·Investigation·

Relation of eye dominancy with color vision discrimination performance ability in normal subjects

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Abstract

• AIM: To evaluate the performance of dominant eye (DE) for color vision discrimination ability among the medical students with normal color vision.

• METHODS: Total of 50 students studying at Başkent University Faculty of Medicine, including 31 males (62%) and 19 females (38%), with visual acuity of 20/20 and without congenital color vision deficiency (CCVD) evaluated by Ishihara pseudoisochromatic plate test (IPPT) were recruited for this prospective comparative study upon their voluntary participation. DE was determined by the Gündogan Method. The color discrimination ability was examined with the Farnsworth-Munsell 100 hue (FM100) test. Test was applied by two days interval to all subjects for the three times while two eyes (TE), right eye (RE) and left eye (LE) were seeing for detecting red-green (r/g), blue-yellow (b/y) local color spectral regions error scores. The error scores were evaluated for both in DE and non-dominant (NDE). *P* values below 0.05 were considered to be statistically significant.

• RESULTS: The students aged 21.18±2.52 years (mean±SD). Without sex difference the RE and the LE dominancy were found 22(44%) and 28(56%) respectively and FM 100 test total error scores of DE in both r/g-b/y regions were found without gender difference 24.12 ± 14.70, 34.68±18.95, respectively. For the NDE in both, r/g-b/y regions error scores without gender difference were 32.20±19.21, 36.24±17.56, respectively. The difference of total error scores between the DE and NDE was found as 58.80 ±29.92, 68.44 ±31.46. The statistical differences among the DE and the NDE in r/g local region and total error scores were found significant in both genders (*P* < 0.05, *P* <0.001).

• CONCLUSION: The color vision discrimination performance ability was found prominent for DE. This superiority was attributed to higher sensitivity of the r/g local color spectral region. We conclude that DE has priority in r/g color spectral region, probably including inhibition of NDE.

• KEYWORDS: dominant eye measurement; Farnsworth-Munsell 100 hue test; Gündogan method; color vision; color discrimination performance ability
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INTRODUCTION

Normal color vision has been explained with the trichromatic theory. According to this theory, the process of vision starts with the absorption of light by three different photo pigments which have different spectral sensitivities in the retina [1-4]. The absorbed light undergoes a series of neural stages between the eye and brain, and then, is processed in the visual field in the visual cortex and converted into different color sensations [3-5]. Color vision capability may be defective due to either congenital or acquired causes. The most common congenital color vision deficiency (CCVD) is X-linked recessive red-green (r/g) vision deficiency[3-6]. Ishihara plates have been widely used as a test for color vision for the purpose of detecting r/g CCVD[7]. The clinical trials of Gündogan, Birch and other authors showed that Ishihara pseudoisochromatic plate test (IPPT) is the most effective test for detecting r/g CCVD [6-8]. Color vision discriminating ability even found normal by IPPT the same subject should be reexamined in detail by Farnsworth-Munsell 100 hue (FM100) test for evaluating local and total error scores of r/g, b/y color spectral regions [8-11]. FM100 test was reported to be reliable and most sensitive test for the determination of the color vision discrimination ability to distinguish colors in detail in healthy subjects [12-15]. Some differences have been found in FM100 test error scores of healthy subjects for their color discrimination ability [15-17]. Because of the differences due to race, age and educational level of the healthy subjects, the color vision discrimination ability are used to classify as high, medium and low level by comparing with standards[12,13].

In recent years, the relationship between the dominant eye (DE) and the brain's functional choice has become one of the research topics in studies which are focused on the brain's functional asymmetry[18-20]. Eye dominance has been described as the inherited tendency to prefer visual sensations in one eye more than the other eye [21]. It is affirmed that this preference stands out in a large number of sensory functions and the eyes have unequal functional roles in anatomically normal two-eye [22]. It is reported that the images are seen more clearly and larger and the settled retinal images disappear on the cortical level later while seeing with the DE [20,23,24]. Moreover, the DE was found to be superior to non-dominant eye (NDE) in visual acuity, contrast sensitivity and motor functions which are requiring spatial attention and visual-managed [17,18,20]. According to advanced imaging studies, while only DE eye was stimulated, the bilateral activation area was found to be larger than that of when only NDE was stimulated [22]. DE was considered as showing functional laterality due to dominancy of one of the cerebral hemisphere. For this reason identification of DE is important and reliable and standard methods should be used[18,23,24].

