes. Individuals who satisfied the exclusion criteria and had colour vision impairment due to anterior or posterior ocular illnesses, such as optic neuritis, diabetic retinopathy, and glaucoma, were deemed unsuitable for inclusion in the study. The presence of a yellow-blue hue in vision impairments may be attributed to many illnesses such as diabetic retinopathy, optic neuritis, glaucoma, or other disorders that alter the sense of colour. Similarly, participants should refrain from using any drugs that change colour vision, such as thiazide diuretics for hypertension, amphetamines, Plaquenil, Viagra, and other similar substances.

B. Materials

The same tools, conditions of examination, and viewing area were utilised by Qassim University and Pacific University as by their examiners. The research participants were subjected to screening procedures before being enrolled. A screening instrument called ColorDx (Figure 1) was used to find out if the subjects had a congenital colour vision deficiency. Participants were tested using digital Farnsworth-Munsell 100-Hue and ColorDx (Waggoner Computerised Colour Vision Test software) with the Enchroma Cx-14 filter, red- and green-tinted filters, and placebo untinted glasses after their eligibility for the study was confirmed and they gave their informed consent. The color-testing instruments were chosen due to their extensive use in clinical environments. Furthermore, a variety of colour perception tasks were evaluated using the selected assessments, including the Farnsworth-Munsell 100-Hue, which measures delicate hue identification, and the ColorDx, which measures colour discrimination.The examination sequencing was determined using the Latin square randomisation technique.

This study experiment tested the following filter conditions: untinted glasses (placebo), Enchroma Cx-14 filter, green filter, and red filter. The red and green lenses had light transmission rates of 15% and 13% respectively. Enchroma, Inc., a company based in Berkeley, CA, USA, currently has a pending patent application. The system uses notch filtering, which is the deliberate removal of certain spectral wavelengths to enhance the amplification of particular colours. Figure 2 depicts the transmission spectrum profile. Green

Figure 1: ColorDX color vision testing application

filters serve the objective of establishing a state of equilibrium by increasing the level of challenge in successfully completing the colour vision examination. Individuals who have a deficit in the red-green colour may effectively pass pseudo-isochromatic plate tests, such as the Ishihara and Hardy Rand and Rittler (HRR) tests, by using red lenses. A mirror coating was placed to each lens to conceal the underlying lens colours from the subjects.

1.3

C. Procedure

Wearer instructions for each of the listed filters were supplied to the participants. Subsequently, the participants underwent testing using the tools enumerated above. The first evaluation was conducted using pre-isochromatic colour vision (ColorDx) (Figure 2). The ColorDx application for the Apple iPad was used to identify red-green and blue-yellow colour vision impairments. The screen of the iPad I (128 GB) displays a series of random plates that flashes for about two seconds. Participants were required to enter the numerical value that appeared on the plates shown on the iPad screen, or alternatively, to identify their location by entering N, which represented "nothing." The test consists of four sets. The first unit consists of a total of twenty-four diagnostic devices. The application terminates with the term "Passage." In the case that this set fails to pass, the programme proceeds to conduct supplementary tests in order to quantify the issue. This part consists of three sets, each including thirty-two plates dedicated to protan, deutan, and tritan, respectively. The second examination was the online execution of the Farnsworth-Munsell 100-Hue arrangement caps test using an Apple laptop. The Farnsworth-Munsell 100-Hue test was chosen for its capacity to evaluate delicate hue discrimination, despite not being especially designed for colour vision evaluation [35]. All trials were conducted using low-intensity lighting. In order to mitigate the risk of individuals growing used to the filter that was previously investigated and to promote their adjustment to white light, the room lights were

