Effect of Refractive Error on Color Vision

Kırma Kusurunun Renkli Görüşe Etkisi

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ABSTRACT

Purpose: Prevalance of refractive error is increasing and without correct color perception everyday tasks such as matching or distinguishing color is a challenge. The aim is to determine the effect of refractive error on the color matching of red, green and blue appearing surfaces and how this color matching changes with refractive correction with glasses.
Method: In this interventional single center study, 127 medical students from Bahcesehir University were enrolled. In a well-lit room (4794 lumen), an A4 paper sized color was placed on a tripod 4 meters away from the participant. They were asked to match the shown color to the scale. The scale consisted of five shades of three main colors (red, green, blue). Answers were categorized as correct or false. Categorical independent data were analyzed with Chi-square tests and for categorical paired data, McNemar tests were used.
Results: 127 students consisted of sixty-four males (Mean: 19.70 ± 1.136) and sixty-three (Mean: 19.49 ± 0.965) females. 60 participants had refractive error and 67 participants had healthy vision. When emmetropes were compared to participants with refractive error, for only red color, emmetropes had significantly lower error rates (9%) compared to participants with refractive error (25%) (p=0.015). 60 participants with refractive error had lowered error rates in red (14%), green (10%) and blue (20%) color after correction. The decreases in error rates were not significant except blue was insignificant on the edge. P values for red, green and blue respectively are p=0.096, p=0.286 and p=0.050.
Conclusion: The study found that refractive error negatively effects color perception and correcting the underlying health problem decreases the error rate in color perception.

Key Words: Refractive Error, Color Perception, Gender, Myopia, Color Identification, Optics

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ÖZET

Amaç: Çalışmanın amacı kırma kusurunun kırmızı, yeşil ve mavi renkli yüzeylerdeki renk algısı üzerine etkisini belirlemek ve görüşün gözlük ile düzeltilmesi sonucunda oluşan değişikliği saptamaktır.
Yöntem: Girişimsel, tek merkezli bu araştırmaya Bahçeşehir Üniversitesinden 127 tıp öğrencisi katılmıştır. İyi aydınlatılmış (4794 lümen) bir odada katılımcıdan 4 metre uzağa yerleştirilen A4 boyutundaki renk, tripod aracılığıyla katılımcıya gösterilmiştir. Gösterilen rengi skaladan eşleştirmeleri istenmiştir. Skalada 3 ana rengin (kırmızı, yeşil, mavi) 5 farklı tonu bulunmaktadır. Cevaplar doğru ve yanlış olarak sınıflandırılmıştır. Kategorisel bağımsız veriler Chi-Square testi, kategorisel çiftli veriler McNemar testi ile değerlendirilmiştir.
Bulgular: 64 erkek (Ortalama: 19.70 ± 1.136) ve 63 kadından (Mean: 19.49 ± 0.965) oluşan 127 kişi deneye katılmıştır. 60 katılımcı görme kusuruna sahiptir. 67 katılımcı emmetroptur. Görme kusuruna sahip olan deneklerin emmetrop olan deneklerle karşılaştırılması sonucunda, sadece kırmızı renkte, emmetropların hata oranlarının (%9) görme kusurlu derneklere (%25) göre istatistiksel olarak anlamlı düşük olduğu gözlenmiştir(p=0.015). Deneye katılan 60 görme kusurlu katılımcının görme kusurun düzeltilmesi sonucunda renk algısı hata oranlarında düşüş gözlenmiştir. Ancak bu farklılık istatistiksel olarak anlamlı değildir. Mavi renk sınırda anlamlı değildir. Kırmızı, yeşil ve mavi için sırasıyla p değerleri p=0.096, p=0.286 ve p=0.050 olarak gözlenmiştir.
Sonuç: Araştırma görme kusurunun renk algısını negatif olarak etkilediğini ve görme kusurunun tedavi edilmesinin renk algısındaki hata oranını azalttığını göstermiştir.

Anahtar Sözcükler: Görme Kusuru, Renk Algısı, Cinsiyet, Miyopi, Renk Tanımlama, Optik

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INTRODUCTION

Refractive errors arise from impaired focusing of light on the retina. Ametropia or the absence of emmetropia (normal vision) may be produced by alterations in the axial length of the eye (the distance from the anterior corneal surface to the retina measured along the visual axis) or the refractive power of the optical elements. Axial length is the main cause of refractive error compared to cornea, lens and other components of the eye (1). Broad classifications of refractive errors are myopia (near-sightedness), hyperopia (far-sightedness), astigmatism and presbyopia. Among these myopia is the most common. In 2010, prevalence of myopia was reported as 23.9% in U.S. It is the most common visual impairment. Effect rates of myopia on both genders are closely matched: 54% for females and 46% for males (National Eye Institute, 2010) (2). By year 2050, it is estimated that 4.7 billion people which will be half of the global population by then, will have myopia (Holden et al., 2016) (3).

