

# Predicting Glaucomatous Sensitivity Loss Using Perimetric Color Saturation Test

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**Purpose:** To predict future glaucomatous sensitivity loss using a perimetric color saturation test (PCST) that measures the color saturation discrimination threshold for six hues (red, yellow, green, green-blue, blue, and purple) at 9° in horizontal and 3° in vertical extrafoveal points.

**Methods:** This new test was carried out on 31 patients (31 eyes) with early glaucoma or ocular hypertension. The sensitivity loss at the four points approximately 9.5° apart from the fixation point was prospectively evaluated annually for 3 years using the Humphrey Field Analyzer (HFA) program central 30-2. The initial results of PCST and the total deviation (TD) in the follow-up HFA results were compared.

**Results:** Twenty-seven patients (27 eyes) were followed up for 3 years. The color saturation threshold for six hues was correlated with the TD of HFA results at 108 points in the 27 eyes. The TD was  $-4$  dB or better at the baseline measurement in 91 out of the 108 points. The averaged TD in the second and the third year in the follow-up period decreased below  $-4$  dB in 10 of these 91 points, which were categorized as progression points in relation to the 81 nonprogression points. In the initial PCST, only the saturation threshold for purple was higher in the progression points when compared with the nonprogression points ( $P = .0004$ , Mann-Whitney  $U$ -test).

**Conclusion:** Future sensitivity loss is most likely at the points where the threshold of color saturation discrimination is increased for purple in eyes with early glaucoma or ocular hypertension. **Jpn J Ophthalmol 2003;47:537-542** © 2003 Japanese Ophthalmological Society

**Key Words:** Central visual pathways, color vision, cone sensitivity, glaucoma, perimetry.

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## Introduction

It is well known that eyes with glaucoma show acquired dyschromatopsia.<sup>1-7</sup> However, conventional color vision tests for congenital dyschromatopsia have disadvantages in detecting the early changes of glaucoma, because the visual dysfunction in glaucoma is localized rather than generalized, especially in its early stages.

To detect the localized color vision defects in eyes with glaucoma, a perimetric color test may be suitable.

With blue on yellow perimetry<sup>8-11</sup> and other similar color tests,<sup>12,13</sup> however, a patient may detect the stimulus light by means of a luminance difference between the test stimulus and the background as well as the color difference.<sup>14</sup>

To eliminate the clue of luminance difference, we have developed a perimetric color saturation test (PCST).<sup>15,16</sup> The color tests, which use a color monitor, are well-known.<sup>17-25</sup> The PCST uses a color display that presents simultaneously six extrafoveal stimuli consisting of one chromatic plate and five achromatic plates. Because these five achromatic plates have different luminances, which span the range of luminance in the colored plates, brightness would not be a clue to detect the color plate. We have previously reported the results of the clinical application of this new perimetric color saturation test, in which the localized color defects could be detected at the extrafoveal locations, where the conventional automated static perimeter failed to detect a relative scotoma in eyes with glaucoma or ocular hypertension.<sup>15</sup> In particular, eyes with ocular hypertension show blue-green saturation discrimination dysfunction in PCST testing. It was not known if this dysfunction predicts future glaucomatous sensitivity loss.

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In this study, we prospectively studied those eyes with abnormal PCST results without field defects, as confirmed by conventional automated static perimetry, to see if these eyes actually would develop glaucomatous changes in the follow-up period.

## Materials and Methods

This prospective observational study was carried out from July 1993 to October 2000 in the glaucoma clinic of the Yamanashi Medical University Hospital. All patients gave informed consent, and the tenets of the Declaration of Helsinki were strictly followed. The criteria for inclusion were as follows:

1. Eyes with ocular hypertension or early glaucoma with 20/20 or better visual acuity.
2. Each eye was tested several times with the Humphrey Field Analyzer (HFA) and showed false-positive error and false-negative error of <33%.

The exclusion criteria were as follows:

1. Patient had congenital color anomaly, ocular diseases other than glaucoma (ie, cataract, age-related macular degeneration).
2. Patient had moderate or advanced glaucoma with  $-8$  dB or less of mean deviation (MD) using the HFA program Central-30-2.

