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## Original Research Article

# A new maximum color contrast sensitivity test for detecting early changes of visual function in age-related macular degeneration

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## ABSTRACT

**Background and objective:** To determine the association between age-related macular degeneration (AMD) and color perception established by the Farnsworth–Munsell 100 hue (F–M 100) and maximum color contrast sensitivity (MCCS) tests.

**Materials and methods:** We performed a case–control study, which comprised of 100 patients with AMD and 100 healthy controls. To test visual acuity (VA), a typical Snellen chart was used. The computerized F–M 100 and MCCS programs were used for color discrimination.

**Results:** The results of VA, and the F–M 100 and MCCS tests in the healthy controls were statistically significantly better than in the patients with AMD (1.0 vs.  $0.82 \pm 0.16$ ,  $P = 0.005$ ;  $87.39 \pm 24.11$  vs.  $185.39 \pm 74.43$ ,  $P = 0.005$ ;  $1.33 \pm 1.17$  vs.  $1.96 \pm 0.46$ ,  $P = 0.005$ , respectively). When VA was 1.0 in patients with AMD, the total error scores of the F–M 100 test and MCCS test compared with healthy persons were even worse ( $166.09 \pm 66.57$  vs.  $87.39 \pm 24.11$ ,  $P = 0.002$ ;  $1.67 \pm 0.92$  vs.  $1.33 \pm 1.17$ ,  $P = 0.001$ , respectively). Analysis of the results of patients with AMD compared to healthy controls showed the highest error score in the blue color range.

**Conclusions:** The results of the color contrast sensitivity test decreased by half in patients with AMD compared with ophthalmologically healthy patients when they performed the F–M 100 test and by one and half when they performed a MCCS test in the blue color range.

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## 1. Introduction

Age-related macular degeneration (AMD) affects the macula and is a leading cause of significant and irreversible loss of central visual acuity in persons aged over 60 in developed countries [1]. In the civilian noninstitutionalized U.S. population aged 40 years and more, the estimated prevalence of any AMD was 6.5%, and the estimated prevalence of late AMD was 0.8% [2].

Epidemiological studies estimate that the prevalence of AMD in Australia, Europe and North America is 0.2% in 55–64-year-old patients and it increases to 13% in the age group of 85 years [3]. According to the Blind Register Centre, about 50% of blind people lose vision due to ADM in Great Britain [4].

It is known that damage to the retina caused by some diseases can result in the loss of color recognition. In fact, the human eye can see at least 7 million colors, interestingly, not all signals reach the brain visual center; about 20% stop at the pituitary gland [5].

Some studies suggest that demographic factors such as age, sex and even ethnicity should also be considered in explaining the communication values of various colors [6,7]. Studies by Guilford et al. have indicated that people prefer colors in the following order: blue, red, green, violet, orange, and yellow but gender differentiation is minor, with men slightly tending to prefer blue to red, and women yellow to orange, although neither preference is sufficient to offset the above order for the general population. Indeed, this order is consistent even across age and national lines [8].

In a variety of central retinal diseases one of the earliest changes in visual processing is the impairment of normal color vision. Therefore, to perform detailed visual examination, various functions, such as cognitive perception, color contrast sensitivity, health of the visual system and the central processing function are tested. Studies have shown that the assessment of the visual acuity testing by the typical Snellen chart using the Landolt rings (C optotypes) alone is insufficient for the visual function testing because it provides limited information about the central vision, thus it is necessary to determine not only the visual acuity, but also the contrast sensitivity [9]. The aim of this study was to assess visual function (visual acuity and color contrast sensitivity) in patients with AMD.

## 2. Materials and methods

A total number of 200 (395 eyes) patients were enrolled in further analysis according to the subject inclusion and exclusion criteria.

Having obtained permission (No. BE-2-14) from the Kaunas Regional Biomedical Research Ethics Committee, the study was conducted in the Department of Ophthalmology at Kaunas University of Medicine.

The inclusion criteria for patients with AMD were as follows: (1) patients of both genders, diagnosed with early mild or early intermediate AMD who did not have other eye disorders found on detailed ophthalmologic examination; (2) the diagnosis confirmed by color fundus photography; (3) participation consent.