As far as we know, the purpose of previous studies was just to compare color vision discrimination ability between right eye (RE)/left eye (LE) and not between DE/NDE. Therefore, the aim of presenting study is to elucidate the issue whether the DE stands out superior to the NDE with the regard to subgroup of color vision discrimination ability which has not been fully elucidated previously.

SUBJECTS AND METHODS

Subjects This study was carried out at the Physiology Department of Başkent University Faculty of Medicine upon approval by Başkent University local research ethical committee (KA09/14). The aim and method of the study were explained in detail and informed consent was obtained for each subject. All procedures were performed in accordance with the ethical standards of the Helsinki Declaration for human subjects. The ethnic origins of all the subjects were Caucasian.

Recruitment We explained to the students that if they have personal interest on the subject of detecting the difference color vision discrimination ability between DE and NDE, they should contact us for participating voluntarily for the survey. We applied IPPT to the all of the volunteers for detecting CCVD [6-8]. The subjects who have CCVD were excluded from the study [6,7]. Subjects with a history of ocular surgery, presence of ocular disease such as strabismus, nistagmus, retinal pathology or a systemic disease such as diabetes mellitus, hypertension which could affect visual acuity and color vision were also excluded from the study[11,12].

Methods Each subject underwent a complete ophthalmologic examination that included best corrected visual acuity, slit lamp bio-microscopy, and dilated funduscopy, visual field test [7]. The color vision examination was carried out by using IPPT [6-8]. Subjects who had been found normal were re-examined by FM100 test for determination color vision sensitivity [9,10]. The DE assessment was performed to all subjects in the same condition by the Gündogan Method[24].

Color Vision Discrimination with FM100 Test Apparatus was prepared on a black floor in front of a window which received daylight from the north at 13:00-14:00p.m. in shiny days from February to June, in the year of 2012 in a quiet environment. The test was not applied in cloudy weather. The test was given three times while two eyes (TE), RE and the LE were seeing respectively. Each of them was done separately with two days intervals without test time limitation. But all these tests were performed within less than 2min. The error scores were calculated in Microsoft Excel [8,11,17]. The total execution time for each subject was approximately one week. The local r/g region error score and the local b/y region error score and total error score were calculated one by one according to the sequences the subjects made [10,11,17]. According to gender difference TE, RE and LE mean values of local and total error scores for r/g, b/y color regions were compared without regarding DE.

Dominant Eye Detection All subjects were tested in the same laboratory conditions by near-far alignment test. The subject has to align two reference points in the horizontal eye-level plane. The line running through the two targets intersects the interocular axis at midpoint between the eyes. The intersection can be imagined as fictive vantage point from which the two targets appear in the same direction. The two equal size black round shaped reference points were used as it was reported by Gündogan previously[24].

After DE and NDE detections FM100 test error scores were sub-grouped according to the eye preference as DE/NDE.

Statistical Analysis The compliance of continuous variables with normal distribution was checked by using the Shapiro-Wilk test. The homogeneity of variances was analyzed with the Levene's test. Because the assumptions of parametric tests were not fulfilled, the Mann-Whitney U test was used to compare two independent groups. Dependent two-group comparisons were performed with the Wilcoxon test. In order to compare three or more dependent groups, the Friedman test and then the Bonferroni-Dunn test, which is

Table 1 Local region and total error scores of FM100 test for TE, RE, LE in normal male and female subjects
($\bar{x} \pm s$, median values)