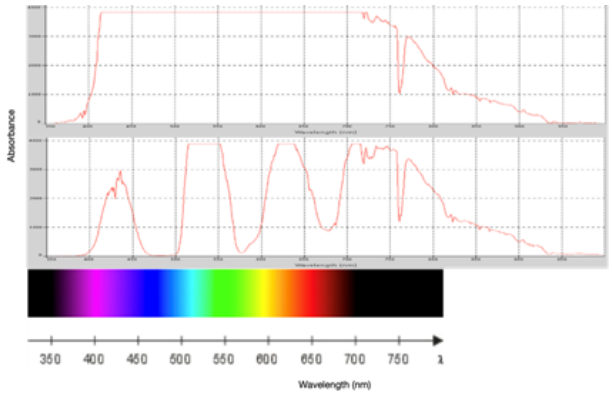

Figure 2: Enchroma Cx-14 spectral transmission. The transmission of light without the Enchroma filter is depicted by the upper curve, while the transmission of light with the Enchroma filter is represented by the lower curve

activated at the conclusion of each experiment. The lighting of the iPad and laptop was calibrated to 6400 K using a Spyer5Pro, which is the ideal illumination for colour vision tests [36].

D. Data analysis

The data was analysed using the IBM SPSS Statistics Model 24. The mean error score of the colour vision test was evaluated using repeated measures ANOVA to investigate variations in filter conditions (Enchroma, green-tinted, red-tinted, and untinted placebo glasses). In the Farnsworth-Munsell 100-Hue test, we looked at the overall error score in each quadrant. The mistake score for each quadrant is not included in the Farnsworth-Munsell 100-Hue test's online version. The purpose of this study is to compare the mistake rates observed in colour vision tests administered with untinted placebo glasses to those employing Enchroma, red, and green-tinted lenses. The findings were considered statistically significant when the p-value was less than 0.05.

3. Results

All ten participants had two-color vision tests, namely ColorDx and digital Farnsworth-Munsell 100-Hue, in line with the randomized treatment conditions (EnChroma, red, green, and placebo). One of the seven deutans and two protans were present in the deutan-protan compound.The colour vision deficit diagnosis of the 10 participants are shown in Table 1 using raw data.

The repeated measures ANOVA analysis revealed a statistically significant main impact of the filter condition when using ColorDx. The F-value ($F(3, 474.8) = 6.8$, $p = 0.002$) indicated this finding. The Enchroma filters only improved cardiovascular disease (CVD) in two people on ColorDx, namely from severe protan to moderate protan and from severe deutan to moderate deutan (Table 2, Figure 3 A). The statistical analysis revealed that there was no significant difference in error scores between the Enchroma and

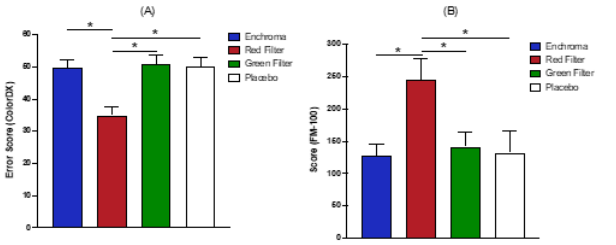

Figure 3: (A) The average error score obtained using ColorDx, with error bars denoting the standard error (SE) of the mean. (B) The error bars in the mean error score with FM-100 Hue indicate the standard error (SE) of the mean.At the significance level of $p < 0.05$, stars are utilized

placebo groups, as shown by the results of post-hoc testing. In compared to the placebo, the use of green filters did not result in a significant improvement in the mean error scores of ColorDx (mean = 51 ± SD 8.8 vs. 50 ± SD 9.34, $t = 0.25$, $p = 0.805$, respectively) (Table 2, Figure 3 A). Cohen's effect size estimates for Enchroma and Green filters, as compared to placebo, demonstrated a diminished practical or clinical significance ($d = 0.04$ and $d = 0.11$ SD, respectively). Additionally, the mean error score did not show any statistically significant difference between the green and Enchroma filters (51 ± SD 8.8, $t = -0.41$, $p = 0.668$; Enchroma = 49.6 ± SD 7.8; Green = 51 ± SD 8.8; The Enchroma filter). Post-hoc analysis demonstrated that the implementation of the red filter resulted in a considerable improvement in colour discrimination, as assessed by the ColorDx metric. The Deutan individuals had a substantial enhancement. One participant showed improvement from severe protan to moderate deutan, whereas all deutan individuals showed improvement from severe deutan to mild deutan. The crimson filter had a Cohen's effect size value of $d = 1.7$, which was found to be very clinically significant when compared to the placebo. Furthermore, it was shown that the effectiveness of the red filter was significantly higher compared to the Enchroma filter (mean error score = 34.9 ± SD 2.5 vs. 49.6 ± SD 7.8, $t = 3.81$, $p = 0.004$; mean error score = 34.9 ± SD 2.5 vs. 51 ± SD 8.8, $t = 3.93$, $p = 0.004$). Figure 3B.

