Evaluation of Contrast Sensitivity, Color Vision and Visual Acuity in Patients with and without Diabetes

Javad Heravian, PhD[1] • Naser Shoeibi, MD[2] • Abbas Azimi, PhD[1] • Shayesteh Yasini, MSc[3]
Hadi Ostadi Moghaddam, PhD[1] • AbbasAli Yekta, PhD[1] • Habibollah Esmaily, PhD[4]

Abstract

***Purpose*:** To investigate the discriminative ability of contrast sensitivity (CS), color vision and best corrected visual acuity (BCVA) in detecting functional losses in diabetic participants with and without retinopathy

***Methods*:** In this cross sectional study we examined 105 patients in Khatam-Al-Anbia Eye Hospital of Mashhad University of Medical Sciences including 70 diabetic patients (35 with retinopathy and 35 without retinopathy in fundus photography) with 35 control non-diabetic subjects matched for age and sex. The diabetic participants were subgrouped according to the level of retinopathy (EDTRS classification). CS was examined by means of CSV-1000 E instrument at 3, 6, 12 and 18 cpd, respectively in each eye. Color discrimination ability was measured with the Farnsworth D-15 test and BCVA by Snellen chart.

***Results*:** When comparing visual performance of the right and left eyes of patients in each group, only the mean CS values at 6 cpd differ significantly in diabetics without retinopathy (P=0.01). CS was significantly lower in the diabetic eyes with retinopathy than in the normal eyes in all spatial frequencies. Comparing to control group, there was a statistically significant CS loss in spatial frequencies of 3, 6, 18 cpd in the diabetic eyes without retinopathy (P<0.05). The mean logMAR BCVA and color vision abnormalities were significantly higher in the diabetic eyes with retinopathy than in the normal eyes or the diabetic eyes without retinopathy (P<0.001). There was no significant difference between the visual performance of those diabetics without retinopathy compared to the control group. The sensitivity and specificity were almost identical for all tests of visual function in the right and left eyes. The sensitivity and specificity of the CS test in 6 cpd were 71% and 82% which were significantly higher than other spatial frequencies. So the discriminative ability of this spatial frequency in detecting diabetics with retinopathy was 71% and in detecting those without was 82%. The sensitivity and the specificity of the color vision test and BCVAs (logMAR≥0.05, Snellen≤$^{9}/_{10}$) were 79% and 94% respectively.

***Conclusion*:** There was significant difference between the visual performance of those diabetics with retinopathy compared to those without. There was excellent agreement between the results of these three tests. The findings also suggest that the appropriate combination of existing tests may be a useful method of improving screening accuracy in diabetic patients.

***Keywords*:** Contrast Sensitivity, Best Corrected Visual Acuity, Color Vision, Diabetic Retinopathy

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1. Associate Professor of Optometry, Department of Optometry, Mashhad University of Medical Sciences
2. Assistant Professor of Ophthalmology, Mashhad University of Medical Sciences
3. MSc in Optometry
4. Associate Professor of Biostatistics, Mashhad University of Medical Sciences

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Correspondence to: *Javad Heravian, PhD*
Department of Optometry, Mashhad University of Medical Sciences, Mashhad, Iran, Tel:+98 511 7610111, Email: heravianj@mums.ac.ir

Introduction

Diabetic retinopathy (DR) is the most common ocular complication of diabetes mellitus (DM). DR is the leading cause of new cases of legal blindness in Americans aged 20 through 74 years, despite the fact that visual loss due to DR may be preventable either through better glycemic control or photocoagulation treatments.[1-4]

Several attempts have been made to develop a test predictive of the development of retinopathy.[5-7] Changes in visual function in diabetics occur before any structural abnormalities can be detected by ophthalmoscopy or even by fluorescein angiography.[8-11] An understanding of the changes of visual acuity, contrast sensitivity (CS) and color vision during various stages of retinopathy may provide information about the real usefulness of these cost effective screening diagnostic tools in diabetic patients. Various studies have shown that cost effective screening can reduce blind registration due to diabetes.[12-16]

The CSV-1000 E CS test is a potential tool for the screening of early stages in DR.[14] However, many studies will be needed to investigate the sensitivity and specificity of the test as a screening tool. Thus, the aim of this cross-sectional study was to investigate the discriminative ability of these tests in identifying patients at risk of developing clinically detectable DR as part of routine examination.

Methods

We tested three groups of individuals: two groups of diabetic patients with and without retinopathy and one group of healthy age and sex-matched control subjects (each one consisted of 35 subjects).