The exclusion criteria for patients with AMD were as follows: (1) related eye disorders (high refractive error, cloudy cornea or lens (nuclear, cortical and posterior subcapsular cataract) except minor opacities, and patients with intraocular lenses, keratitis, acute or chronic uveitis, glaucoma, late age-related macular degeneration, diseases of the optic nerve); (2) systemic illnesses (diabetes mellitus, oncological diseases, systemic tissue disorders, chronic infectious diseases, conditions after organ or tissue transplantation), (3) color fundus photography because of the obscuration in the eye optic system or because of fundus photography quality, (4) congenital color vision deficiencies were excluded by history, (5) patients taking epileptic and sedative drugs.

The inclusion criteria for healthy patients were as follows: (1) no ophthalmological eye disorders were found on detail ophthalmological evaluation; (2) participation consent.

The exclusion criteria for healthy patients were as follows: (1) any eye disorders, (2) patients taking epileptic and sedative drugs.

In this study, visual acuity as well as the transparency of the cornea and lens, and the fundus were investigated in the patients. Biomicroscopy was performed in order to assess the corneal and lenticular transparency. Non-corrected and the best-corrected visual acuity (measured in decimals from 0.1 to 1.0) was evaluated using Landolt's rings (C optotypes) by Snellen test types at a 5 m distance from the chart.

The lens was evaluated by biomicroscopy. The lens was examined using a slit-lamp, positioning the illumination source at a 45° angle and the light beam being set to 2 mm width. Classification and grading of lens opacities was performed according to the Lens Opacities Classification System III.

Refraction testing was performed at each examination to determine the best corrected visual acuity.

Auto Refractometer Accuref-K 9001 Shin Nippon was used for refraction measurement.

Intraocular pressure was measured with Schiottz tonometer. Pupils of the subjects were dilated with tropicamide 1%. After dilation of the pupils, funduscopy was performed with an ophthalmoscope of the direct monocular type and the slit-lamp, using a double aspheric lens of +78 diopters.

Stereoscopic color fundus photographs of the macula were obtained: centered at 45° and 30° to the fovea for a detailed macula analysis with Visucam NM Digital camera (Carl Zeiss Meditec AG, Germany).

AMD was classified according to the Age-Related Eye Disease Study [10]. Early AMD consists of combination of multiple small drusen, few intermediate drusen (63–124 μm in diameter), or retinal pigment epithelium abnormalities. Intermediate AMD is characterized by extensive intermediate drusen, at least one large (giant) druse (≥125 μm in diameter), or geographic atrophy (GA) not involving the center of the fovea. Advanced AMD: GA involving the fovea and/or or any of the features of neovascular AMD [10]. Diagnosis of early AMD was made if it was confirmed by two ophthalmologists and no other eye disorders were found during a detailed ophthalmological examination.

In the investigation of patients, the following computer tests of color sensitivity were used: the F–M 100 hue test [11] and maximum color contrast sensitivity test [12]. The tests

were carried out under artificial daylight illumination; care was taken to use the same instructions in all testing sessions. The light was at about an angle of 90° from the patient's side, the angle of viewing was about 60°, at about 45° to the plate surface and the monitor was free from glare. The F-M 100 hue test requires arrangement of color samples by hue. Four trays containing 85 plastic color samples were provided. Two color samples in each tray were repeated and used as supportive colors, between which other color samples had to be arranged so that a consistent transition of hue between the two supportive colors was achieved. The color samples were chosen in such manner as to cover the entire range of hues. The samples differed in tone but their hues were of approximately the same brightness and intensity. Two minutes were given for each tray, though the speed of accomplishment of the test was not highly accentuated, but the total time to complete the test was recorded.

A sequence number was assigned to each color sample. The result was evaluated as the total differences between the number of color sample chosen by a subject and the sequence number of the color sample actually belonging to that position. The degree of distinction of colors is assessed. The sensitivity of colors may be very high, i.e. the number of mistakes is up to 20; or normal average, i.e. the number of mistakes from 21 to 100; or disturbed, i.e. the number of mistakes is more than 101.

In the computer test of maximum color contrast sensitivity, a subject had to determine the correct direction of a bar in a circle. The subject had to press a button with a bar matching the direction of a bar in the circle. The luminance of the gray background of the monitor was 350 cd/m<sup>2</sup>. The luminance of the surrounding area was 400 cd/m<sup>2</sup>.