The unprocessed data on the participants' score on the Farnsworth-Munsell 100-Hue is shown in Figure 4. The statistical analysis using the Farnsworth-Munsell 100-Hue test revealed that there was no significant difference in the mean score between Enchroma and the placebo. The mean score for Enchroma was 127.9 ± 52.9 SD, while the mean score for the placebo was 132.2 ± 108.9 SD ($t = 0.17$, $p = 0.86$). On the other hand, the red filter had significantly less positive effects compared to the placebo. However, when comparing the performance of the individuals on the red filter (Fig. 3B) to that of Enchroma ($t = 4.45$, $p = 0.002$) and the green filter (mean = 142.1 ± 71.5 SD, $t = 4.5$, $p = 0.001$), it was shown that the patients performed significantly worse on the red filter. The mean error score for the deutan and

Subject	Gender	Screening (5)	Protan (32)	Protan Diagnosis	Deutan (32)	Deutan Diagnosis	Tritan (12)	Tritan Diagnosis	General Diagnosis
1	M	0	1	Severe	12	Moderate	11	Pass	Severe Protan
2	M	0	0	Severe	0	Severe	11	Pass	Severe Protan/Deutan
3	M	0	9	Moderate	0	Severe	10	Pass	Severe Deutan
4	M	0	6	Moderate	0	Severe	11	Pass	Severe Deutan
5	F	0	5	Moderate	2	Severe	10	Pass	Severe Deutan
6	M	0	0	Severe	18	Mild	12	Pass	Severe Protan
7	M	0	16	Mild	8	Moderate	12	Pass	Moderate Deutan
8	M	0	9	Moderate	0	Severe	12	Pass	Severe Deutan
9	M	0	1	Severe	17	Mild	12	Pass	Severe Deutan
10	M	0	17	Mild	1	Severe	11	Pass	Severe Deutan

Table 1: The unprocessed data pertaining to the assessment and diagnosis of subjects via the ColorDx color vision analyzer. Each form of color vision deficiency is represented in parentheses in the upper row, which contains the total number of plates. The severity of CVD corresponding to the quantity of ColorDx plates accurately identified by each subject is denoted by the numbers preceding their names

ID	Age	EnChroma Filter	DiagnosisEnChroma	Red Filter	Diagnosis Red Filter	Green Filter	Diagnosis Green Filter	Placebo	Diagnosis Placebo
1	21	43	Moderate Protan	39	Moderate Deutan	46	Severe Protan	49	Severe Protan
2	51	45	Severe Protan	49	Moderate Deutan	47	Severe Protan	44	Moderate Deutan
3	22	42	Severe Protan	34	Mild Deutan	53	Severe Protan	48	Severe Protan
4	20	57	Severe Deutan	28	Mild Deutan	62	Severe Deutan	59	Severe Deutan
5	19	54	Severe Deutan	42	Mild Deutan	56	Severe Deutan	55	Severe Deutan
6	19	61	Severe Deutan	33	Moderate Deutan	33	Severe Deutan	65	Severe Deutan
7	19	58	Severe Deutan	35	Mild Deutan	62	Severe Deutan	57	Severe Deutan
8	22	44	Moderate Deutan	21	Mild Deutan	50	Severe Deutan	45	Severe Deutan
9	29	39	Moderate Deutan	39	Moderate Deutan	45	Moderate Deutan	32	Moderate Deutan
10	30	53	Severe Deutan	29	Mild Deutan	56	Severe Deutan	46	Severe Deutan