All enrolled subjects received an accurate and complete ophthalmological examination including visual acuity, slit-lamp biomicroscopy, intraocular pressure measurement, direct and indirect ophthalmoscopy and fundus photography. Control subjects (patients and employees of khatam-Al-Anbia Eye hospital) were included in the study, if they showed normal ophthalmological examination.

Exclusion criteria for both diabetic and control subjects in the study were significant ocular disease beside DR including cataract, glaucoma, optic nerve disease, macular diseases and anterior segment diseases. In addition all patients had ametropia below ±4 DS and ±2 DC and no history of amblyopia that influence CS and color vision.[16,17] Patients with a family history of or a known congenital color defect were also excluded, as were those taking medications that affect color vision and CS.

The majority of the patients were type II (non-insulin dependent) diabetics; three had type 1 (insulin dependent) diabetes.

Classification of retinopathy was made using slit-lamp biomicroscopy and a 90 D lens and fundus photography following mydriasis which was then converted to slide for inspection (EDTRS classification).[4] In this study, eyes were classified as having mild, moderate, severe and very severe nonproliferative retinopathy and early proliferative retinopathy.

Testing of diabetic and control subjects was over the same time period. Medical history including duration of diabetes, mode of control, last fast blood glucose level, hypertension, renal disease and history of ocular photocoagulation were recorded. None of subjects received laser treatment including macular photocoagulation (MPC) and panretinal photocoagulation (PRP). The mean duration of diabetes were 5.9±3.3 years in diabetics without and 9.33±4.33 years in diabetics with retinopathy.

The protocol was approved by the district ethical committee of Mashhad University of Medical Sciences, and all subjects gave written informed consent.

Procedure

Snellen visual acuity, CS test and Farnsworth panel D-15 color vision test were performed on the three groups without any significant prior training. Visual acuity was measured monocularly with the appropriate optical correction at the viewing distance of 6 m using a Snellen chart. CS was evaluated using CSV-1000 E with stationary sinusoidal sine-wave grating at four spatial frequencies. This is a clinically reliable, quick and low cost test to detect early retinopathic changes in diabetic patients.

The CSV-1000 is a distance chart system that displays circular patches of sine-wave

gratings varying in contrast and spatial frequency. It consists of four rows of patches. The upper row tests CS at the spatial frequency of 3 cpd, the second row tests at 6 cpd, the third row tests at 12 cpd, and the bottom row tests CS at 18 cpd.

The chart is back-illuminated and viewed from 8 feet distance. The mean luminance of the charts is 85 cd/m^2 (low photopic conditions). In each row, seventeen circular patches, 1.5 inches in diameter are arranged. The far left patch contains a grating of high contrast, which serves as sample. The remaining 16 patches appear in eight columns, each containing a pair of patches. In each pair, only one patch contains a grating, whereas the other is blank. The patches containing gratings decrease in contrast from left to right across the row (Figure 1). After initial demonstration to each subject, each eye was tested at each spatial frequency. The participants were instructed to choose which patch of the pair contained the grating (top or bottom patch). CS for each spatial frequency was determined from the last correct response. The sensitivity values were transformed into a logarithmic scale, and each subject's CS function curve was generated, describing the entire visual system sensitivity to contrast. After evaluating mean CS for each group, we compared the four mean values (one at each spatial frequency) of the two diabetic groups to the four mean values of the control group for each eye. Group differences in CS scores were tested for significance.

Psychophysical estimates of color vision were investigated using the Farnsworth panel D-15 test. This test is widely used clinically for the detection of acquired and congenital color vision defects. Color vision was assessed monocularly with appropriate near correction. The test was performed under illuminant "C" (Standard illumination "C" of the International Commission on Illumination) lighting conditions at an illuminance of 200 lux. This test was done at the distance of approximately 50 cm. Subjects were required to arrange the caps according to perceived hue-matching sequence and a time of 2 minute was suggested to the subjects prior to presenting the test. Subjects were instructed to select the cap most similar to the reference cap, then the cap most similar to the previously chosen one, and so on, and to place them in sequential order until all 15 caps were arranged in a hue-matching sequence. The subject first viewed the test, which was explained to him then the caps were removed and mixed. Subjects were allowed to review their ordering and make any necessary changes.

However, if subjects exceed this time, they were not disturbed from completing the task. Failure on the test occurred whenever there were two or more, major crossings that were parallel to one of the confusion axes on the score sheet. A major crossing in this study was defined as an algebraic difference between adjacent caps that was greater than three.