If the direction was unclear, blank button was pressed. After a button was pressed a, blank screen appeared, and then after one second, a circle with a randomly chosen direction of bars was shown. If the direction of the bar in the circle was chosen incorrectly, its color was automatically highlighted. After the correct choice of the direction of the bar, the intensity of its color was automatically dulled and in the presence of this chromatic contrast of the bar, brightness of background of the circle was changed. The first correct answer after a series of incorrect answers or the first incorrect answer after a series of correct answers was accepted as subject's maximum sensitivity to the target color of the bar. When subject's maximum sensitivity to the target color of the bar had been assessed, the color of the bar was changed and everything started from the beginning again. The bar could be of six colors: red, green, blue, greenish blue, violet, or yellow. Once subject's sensitivity to all these colors had been assessed, all the findings were recorded in a database, and the results of the test were presented in a result window. Color contrast sensitivity tests were performed with best-corrected visual acuity.

Stimuli were generated and presented on a color monitor for calibration. The chromaticity of the monitor's phosphors was calibrated using a spectrometer (VIS-LIGA of STEAG microParts GmbH). The computerized tests were compared with the original test using a Bland and Altman plot [13]. The range of square root of TES for 18 subjects tested was from 6.7 to 16.4. The results of comparison yielded the bias (absolute systematic error of computerized test) of 14.7%, the upper limit of 34.6% (+1.96 SD), the lower limit of 5.1% (-1.96 SD).

Statistical analysis was performed using the computer program SPSS/W 13.0 (Statistical Package for the Social Sciences for Windows, Chicago, IL, USA). The data are presented as absolute numbers (percentage), the average values and standard deviations (SD). The t test and the Mann-Whitney U test were used for the comparison of the two groups. A statistically significant difference was considered if  $P < 0.05$ .

### 3. Results

A total number of 200 participants were enrolled in the study. The control group (Group 1) consisted of 100 (198 eyes) healthy persons (34 men and 66 women). The study (Group 2) included 100 individuals (197 eyes) with AMD (34 men and 66 women) (Table 1). Patients and healthy controls were matched by age and gender.

The presence of AMD in one eye was diagnosed in 2 subjects (2% of patients) and in both eyes, in 98 individuals (98% of the patients), and 1 patient had eye prosthesis because of an eye trauma. In all patients, early mild or early intermediate age-related macular degeneration was diagnosed.

The results of the study showed that visual acuity of the eyes in the control group (Group 1) was significantly higher than in the patients (Group 2) ( $1.0$  vs.  $0.82 \pm 0.16$ ,  $P = 0.005$ ). The total error score of the F-M 100 hue test in the Group 1 were better than in the Group 2 ( $87.39 \pm 24.11$  vs.  $185.39 \pm 74.43$ ,  $P = 0.005$ ) (Table 2). The F-M 100 hue test results ranged from 28 to 140 in healthy persons, and from 72 to 388 in patients with AMD. In the persons with AMD the results of maximum color contrast sensitivity test were significantly higher than in the controls ( $1.33 \pm 1.17$  vs.  $1.96 \pm 0.46$ ,  $P = 0.005$ ). The results of the maximum color contrast sensitivity test ranged from 0.26 to 3.17 in the healthy patients group, and from 0.66 to 3.99 in patients with AMD. When visual acuity was 1.0 in patients with age-related macular degeneration, the results of the F-M 100 hue test and maximum color contrast sensitivity test were even worse compared with healthy persons ( $166.09 \pm 66.57$  vs.  $87.39 \pm 24.11$ ,  $P = 0.002$ ;  $1.67 \pm 0.92$  vs.  $1.33 \pm 1.17$ ,  $P = 0.001$ ).

Color contrast sensitivity was very similar in men and women, and we did not find any difference between the control group (Group 1) and in the patients group (Group 2) (Table 3).

During the F-M 100 hue test, Group 2 participants with AMD made mistakes related to the different range of the following colors: red, 9.7%; green, 14.7%; and blue, 75.6%. They showed

**Table 1 – The groups studied.**

Characteristic	Healthy subjects (Group I), n = 100	Patients with AMD (Group II), n = 100	P
Men, n (%)	34 (34)	34 (34)	NS
Women, n (%)	66 (66)	66 (66)	NS
Age, mean ± SD, years	62.85 ± 11.88	63.15 ± 9.93	NS

AMD, age-related macular degeneration; NS, not significant.