Myopia occurs when the eye has more refractive power than necessary for its axial length which may be the consequence of elongated axial length or increased refractive power. When the refractive power of the eye is inadequate for its axial length, hyperopia occurs. This is the consequence of shortened axial length, decreased refractive power or both (4).

Light is focused onto the retina. Afterwards it is absorbed by photoreceptors and converted to neural signals. There are three types of color sensitive photoreceptors called cones. Cones are named as short, medium and long based on the wavelength they are most sensitive. There is also another type of receptor known as rod which functions at low levels of light. Although rods can contribute to color vision, cones are the color perception mechanism in most cases (4).

Difference observed after refractions in the characteristics of an object such as size and color is called aberration. This effect is caused by the relatively different refraction indexes for different wavelengths. Short wavelengths focus closer to the light source whereas longer wavelengths focus further away. This chromatic difference in focus is called Longitudinal Chromatic Aberration (LCA) (5). Measured values of chromatic aberration are very consistent across subjects. From red to blue, as much as 2 diopters of focus difference occurs. When one considers this large value of chromatic aberration, it seems logical that its correction would have a significant impact on the quality of vision.

Color is not a physical attribute but rather perception of a specific wavelength. Color is what the eye observes and is the result of excitation of the cones by wavelength. Color perception has a large number of factors. Including, wavelength of the object and wavelengths coming from the neighboring objects, recently observed objects and the background (6).

There were previous studies which investigated the factors that affect color perception and refractive error. Huang et al. has studied on 48 students with low vision (whose visual impairment cannot be corrected even with glasses, lenses or surgery), myopia and normal vision and found that long wavelengths, distance and low vision increases the duration needed to locate a target (7). Thyagarajan et al. reported that refractive blur above +3D increases error rates in color vision by performing the FM-100 and CCT tests (8). Rucker and Kruger have shown that accommodation is affected by both refractive error of the subjects and the wavelength composition of the stimulus (9). In the study of Panchal, comparison of 50 male and 50 female showed that female and non-myopic group have lower error rates in FM-100 test compared to male and myopic groups. Dark adaptation and color vision in high myopia was found within normal ranges except color discrimination in blue. Myopic group has significantly increased error rates in blue color discrimination compared to healthy subjects (10). None of the studies above investigated the effects of refractive error on color perception by comparing the corrected-uncorrected vision on three different color scales.

The aim of the study was to determine the effects of refractive error on red, green and blue colors and the effect of corrective glasses on color perception. This experiment will test the hypothesis that refractive error will result in higher error rates in color perception when uncorrected.

METHODS

Participants

This was an observational single center study. Participants were volunteers from Bahçeşehir University. None of the participants had any ocular pathology or any health conditions that would affect the experiment. Ocular health status was obtained by self-report. Participants were grouped according to their refractive status. There are two groups in the experiment. Emmetropes (<+/- 0.5D) and participants with refractive error (>+/- 0.5D). Participants with refractive error were further divided into participants with contact lenses (n=25), participants with no correction (n=8), myopes (<-0.5D) and hyperopes (>+0.5D). Participants with color vision deficiency were not enrolled. Participants with refractive error without correction (glasses, contact lenses) and participants with refractive error, who used contact lenses for correction, were not statistically analyzed. The study was explained prior to the experiment and an informed consent was obtained from the volunteers. Name, surname, age, gender and refractive error (if any) of the participant were recorded on the data record form. The study was approved by the ethics committee of Bahçeşehir University, Istanbul, Turkey (2016-06/01, 07.09.2016).