Parameters	M (n=31)	F (n=19)	Total (n=50)
Red-green local error score			
TE	27.19±14.30 (24.00)	22.52±31.13 (23.00)	25.42±14.65 (24.00)
RE	31.70±16.37 (30.00)[a]	26.31±22.40 (19.00)	29.66±18.85 (26.50)
LE	26.41±16.49 (24.00)	26.57±16.47 (26.00)	26.48±16.31 (25.00)
P	0.032	0.698	0.073
Blue-yellow local error score			
TE	40.25±18.83 (39.00)	25.52±18.32 (28.00)	35.80±19.32 (36.50)
RE	39.48±18.56 (39.00)	27.10±14.49 (25.00)	34.78±17.90 (33.50)
LE	35.54±18.00 (31.00)	35.94±20.12 (36.00)	35.70±18.63 (33.00)
P	0.452	0.210	0.645
Total error score			
TE	67.45±29.95 (61.00)	51.05±28.84 (47.00)	61.22±30.32 (58.50)
RE	71.19±28.68 (73.00)	53.42±32.46 (48.00)	64.44±31.09 (59.00)
LE	61.96±30.24 (60.00)	62.52±34.03 (66.00)	62.18±31.09 (62.00)
P	0.098	0.611	0.506

[a]P<0.05 *vs* r/g local error score of RE different from TE and LE in male.

one of the multiple comparison methods, were used. The results of tests were expressed as the number of observation (n), mean ±standard deviation and median. Categorical variables were statistically evaluated by Fisher's Exact test. The results of tests were expressed as the number of observations (n) and percentages (%). Data sets were evaluated using SPSS software (SPSS version 17.0; SPSS Inc.,Chicago IL, USA). P values below 0.05 were considered to be statistically significant.

RESULTS

Local Region and Total Error Scores of FM100 Test Total of 50 healthy university student volunteers with the normal color vision 31 males (62%, 21.03±2.12 years) and 19 females (38%, 21.42±3.11 years), aged 21.18±2.52 years were included in this study. For all subjects without gender difference (n=50) there were no statistically significant difference in r/g, b/y color spectral regions for both local, and total error scores between TE, RE and LE, the statistical values of mean test results were P=0.073, P=0.645 and P=0.506, respectively. For male subjects (n=31), there were no statistically significant differences in b/y color spectral regions for local, and total error scores between TE, RE and LE tests results were P=0.452 and P=0.098. But when we compared r/g color spectral region error scores of TE, RE and LE groups, the local and total error scores of the RE were found statistically higher than TE and LE (P=0.032). For female subjects, there were no statistically significant differences in r/g, b/y color spectral region for both local and total error scores between the TE, RE and LE test results. The statistical values of groups were P=0.698, P=0.210 and P=0.611, respectively (Table 1).

Dominant Eye Percentage in Gender In male subjects, right eye dominancy (RED) and left eye dominancy (LED) were found in 15 eyes (48.4%), in 16 eyes (51.6%) respectively. In female subjects, RED were found in 7 eyes (36.8%) and the LED were found in 12 eyes (63.2%). LED was found prominent in both male and female subjects. There was not a significant correlation between genders and eye preference (P=0.425).

Evaluation of Error Scores for the r/g – b/y Color Spectral Regions with FM100 Test In order to evaluate the difference of color vision discrimination ability between DE and NDE for the r/g, b/y color spectral regions local and total error scores were compared. For the male subjects there was a statistically significant difference in r/g local error scores between the mean group values of DE (25.48±14.55) and NDE (32.93±17.31) (P=0.014). But, there were no statistically significant difference in b/y local error and total error scores between the mean group values of DE and NDE (P=0.943, P=0.153).

For the female subjects, there was also statistically significant difference in r/g local error scores between the mean group values of DE 21.89±15.06 and NDE 31.00±22.42(P=0.043). On the other hand, it was not found statistically significant difference in b/y for local error and total error scores between the mean group values of DE and NDE(P=0.533, P=0.074). But when total error scores compared between the mean group values of DE 58.80±29.92 and NDE 68.44±31.46 (P=0.025) was found significant.