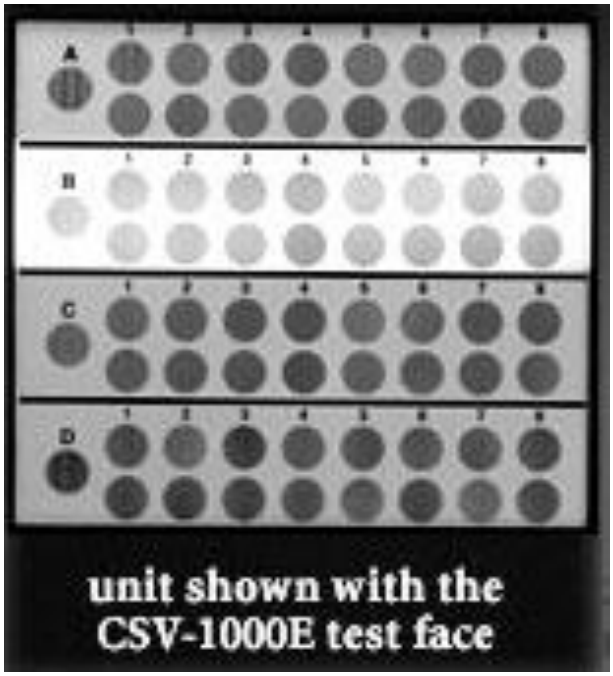

Figure 1. Contrast sensitivity test system

Statistical methods

The SPSS 11.5 statistics software package was used. Data were summarized using means, standard deviation and tables. To study the relationship of two quantitative variables and two qualititative variables Pearson correlation test and χ^2 were used, respectively. The analysis of the qualitative related variables was done with the McNemar test. The McNemar test assessed the significance of the difference between two dependent samples when the variable of interest was a dichotomy. Independent sample T-test compared the means of two independent groups and paired-sample T-test

was used for comparison of the means of the two correlated (paired) groups. One-way ANOVA was used to test for differences among more than two independent groups and significant differences between groups were evaluated by Post Hoc Tukey test. Values of P<0.05 was considered to be statistically significant.

Results

The mean age for diabetics with retinopathy was 54.1±6.6 years, and 51.0±9.9 years for diabetics without retinopathy and 50.0±5.2 years for controls. 58.1% of diabetics with retinopathy, 60.0% of diabetics without retinopathy and 62.9% of controls were female. No statistically significant differences were observed when comparing groups in term of mean age and sex (P=0.06 and P=0.60 respectively).

Mean and standard deviation of CS values at the four spatial frequencies tested for right and left eyes for the three groups are shown in Table 1.

Paired T-test was used to reveal significant difference of CS between two eyes of each group. A statistically significant difference in mean CS values at 6 cpd was observed between two eyes only in diabetic patients without retinopathy (P=0.01). A one way analysis of variance (ANOVA) was performed to test the differences among all the three groups and significant differences between each paired groups was then evaluated by the Post Hoc Tukey test. The results are as following:

In both eyes of diabetics with retinopathy, mean CS differed significantly from the control group at all spatial frequencies (P<0.05). Comparison of CS between each stage of retinopathy and control groups was not performed due to small size of each subgroup and requirement of several statistical tests and tables. Comparing two groups of diabetics with and without retinopathy revealed statistically significant difference in mean CS at 3, 6 and 18 cpd in right and left eye (P<0.05).

When comparing the group of diabetics without retinopathy with controls, it was found significant difference at 12 and 18 cpd in left eye (P<0.05). However for the right eye the differences were not significant.

McNemar test was used for comparing color vision abnormalities of two eyes which revealed no significant difference between two eyes in each group. χ^2 test showed significant differences between color vision of groups (P=0.001) (Table 2).

Paired T-test did not show any significant differences between best corrected visual acuity (BCVA) of two eyes in each group (Table 3). There was statically significant difference in BCVA between diabetic eyes with retinopathy and two other groups. However, there was not significant difference in BCVA for diabetic eyes without retinopathy and controls.

Pearson correlation coefficient was calculated between duration of diabetes and CS at four spatial frequencies for the right and left eyes of diabetic patients. In diabetics with retinopathy, a negative correlation was observed between CS and duration of diabetes at 6.0, 12.0 and 18 cpd of the right eye (r=-0.34, P=0.04 and r=-0.46, P=0.005 and r=-0.34, P=0.04 respectively) and at 18 cpd of the left eye (r=-0.47, P=0.006). However in those without retinopathy no correlation was found at any of spatial frequencies.