Stimulus, Materials and Design

The experiment was conducted in a well-lit (4794 lumen), quiet $47m^2$ (6.6m*7.2m) room with 2 lights, a tripod, a table and a chair. The chair was 4 meters away from the tripod and the table was placed between tripod and chair. 6400K daylight bulbs were placed on the sides of the chair one meter away on each side. Tripod, used to show randomly selected color, was placed at the eye level of the volunteer in front of a white background (Figure 1). An A4 paper with two sets of five shades of each three main colors was given to the participants. A color was shown on the tripod and the volunteer was asked to mark the color onto the given paper. Fifteen colors were selected from Excel 2010 RGB color model according to increasing pixel brightness. Five shades of three main colors are listed in the table 1 according to the CIE (Commission Internationale de l`Eclairage) color coordinate values (Y, x, y). Matching marking was counted as correct whereas any other marking was considered incorrect. (The plan was to examine the offset from the correct marking but results showed that almost all of the volunteers were always offset by one shade.) Light levels were obtained using the Light Meter app.

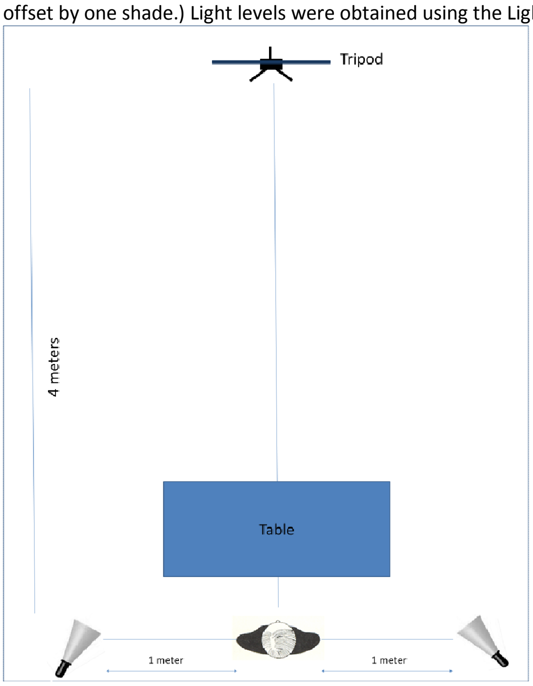

Figure 1. Experiment set-up indicating the placement of lights and tripod.

Table – 1: Five shades of red, green and blue based on CIE (Commission Internationale de l`Eclairage) color coordinate values (Y, x, y)

Red			Green			Blue		
Y1: 4.5891	x:0.64	y:0.3299	Y1*:9.5027	x:0.3	y:0.6	Y1:0.9593	x:0.15	y:0.06
Y2*:6.7723	x:0.64	y:0.3299	Y2:15.4383	x:0.3	y:0.6	Y2:1.5585	x:0.15	y:0.06
Y3:8.1091	x:0.6056	y:0.3110	Y3**:44.1285	x:0.3016	y:0.5650	Y3*:16.7227	x:0.1674	y:0.1228
Y4**:21.26	x:0.6400	y:0.3299	Y4:74.5837	x:0.3175	y:0.5661	Y4:30.0024	x:0.1859	y:0.1895
Y5:23.6276	x:0.6204	y:0.3455	Y5:75.304	x:0.3035	y:0.5238	Y5**:50.4057	x:0.2061	y:0.2621

*= used in the first stage of the experiment
**= used in the second stage of the experiment

Two independent variables were investigated in the experiment. The shades of three main colors and the correction of refractive glasses. To test the first hypothesis that refractive error increases error rates in color perception of red, green and blue; color perception on five shades of three main colors was recorded.

To test our second hypothesis that if refractive error is corrected, rate of correct color perception will increase; was examined by the comparison of glasses-on (with corrective-glasses) and the glasses-off states (without corrective-glasses) of participants with refractive error.

Procedure

Prior to the experiment, participants were instructed to familiarize them with the experiment. In three seconds they were expected to match the randomly selected color to the scale. At the first step of the experiment, participants with refractive error (myopes and hyperopes) were asked to observe color with their corrective glasses and emmetropes were asked to observe color without glasses as in their daily life. At the second step of the experiment, participants with refractive error were asked to observe color without using their corrective glasses (labeled as uncorrected refractive error) and emmetropes were asked to observe color with non-corrective (0.0D) glasses. Ametropes were instructed to always match from the color matching sets with their refractive error corrected. Emmetropes were instructed to always match from the color matching sets without glasses. Observing and matching was repeated three times, once for each main color, for both first and second steps. Each participant completed the test in approximately three minutes.

Data Analysis

SPSS 24.0 (SPSS Inc., Chicago, IL) was used for all statistical analysis. Descriptive statistics of continuous variables are given with mean, standard deviation, median, minimum, maximum values, frequency and percent for categorical variables. Pearson Chi-square was used to compare between participants with refractive error and emmetropes. McNemar was used to examine color perception in comparison to refractive error in participants with refractive error. For all statistical comparisons, a p value lower than 0.05 was assumed to indicate statistical significance.