For all subjects (n=50) statistically significant difference was found in r/g color spectral region for local and total error scores between the mean group values of DE and NDE

Table 2 Evaluation of error scores for the r/g- b/y color spectral regions with FM100 test for DE and NDE eyes in genders

Parameters	Male (n=31)	Female (n=19)	Total (n=50)
r/g error scores			
DE	25.48±14.55 (24.00)[a]	21.89±15.06 (18.00)[a]	24.12±14.70 (23.00)[b]
NDE	32.93±17.31 (34.00)	31.00±22.42 (27.00)	32.20±19.21 (30.50)
P	0.014	0.043	0.002
b/y error scores			
DE	37.77±18.78 (36.00)	29.63±18.62 (26.00)	34.68±18.95 (31.00)
NDE	37.96±17.73 (39.00)	33.42±17.38 (33.00)	36.24±17.56 (39.00)
P	0.943	0.533	0.739
Total error scores			
DE	63.25±28.76 (58.00)	51.52±31.13 (46.00)	58.80±29.92 (51.00)[a]
NDE	70.90±29.68 (69.00)	64.42±34.62 (70.00)	68.44±31.46 (69.50)
P	0.153	0.074	0.025

[a]$P<0.05$ *vs* r/g error scores between DE and NDE in male; total error scores between DE and NDE; [b]$P<0.01$ *vs* r/g total error scores between DE and NDE.

24.12±14.70 and 32.20±19.21, respectively (P=0.002, P= 0.025). But it was not found statistically significant differences in b/y color spectral region for local error scores between the mean group values of DE and NDE (P=0.739, Table 2).

DISCUSSION

In healthy subjects the color vision distinguishes ability is affected by race, age, gender and educational level. This physiological variability leads to differences in the error scores of the FM100 test. Such as Abramov and coworkers [25] found a significant but a small differences between female and male in appearance of monochromatic lights. Even they could not explain the exact mechanism of their observation; they reported that, the final rotation of LGN color space to match the sensory space is not the same for the sex. The ethnic differences in color discrimination ability can be related with macular pigment densities [26]. In Caucasians, color vision discrimination ability was found higher than the other races[6-8,27]. Another important factor which may affect color vision test results is the age range [7,12,13]. This situation is attributed to the age-related decline in Lutein and Zeaxanthin pigments in macula [26,27]. Age-related changes in the crystalline lens, as well as myosis also negatively affected color vision in the elderly [6,7,13]. For this reason the young Caucasian subjects with the mean age was 21.18 ±2.52 years were included in our study. Karaca *et al* [15] reported that FM100 test error scores decreased as educational levels of the subjects increased. Because of this point of view the subjects of our study were taking higher education.

IPPT and FM100 test were applied to subjects with visual acuity 10/10 without refractive correction[6-8]. Among healthy individuals there was no gender difference for color discrimination ability [15]. The subjects were included in our study without gender difference.