Pearson correlation coefficient showed inverse correlation between fasting blood sugar level and mean CS at 6 cpd in right eye of diabetics without retinopathy (r=-0.34, P=0.04) and left eye of diabetics with retinopathy (r=-0.35, P=0.04).

Color vision abnormalities and logMAR BCVA failed to show significant correlation with diabetes duration, fasting blood sugar, macular edema or retinopathy level.

The sensitivity and specificity values of CS, color vision and BCVA are shown in Table 4.

It reveals that sensitivity and specificity of detection of diabetic is almost similar for color vision and BCVA (LogMAR≥0.05, Snellen≤$^{9}/_{10}$), and better than CS.

There was no significant difference between the visual performance of those diabetics with retinopathy compared to those without.

Table 1. Mean and standard deviation of log contrast sensitivity values for each group

Spatial frequency (cpd)	Right eye			P-value	Left eye			P-value
	Controls	No retinopathy	Retinopathy		Controls	No retinopathy	Retinopathy	
3	1.84±0.09	1.80±0.18	1.69±0.26	0.004	1.82±0.10	1.77±0.12	1.67±0.27	0.001
6	2.04±0.15	2.02±0.18	1.67±0.25	0.001	2.03±0.16	1.93±0.22	1.69±0.26	0.001
12	1.67±0.17	1.54±0.33	1.33±0.38	0.001	1.71±0.20	1.50±0.32	1.35±0.33	0.001
18	1.21±0.23	1.09±0.30	0.83±0.33	0.001	1.25±0.23	1.07±0.33	0.87±0.34	0.001

Table 2. Percentage of color vision defects in diabetic patients and control group

D 15	Controls		No retinopathy		Retinopathy	
	Right eye	Left eye	Right eye	Left eye	Right eye	Left eye
Pass	35 (100.0%)	32 (91.4%)	31 (88.6%)	30 (90.9%)	7 (20.6%)	5 (15.2%)
Fail	0 (0.0%)	3 (8.6%)	4 (11.4%)	3 (9.1%)	27 (79.4%)	28 (84.8%)

Table 3. LogMAR BCVA in controls and diabetic patients with and without retinopathy

	Controls		No retinopathy		Retinopathy	
	Right eye	Left eye	Right eye	Left eye	Right eye	Left eye
BCVA (logMAR)	0.000±0.0	0.0029±0.01	0.0057±0.02	0.0061±0.02	0.1919±0.16	0.1419±0.14

BCVA: Best corrected visual acuity

Table 4. Sensitivity and specificity and 95% confidence interval (%) for screening of diabetics with retinopathy from diabetics without retinopathy

		Right eye		Left eye	
		Sensitivity	Specificity	Sensitivity	Specificity
Contrast sensitivity	3	82.0 (67-90)	44.0 (28-60)	81.0 (65-91)	51.0 (35-67)
	6	71.0 (54-83)	82.0 (66-91)	60.0 (43-75)	81.0 (65-91)
	12	60.0 (43-74)	76.0 (60-87)	66.0 (49-80)	66.0 (49-80)
	18	82.0 (67-91)	61.0 (45-76)	75.0 (58-87)	54.0 (37-70)
Color vision		79.0 (63-89)	94.0 (81-98)	79.0 (63-89)	88.0 (74-95)
BCVA		79.0 (63-89)	94.0 (81-98)	72.0 (55-84)	93.0 (80-98)

BCVA: Best corrected visual acuity

Discussion

There is a marked controversy about the loss of CS in diabetic patients with and without retinopathy and the spatial frequencies at which losses occur in the presence of retinopathy.[18]

In our study, in diabetic patients with and without retinopathy, the loss of the CS at 3, 6 and 18 cpd was found in both eyes. Comparing those with retinopathy to the control group, mean CS differed significantly at all spatial frequencies. However when

comparing the group of diabetics without retinopathy with controls, it was found significant difference at 12 and 18 cpd in the left eye but for the right eye the differences were not significant. This could be attributed to the course of disease and retinal changes between two eyes. The present results confirm the findings of most other studies that a CS loss is present in early DR. Using a high contrast Bailey-Lovie chart and a Pelli-Robson chart in 20 type 2 diabetic patients and 24 age-matched control subjects, Stavrou and Wood found a significant loss of CS in patients with retinopathy compared with the control group.[8]

Support for these finding is also provided by Beszédesová et al,[13] who used Sine Wave Contrast Test (SWCT) and Pelli-Robson test in diabetic patients with mild nonprolifrative diabetic retinopathy (NPDR). They demonstrated that in comparison to the control group, there was a statistically significant difference of CS in spatial frequencies of 1.5, 6, 12, 18 cpd. They also found a significant difference of CS in spatial frequencies of 6, 12 and 18 cpd in diabetics with mild NPDR in comparing to diabetic without retinopathy.