RESULTS

Emmetropes included 67 participants. There were 34 male and 33 female aged between 17 to 22 years of age (Median: 19.57, Std. Deviation: 1.158). Participants with refractive error consisted of 30 male and 30 female with ages between 18 to 22 years (Median: 19.63, Std.Deviation:0.938) (Figure 2). In participants with refractive error group, myopia ranged from -0.5 to -9 diopters. Hyperopia ranged between 0.5 and 5.5 diopters. Participants with refractive error was predominantly myopic. Some participants had different degrees of refractive error for their respective left and right eye, average of both were considered as their error degree.

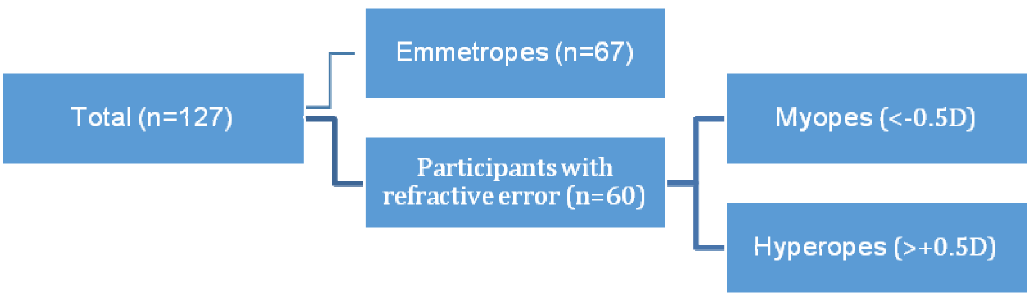

Figure 2. Distribution of participants according to refractive error.

Figure 2 shows the grouping of participants according to their refractive errors. Only statistically analysed participants are shown in this figure.

Results of emmetropes in comparison to uncorrected refractive error were shown in Table 2. Error in color perception presented in chi-square test was significantly higher in participants with refractive error than emmetropes for red color in both genders. The results show that the effect of refractive error on color vision was not significant in green and blue colors.

Table – 2 : Accuracy rates of color vision in emmetropes and participants with refractive error without glasses									
	Red			**Green**			**Blue**		
	Correct			**Correct**			**Correct**		
Female	**N**	**%**	**P Value**	**n**	**%**	**P Value**	**N**	**%**	**P Value**
Ref. Er.	22	73.3%	P=0.000	17	56.7%	P=0.108	15	50%	P=1.000
Emmetropes	32	97%		25	75.8%		18	54.5%	
Male									
Ref. Er.	23	76.7%	P=0.001	19	63.3%	P=0.736	15	50%	P=0.424
Emmetropes	29	85.3%		18	52.9%		24	70%	
Total									
Ref. Er.	45	75%	P=0.015	36	60%	P=0.628	30	50%	P=0.150
Emmetropes	61	91%		43	64.2%		42	62.7%	

To examine whether correcting refractive error, would decrease the error rate in the group of refractive error; the same group was tested with glasses.

Table 3 shows the McNemar analysis of their respective error rates without glasses in comparison to with glasses. Although not significant, p=0.050102 value of blue color indicates that correcting refractive error, may decrease the error rate of blue color vision.

Table – 3: Uncorrected and corrected color vision of participants with refractive error				
Red	**Correct**	**Percentage**	**Total**	**P Value**
Uncorrected	45	75.0%	60(100%)	P=0.096
Corrected	53	88.3%	60(100%)	
Green	**Correct**	**Percentage**	**Total**	**P Value**
Uncorrected	36	60.0%	60(100%)	P=0.286
Corrected	42	70.0%	60(100%)	
Blue	**Correct**	**Percentage**	**Total**	**P Value**
Uncorrected	30	50.0%	60(100%)	P=0.050*
Corrected	42	70.0%	60(100%)	
*: p=0.050102				

Table 4 shows the comparison of color perception in myopia group with and without glasses. There were no significant correlations in any of the colors. The increase in error rates with green color will be discussed in discussion.