Table 2: Unprocessed data regarding the execution of each filter type by the participants on ColorDx. The error plates for the plates that assess red-green color vision are denoted by the numbers in the filter column. Deutan was allocated 32 plates, for a grand total of 64 plates. Protan comprised 32 plates

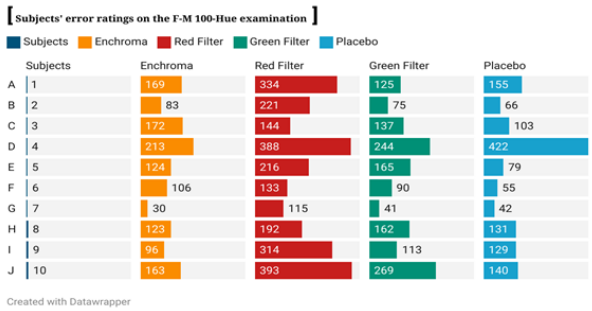

Figure 4: Subjects' error ratings on the F-M 100-Hue examination, in their unprocessed form. At least one error score of 83 is considered as the pass criterion

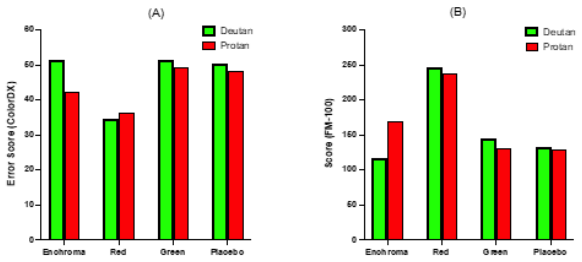

Figure 5: Mean error ratings for deutans and prosTANS subjects are compared. (A) The average error score for deutans and protans computed using ColorDx with the four different filter types. (B) The mean error score for deutans and protans acquired through the utilization of four distinct filter types in FM 100-Hue

protan subjects for each filter condition is shown in Figures 5A and B on the Farnsworth-Munsell 100-Hue and ColorDx. The filters underwent individual performance testing on both the deutan and protan groups. Due to the small sample size, a significance test was not conducted when the participants were separated into deutans and protans. The implementation of filters did not result in a significant reduction in mistake scores.

4. Discussion

This research aimed to investigate the potential impact of Enchroma glasses on colour vision in individuals diagnosed with colour vision deficit. Enchroma was compared against red filter, green filter, and untinted placebo glasses for assessing error scores on conventional colour vision tests. Enchroma filters, which have recently gained popularity, claim to enhance colour vision in those with both impaired and normal colour vision. Our results greatly influence the clinical consequences of using Enchroma lenses. Two individuals had a reduction in cardiovascular disease (CVD): transitioning from severe protan to moderate protan, and transitioning from severe deutan to moderate deutan. The findings of the study revealed that the administration of Enchroma did not provide a statistically significant improve-

ment in the ColorDx test scores of the subjects.

Similarly, the Farnsworth-Munsell 100-Hue test did not demonstrate any noticeable improvement in colour perception. At the time of doing this study, there was a lack of existing research investigating Enchroma's filter claim [37]. However, our study aligns with the findings of previously published studies [38]–[40].

The efficiency of Enchroma on tendeuteranopic, eight deuteranomalous, and nine protanopic samples was previously investigated by Mastey et al. via the use of the Colour Assessment and Diagnosis (CAD) test. There was no substantial alteration seen in the reddish-green thresholds of both deutans and protans when exposed to Enchroma glasses. Furthermore, it has been shown that the presence of Enchroma resulted in insufficient differentiation between blue and yellow deutans [41]. Similar findings were reported in previous studies [37], [42], when people with normal colour vision had a tritan-like deficit upon exposure to enchroma.Enchroma, like other filters, has the capacity to improve the clarity of certain colours. However, it does not have the capability to differentiate wavelengths based on their luminance strength.