**Table 2 – The results of the Farnsworth–Munsell 100 hue, maximum color contrast sensitivity and visual acuity tests in healthy subjects and patients with age-related macular degeneration.**

Factor	Healthy subjects (Group I) n = 100	Patients with AMD (Group II) n = 100	P
Farnsworth–Munsell 100 hue test, mean ± SD	87.39 ± 24.11	185.39 ± 74.43	0.0005
Maximum color contrast sensitivity, mean ± SD	1.33 ± 1.17	1.96 ± 0.46	0.0005
Noncorrected visual acuity, mean ± SD	1.0 ± 0	0.53 ± 0.35	0.001
Best corrected visual acuity, mean ± SD	1.0 ± 0	0.82 ± 0.16	0.005

AMD, age-related macular degeneration.

the worst result (the highest error score) in the blue color sense.

During the maximum color contrast sensitivity test, Group 2 patients made more mistakes in the blue color range, 74.6% of patients, while 14.2% of patients made mistakes in the green color range, and 11.25% in the red color range. The blue color range was considerably harder to distinguish for AMD patients (Table 4).

The control and the patient groups did not differ ( $P > 0.005$ ) in the duration of performance of the F–M 100 hue and maximum color contrast sensitivity tests.

#### 4. Discussion

There are no numerous large studies on the impact of AMD on color vision with the F–M 100 hue test, and there is no study that evaluated the impact of the maximum color contrast sensitivity test on color vision in AMD patients. Color sensitivity is extremely sensitive [14]. Literature data analyzing the effect of AMD on color vision are inconsistent, therefore the purpose of this article is to assess how the presence of AMD is associated with the decreasing perception of colors and visual acuity. The F–M 100 hue test and maximum color contrast sensitivity tests are useful to determine this relationship, because the F–M 100 hue test and maximum color contrast sensitivity tests enable researchers to find out not only red–green and blue–yellow color perception disturbances, but also the saturation of the color. Our study demonstrated that the F–M 100 hue test and maximum color contrast sensitivity test results in healthy controls were significantly better than in patients with AMD. Some scientists have found age-related macular degeneration increased the F–M 100 hue test scores [15], others detected that the F–M 100 hue test was normal in all AMD patients [16]. Kleiner et al. also found that the impairment of the contrast sensitivity function increased with increasing drusen grade but according to their concept of drusen grade, drusen number, size, and degree of confluence were grouped

together, so they were not able to analyze the influence of the different drusen characteristics on spatiotemporal contrast sensitivity [17]. Frennesson et al. established that color contrast sensitivity may offer an additional possibility of predicting exudative AMD [18]. Eisner et al. found that performance on the color test was significantly impaired in AMD risk eyes compared to control eyes [19]. Therefore many studies are in agreement with our study. Also it is a very interesting fact that when visual acuity was 1.0 in patients with age-related macular degeneration, the total error score of the F–M 100 hue test and maximum color contrast sensitivity were even worse compared to healthy persons, suggesting that color sensitivity is one of the most sensitive functions of the visual system.

Moreland together with Dain in their study established that the F–M 100 hue test results depended on macular pigmentation [20]. Woo and Lee found that the differences in macular pigmentation between Europeans and Asians significantly influenced the results of the F–M 100 hue test [21]. However, these authors also pointed out that the difference was notable between Asians and brown-eyed Europeans [22].

Women are believed to be more discriminating in the use of color names than men and this is often taken to imply superior color vision. Differences between men and women in red–green color discrimination have been reported as not being significant [23]. Conway BR established that the gender-related differences of “physiologic color space” remained unknown [24].

The results of the F–M 100 hue test and maximum color contrast sensitivity tests in the healthy men and women were statistically insignificant. Other scientists evaluated 60 ocular healthy subjects (equal number of males and females) in the 17–22-year age group [25]. The task was to match 22 test color strips with 2 shade charts of different colors. Total number of correct answers and total time taken in matching all the test color strips with the shade charts was recorded and analyzed in both sexes. The results of this study showed that women in general gave more correct responses ( $P < 0.001$ ). Our study showed that color contrast sensitivity does not depend on

**Table 3 – The results of the Farnsworth–Munsell 100 hue and maximum color contrast sensitivity tests in men and women with age-related macular degeneration (AMD) and in healthy patients.**

Test	Men with AMD	Women with AMD	P	Healthy men	Healthy women	P
Farnsworth–Munsell 100 hue test	191.22 ± 68.05	182.17 ± 77.79	NS	88.38 ± 24.14	86.39 ± 12.34	NS
Maximum color contrast sensitivity test	1.96 ± 1.2	1.95 ± 1.14	NS	1.41 ± 1.27	1.25 ± 1.07	NS

AMD, age-related macular degeneration; NS, not significant.