Abrishami et al stated that the loss of CS in diabetes has been variously attributed to retinal changes, but also to lens changes.[19] Risk factors for this loss include advanced age, high systolic blood pressure, and nephropathy.[20] In the present study we tried to exclude all factors that could apparently affect CS function. Yet we observed a significant CS loss in diabetic patients compared with normal subjects.

Mackie and Walsh demonstrated a significant increase in the CS threshold, which was most marked in a diabetic group who had prolifrative diabetic retinopathy (PDR), but was also elevated significantly in the diabetic group with background retinopathy when compared with patients with no retinopathy.[21] North et al also reported abnormal CS at all spatial frequencies in a group of non-insulin dependent diabetes mellitus (NIDDM) patients with background retinopathy.[22] This findings confirm our results that a CS loss is presented in diabetic group with retinopathy. Lobo et al and Lovestam-Adrian et al both reported changes in CS that was related to the degree of retinopathy.[23,24] Brinchmann Hansen and colleagues also found an association between CS and grade of DR, but only at 6 cpd.[25]

Wong et al suggested that the reason for decreased CS in diabetics with minimal to no retinopathy is not clear. Abnormal fluid accumulation in the retina or disturbance of neural function in the retina or the visual pathways by overloading of the aldose reductase system may theoretically be invoked as possible mechanisms.[26]

Impaired visual pathway function might be the result of preretinal factors, such as refractive error, anterior segment disorders, and media opacities that impede the passage of light to the photoreceptors. Any type of lens opacity is associated with a progressive decrease of CS, but the association is greatest for nuclear lens opacity. In the present study, the lens opacity did not differ between the experimental groups under investigation. These data suggest that the observed reduction of CS is not due to lens opacity; which is in agreement with the data reported by Hardy et al.[27]

Several studies have examined the association between abnormal color discrimination and DR.[11,27-29] Our results showed color vision abnormalities were significantly higher in the diabetic eyes with retinopathy than in the normal eyes or the diabetic eyes without retinopathy. Mortlock et al, although reporting that one-third of their diabetic subjects had significant dyschromatopsia, did not find any difference between those with and without DR.[30] In a separate study, Ong et al detected a deterioration in 100-Hue Test scores in subjects with insulin dependent diabetes mellitus (IDDM) who had retinopathy but did not find any correlation with early retinopathic changes.[31] Davies and Morland and Ong et al reported a significant deterioration in performance on color testing in subjects with retinopathy, particularly in the yellow-blue spectral region.[29,31] A possible explanation for the tritan color defect-similar to retinal detachment-might be the oblique orientation of the photoreceptors that occurs after retinal detachment and other retinal pathologies.[1,30]

Wong et al found a positive correlation between color discrimination and extent of retinopathy.[26] Sixty-five percent of those with proliferative changes had abnormal 100-Hue

Test results and those with central changes, specially macular edema, were most affected. In a separate study Verrotti et al also found that the subjects who had PDR performed most poorly on color vision test.[12]

The sensitivity and specificity of detection of diabetes were almost identical for color vision and Snellen visual acuity tests and better than CS. The clinical diagnostic application of CS measurement of patients with DM does not have additional advantage over the color vision or visual acuity. So the appropriate combination of existing tests may be a useful method of improving screening accuracy in diabetic patients.

This study showed the discriminative ability of these tests in screening of diabetic patients. However, there was insufficient sample size to subgroup patients according to the stage of DR and compare the statistical results of these groups. Thus a further study with larger sample size is recommended.

Conclusion

DR is a sight threatening disease where early and effective treatment has been shown to reduce significantly the incidence of blindness. Practicality and patient acceptability are important aspects of any widely used screening test. The psychophysical tests of both CS and color vision meet these criteria and have the potential to be of use in primary care settings as well as the hospital diabetes clinic. In this study we found that diabetic patients with and without retinopathy had significantly more CS, color vision and visual acuity losses than controls of similar age and sex. These tests, which are simple and quick to perform, could complement the existing screening tests for retinopathy, providing additional information about visual function, specially its change over time. Any role of these tests have to play in routine screening for early visual dysfunction remains to be evaluated, but an easily performed test of clinical value with high sensitivity and specificity is obviously desirable.

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