The mistake rate of the ColorDx colour vision test shown a more pronounced reduction when red lenses were used in comparison to green and Enchroma filters. While donning the red filter, no individual passed the ColorDx assessment. However, they exhibited a much lower number of mistakes compared to while wearing a placebo lens.Author found that individuals with colour deficit showed a significant improvement in colour perception when using X-Chrom. Despite the significant enhancement shown in the individuals' performance with ColorDx, it is essential to emphasise that this does not necessarily indicate colour perception or the capacity to distinguish between different shades. The ColorDx plates and other pseudoisochromatic colour vision tests were developed based on the fact that normal viewers can distinguish figures when the foreground and background have different colours but the same degree of brightness [43]. However, persons with colour vision problems may not be able to see these differences.

Therefore, the use of a red filter allows for the differentiation of "symbols" in the foreground only based on contrast (brightness) by generating a luminance cue difference between the figure and the backdrop [25]. Despite the manipulation of the light colour temperature, this phenomena persists. The use of a colour temperature lower than illuminant C, such as the colour temperature applied during normal colour vision testing, is anticipated to result in a reduction of mistakes committed by subjects on pseudoisochromatic plate tests. It is expected that faults would develop if the colour temperature exceeds the normal illuminance C [44], [45].

The research conducted by Hovis examined the performance of long wavelength pass filters using several colour vision tests, including the Ishihara, Farnsworth-Munsell 100-Hue, D-15, and SPP1. The findings of this study align with our own results, despite the fact that our lens system is binary-optic, as opposed to X-Chrom. The use of the long wavelength pass filter led to a significant decrease in the occurrence of mistakes [28], as shown by the fact that all participants successfully completed the assessment with an Ishihara error rate of eight errors. Conversely, the red lens worsened the Farnsworth-Munsell 100-Hue test results of our participants in comparison to the placebo. Due to the use of an online Farnsworth-Munsell 100-Hue test, we were unable to get the confusion lines provided by our participants to determine which colour axes were confused. In a study conducted, it was shown that the higher Farnsworth-Munsell 100-Hue error score seen in color-deficient individuals using long wavelength pass filters might be attributed to a little increase in red-green mistakes and an increase in blue-yellow errors.A limited number of Farnsworth-Munsell 100-Hue cap colours were perceptible to all participants in our study, since they consistently reported challenges in distinguishing between them. Furthermore, the presence of a red-green defect in individuals lacking the red-green colour was found to be in line with previous research that showed the induction of a blue-yellow-like defect by long wavelength pass or "blue blocking" filters [45].

5. Conclusion

With the exception of two participants, the use of enchroma filters did not result in a statistically significant enhancement in the diagnosis of cardiovascular disease (CVD), and did not exhibit any noticeable influence on the other subjects. However, the red filter did improve performance on the ColourDxcolor vision test. Our hypothesis posits that the better performance may be attributed mostly to luminance aberrations resulting from the deterioration of the red filter. Furthermore, the functionality of the Farnsworth-Munsell 100-Hue was hampered upon the use of the red filter. Colour vision is defined as the capacity to distinguish between various coloured surfaces by analysing the spectral distribution acquired by the eye, regardless of the intensity of light. Enchroma Cx-14 has the potential to improve some colours, however our research does not provide evidence for its use as a treatment for colour deficiency.

6. Limitation

A noteworthy limitation is the very limited sample size, which may be ascribed to the difficulties encountered in recruiting subjects with colour vision loss. A considerable percentage of the patients analysed in our study had a pronounced manifestation of colour vision impairment. Furthermore, a significant proportion of our participants had deuteran colour vision impairment. In order to accurately assess the effectiveness of the Enchroma filter in addressing colour vision defects of different levels of severity, it is necessary to expand the sample size to include people with a diverse range of colour vision deficiencies.

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Conflict of interest

The authors declare no conflict of interests. All authors read and approved final version of the paper.

Authors Contribution

All authors contributed equally in this paper.

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