**Table 4 – Best and worse color sense discrimination using the Farnsworth–Munsell 100 and maximum color contrast sensitivity (MCSS) tests in healthy patients and in patients with age-related macular degeneration.**

	Eyes, n (%)		P
	Group 1	Group 2	
<i>Best color sense discrimination using F–M 100 hue test</i>			
Red color	154 (77.7)	144 (73)	0.2
Blue color	19 (9.6)	0 (0)	0.0001
Green color	25 (12.6)	53 (27)	0.0004
<i>Worse color sense discrimination using M–F 100 hue test</i>			
Red color	30 (15.2)	19 (9.7)	0.12
Blue color	80 (40.4)	149 (75.6)	0.0008
Green color	88 (44.4)	29 (14.7)	0.0001
<i>Best color sense discrimination using MCCS</i>			
Red color	109 (55.1)	135 (68.5)	0.0071
Blue color	41 (20.7)	0 (0)	0.0001
Green color	48 (24.2)	62 (31.5)	0.11
<i>Worse color sense discrimination using MCCS</i>			
Red color	48 (24.2)	22 (11.2)	0.0009
Blue color	60 (30.3)	147 (74.6)	0.0007
Green color	90 (45.5)	28 (14.2)	0.0001

gender in healthy persons. Also the test revealed that color contrast sensitivity in men and women with AMD did not depend on gender too (Table 3).

Our results of patients with age-related macular degeneration showed the highest error score in blue color range compared to the healthy controls. It is known that some macular disorders may cause a relative blue–yellow deficiency [26]. Arden et al. described that AMD led to a greater loss of blue–yellow than of red–green sensitivity [27]. Red/green and yellow/blue color discrimination thresholds are sensitive measures of normal retinal function and poor yellow/blue discrimination is often taken as an indicator of retinal disease, though it is generally acknowledged that red/green loss is also present in most cases of acquired deficiency. Although structural changes in age-related macular degeneration and diabetes share some similarities, significant differences remain and this may result in different patterns of red/green and yellow/blue loss. O'Neill-Biba et al. [28] showed a significant but unequal loss of yellow/blue and red/green chromatic sensitivity, with yellow/blue discrimination showing the greatest loss in AMD patients. Holz et al. indicated that blue color contrast sensitivity determined over time could serve as a measure to assess the progression of age-related maculopathy prior to the manifestation of atrophic or exudative macular lesions associated with visual loss [29].

The F–M 100 hue test total error score is highly dependent on the age, the older a subject is, the more errors he makes. The study by Mantjarvi and Terasvirta showed that the total error scores of the F–M 100 test were 120 mistakes in the 60–69-year-old age group [30]. Kessel et al. found that the results of the F–M 100 test were very similar (83 ± 79 mistakes) in healthy persons in Denmark [31] compared to our results (87.39 ± 24.11 mistakes). Hence age is one of the most important factors in the error scores, but it also depends on illness, as it is a disease associated with aging that gradually

and painlessly destroys sharp, central vision therefore color vision decreases, as our study revealed that the presence of age-related macular degeneration was associated with decreasing perception of colors and visual acuity. Our research revealed that color contrast sensitivity results in patients with AMD were twice as bad using the F–M 100 hue test and 1.5 times worse using maximum color contrast sensitivity tests compared with healthy persons, and most of the impact was in the blue color range.

## 5. Conclusions

The results of color contrast sensitivity test in patients with AMD decreased 2 fold in comparison to ophthalmologically healthy patients when they performed the Farnsworth–Munsell 100 hue test and 1.5 fold when they performed a maximum color contrast sensitivity test. Patients with age-related macular degeneration when performing the Farnsworth–Munsell 100 hue test and maximum color contrast sensitivity test had visual acuity worse by 100% compared to healthy persons.

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