Table – 4: Uncorrected and corrected color vision of participants with only myopia					
Red Myopia		**Uncorrected**			
		Correct	**False**	**Total**	**P Value**
Corrected	**Correct**	19	4	23	p=0.375
	False	1	0	1	
	Total	20	4	24	
Green Myopia		**Uncorrected**			
		Correct	**False**	**Total**	**P Value**
Corrected	**Correct**	12	4	16	P=1.000
	False	5	3	8	
	Total	17	7	24	
Blue Myopia		**Uncorrected**			
		Correct	**False**	**Total**	**P Value**
Corrected	**Correct**	9	10	19	p=0.302
	False	5	0	5	
	Total	14	10	24	

DISCUSSION

The hypothesis was tested in two steps. At first step, uncorrected participants with refractive error and emmetropes were compared. Difference between participants with refractive error and emmetropes were significant in red color. Although no significant results were found on green and blue color, uncorrected participants with refractive error group had higher error rate than emmetropes (Table 3). In both genders decrease in error rates in red color perception were observed. A study by Verrelli B.C. and Tishkof, S. A. shows that the red vision gene found on the X chromosome variates more than other genes as much as three times which reduces sensitivity to red color for males (11). On the other hand, the variation results in an enhanced ability to observe color for females due to two X chromosomes. 97% correct rate on red color perception of healthy females is compatible with their statement. Table 3 supports the results of the previous experiments which stated that refractive error increases error rates in color perception.

In second step, corrected and uncorrected states of participants with refractive error were compared. Our expectation was to see a decrease in error rates when refractive error was corrected and to observe the highest correction in shorter wavelengths.

Shorter the wavelength, more its focus will shift towards the retina and have lower error rates compared to uncorrected myopic vision (10). Although not statistically significant, decrease in error rates of blue color perception in table 4 suggests that correcting refractive error will improve blue color perception. Blue is more susceptible to refraction whereas red, having longer wavelength, is more resistant. The problem with myopia is that the image is focused in front of the eye because of the increase in longitudinal length of the eye (12,13). Or relatively, the eye refracts more than needed which also results in longitudinal chromatic aberration (LCA). Expected observation was; blue color perception would be affected more than green color perception whereas red color perception will be affected the least. This can be seen very evidently in the error rates of uncorrected refractive error and uncorrected myopes results. Blue has the highest error rate whereas red has the lowest. Rucker and Kruger explained this as; long wavelength is focused closer to the retina in myopic vision therefore L-cones will have higher contrast compared to the M-cones and this will result in an increased sensitivity to red (9). Decreased sensitivity of blue color perception in myopes without degenerative fundus changes was also observed (10). Although there were no significant correlation in red and green colors, analysis shows that error rates of participants with refractive error decreased with corrective glasses for all of the three colors (Table-4).

Similar results were also seen in only myopic group except green color perception (Table-5). When corrected, green color perception resulted in increased error rate. This maybe the result of the small population and is reflected with a p-value of 1.000. Even though there were no statistical correlation between red and blue colors; all 10 participants that made errors in blue color without correction, chose the correct color after correction of refractive error. Although the number of participants was 4, same result was also observed with red color. After conducting post-hoc power analysis with G-Power software, the number of participants for all colors was found inadequate for interpretation. Therefore conducting another experiment with increased participant count may shed some light to this topic.

Farnsworth-Munsell 100 Hue Color Vision test is one of the most famous hue discrimination tests. Goal of this test is to identify color vision deficiencies by placing color hues in the correct order (14). It has been used in many scientific studies to compare color discrimination of emmetropes and participants with refractive error (15). However, none of these studies compared uncorrected and corrected states of refractive error group. The reason we used an experiment setup based on Excel 2010 RGB color plate is that FM100 test cannot differentiate between the two different conditions of the same participant. If a color is observed repeatedly under the same conditions such as glasses-on, an error will be made during both observation of the color and marking the color which means that researchers will not be able to observe the error. We tried to create a setup where sole variable was observing the color with and without glasses. Therefore, after observing the color in the first time with glasses and in the second time without glasses, the participants always looked at the scale with glasses; which makes observation of the color with and without glasses the only variable.

One of the main limitations of our study was that participants' ocular health status was obtained by self-report therefore we cannot be sure whether all participants have the best corrected 20/20 acuity. The color scale used in the experiment was not continuous and had low resolution which affects the precision of the matching procedure. The colors chosen were limited by our current printing abilities. Another main limitation was small population size.

CONCLUSION

This study concludes that compared to emmetropes; error rates in red color perception increases with refractive error. Correcting the underlying health problems by using corrective glasses, decreases the error rate.

Conflict of interest
No conflict of interest was declared by the authors.

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