We examined the illumination of environment before FM100 test application. It was found that a wide range of different levels of enlightenment ranging from 200lx-1300lx was used. In addition, there was no standard practice for the direction of the light source towards the eye. It has been reported that the distance between the light source and the eye as well as the distance between the light source and the test, and the direction of the light are also important [17,28]. However, it has been established that these conditions were not paid attention to and there was no standard practice. It has been predicted that the light source affects the brightness of the colors and can lead to changes in the color quality of the pieces due to the long-lasting effect of the temperature. For this reason, when adjusting the illumination of the working environment, it is thought to be more appropriate to take advantage of natural daylight. Among the options specified in the literature, natural daylight is preferred rather than artificial lighting. The requirements specified in the literature were implemented and each test was applied in front of a window which receives daylight from the north at the same time in same condition [17]. Mantyjarvi [10] who used artificial lighting found no difference between error scores for RE/LE color vision discrimination ability. Giuffrè *et al* [29] had not found difference between the total error scores of the RE/LE, who also mentioned about the changes color vision discrimination during menstrual cycle and we take care of this point in our study for female subjects. Among the studies tested with artificial lighting different results were observed such as, Karaca *et al*'s [15] study aimed to obtain the reference values of the FM100 test total error scores. He applied test to the each subject while their RE and LE were open, the mean total error scores were found 66.23±31.34 and 54.27±29.81 for RE/LE respectively. According to these results color vision ability of the LE was found higher than RE and the difference was statistically significant. This difference was described as a learning effect due to application of test which was firstly applied to the RE and then to the LE. Such as ours study in which more than one test is applied to the same subject the effect of learning on the results of the test is a point at issue. As it was declared in Costa *et al*'s [30] study, a learning effect was not observed among the tests, while the effects of learning are discussed in the study of Karaca *et al* [15], Kaimbo *et al* [27] and Hovis *et al* [14]. The subjects align the pieces after the observation of the colors that they see on the pieces undergoes a mental questioning process. This type of memory, which is formed by creating a short-term memory, is often effective in seconds to a few minutes. If the same data were encountered many times and stored for a long time in the mind, it has been reported that the data would be transferred from short-term to long-term memory and a consolidation would take place. But short duration of the test and the presence of the two-day interval between tests exclude the learning factor from our study. On the other hand, the absence of statistically significant differences in the total error scores between TE the RE and the LE seeing respectively, has shown that the learning factor did not affect our study (Table 1). It has been reported that there was an increase in error scores of consecutive tests due to fatigue but in our study the time intervals between tests was also excluded this effect.

People with normal color perception have three different types of cones. Each type of cone is tuned to perceive predominantly long wavelengths (reddish), middle wavelengths (greenish), or short wavelengths (blueish), referred to as L-, M-, and S-cones. The cone cells on the retina are the crucial physical components of seeing color. The ratio between signals received from the three cone types allows the brain to perceive all possible colors. At lower light levels, the sensitivity is greatest at a bluish-green wavelength. At moderate to bright light levels in which we performed our test, where the cones function, the eye is more sensitive to yellowish-green light than other colors because this stimulates the two most common (M and L) of the three kinds of cones almost equally. The peak wavelengths are near 564-580nm in L, 534-545nm in M, and 420-440nm in S. The lens and cornea of the human eye are increasingly absorptive to shorter wavelengths. In R-G perception the total wavelengths are located in a wide range (535-580nm) which may cause scatter in the eye. Not only wavelength and environmental brightness but also inheritance of color vision is important for color perceptions. People with normal clinical color perception may have genetic mosaicism and has different spectral sensitivity, and cause variation in human color vision sensation. These factors may cause difference of r/g but not in b/y discrimination performance due to eye dominance[1,3,4]

At the beginning of the study we compared the difference between RE/LE. The r/g local region error scores for male subjects were found 31.70±16.37 and 26.41±16.49, respectively (P<0.05) and for female subjects 26.31±22.40 and 26.57±16.47, respectively (P<0.698, Table 1). Which means for male subjects color vision performance ability of LE was higher than RE in r/g local color region. But when r/g and b/y local regions error scores of the same subjects were compared for evaluating the difference between DE/NDE the results were far difference than RE/LE findings (Table 2). The local and total error scores in r/g color spectral region of FM100 test for DE were found to be lower than the NDE which means color vision discrimination ability was higher than NDE (Table 2). In our research study the subjects who had r/g CCVD were excluded by IPPT. For this reasons, the error score difference in FM100 test in r/g axis between to DE and NDE cannot be related r/g CCVD. Therefore, findings of our study show that the DE has superior color vision performance ability both male and female subjects for in r/g local color spectral region (Table 2).

Previous studies in the literature had been compared color vision discrimination abilities only for RE/LE. We are unaware of any previously published data that examine the color vision discrimination performance ability between DE/NDE with FM100 test.

We hope that advanced studies with the help of developing imaging techniques will obtain more descriptive information about DE and its relation to functional changes in the cerebral visual center and cooperation with the other cerebral functions.

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