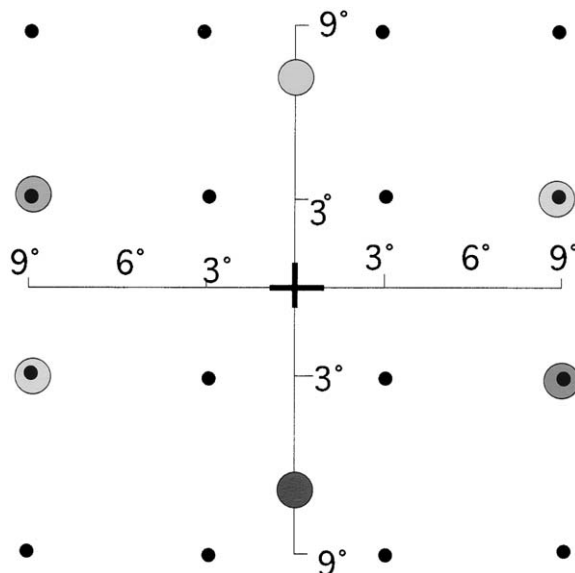
The visual field was tested using the HFA program Central 30-2 before the PCST measurement and repeated in the following 3 years. Four of six stimulus locations of the PCST are in accord with the stimulus locations of HFA. The color saturation threshold and total deviation (TD) of HFA were compared. Four of the six retinal sites were identical to the testing points of the HFA program as shown in Figure 1. Those eyes that showed a total deviation of better than  $-4$  dB (and thus showed no visual field defect) were analyzed.

Thirty-one eyes of 31 patients with early glaucoma or ocular hypertension were selected consecutively for this study at the glaucoma clinic of the Yamanashi Medical University Hospital.

The color saturation thresholds of six hues (red, yellow, green, green-blue, blue, and purple) were measured with PCST in these 31 patients, as previously reported.<sup>15,16</sup> (See next section for details of the PCST.)

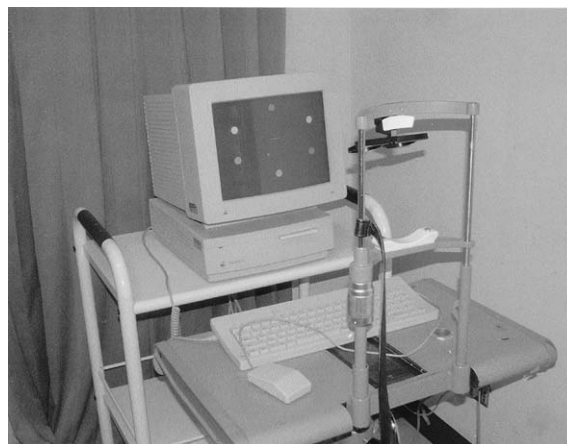
## Perimetric Color Saturation Test

The PCST was developed by the authors to assess the color saturation threshold at any location in the central field. The test is conducted using a color monitor (13"



**Figure 1.** Test locations of perimetric color saturation test (PCST) and Humphrey Field Analyzer (HFA) program central 30-2. Small dots show the test locations of HFA. Six large circles show the test locations of PCST. Four of six stimulus locations of the PCST are in accord with the stimulus locations of HFA.

high-resolution RGB color monitor, Apple) controlled with a personal computer (Macintosh IIsx, Apple) in a dark room. This color monitor has a  $640 \times 480$  pixel display with a 67-Hz refresh rate. The chromaticity and brightness of this monitor was confirmed with a color meter (Minolta CS-100) before measurement. The brightness of these displays ranged from  $1.61$  cd/m<sup>2</sup> to  $77.7$  cd/m<sup>2</sup> in the dark room. The face of the subject was fixed at 57 cm in front of the cathode ray tube (Figure 2) to assure



**Figure 2.** Stimulator of perimetric color saturation test and chin rest. The patient sat with head supported by a chin-rest 57 cm in front of the cathode ray tube.

the constant retinal location of the test area. The subject was tested with best spectacle correction.

To increase the reliability of the color test, large-sized stimulus spots (1.5°) were used in PCST. The stimulus duration is as important as the stimulus size. Our preliminary study investigated the best stimulus duration of PCST in normal eyes. The short stimulus, under 500 milliseconds, decreased the sensitivity, and the long stimulus, over 1500 milliseconds, involved eye movement. Thus, we used 1000-millisecond stimulation duration in this test. After the display of a central fixation point for 1 second, a stimulus screen with six stimulus points, as shown in Figure 3A, was presented. Six visual targets, comprising one chromatic and five achromatic targets with various degrees of luminance, were presented simultaneously in random arrangement for 1 second and the subject's task was to select the colored target among the six targets. This method requires color discrimination for the detection of the test target in the absence of any luminance clue. The luminances of the achromatic target ranged from 4.27 cd/m<sup>2</sup> to 77.7 cd/m<sup>2</sup>. The luminances of the chromatic targets varied within this range; blue (5.64–54.8 cd/m<sup>2</sup>); purple (25.1–62.1 cd/m<sup>2</sup>); red (19.1–59.5 cd/m<sup>2</sup>); yellow (74.8–77.0 cd/m<sup>2</sup>); green (58.6–69.9 cd/m<sup>2</sup>); blue-green (62.8–72.5 cd/m<sup>2</sup>).

The subject was required to select one of the six targets or “nothing.” If the subject failed to answer, PCST did

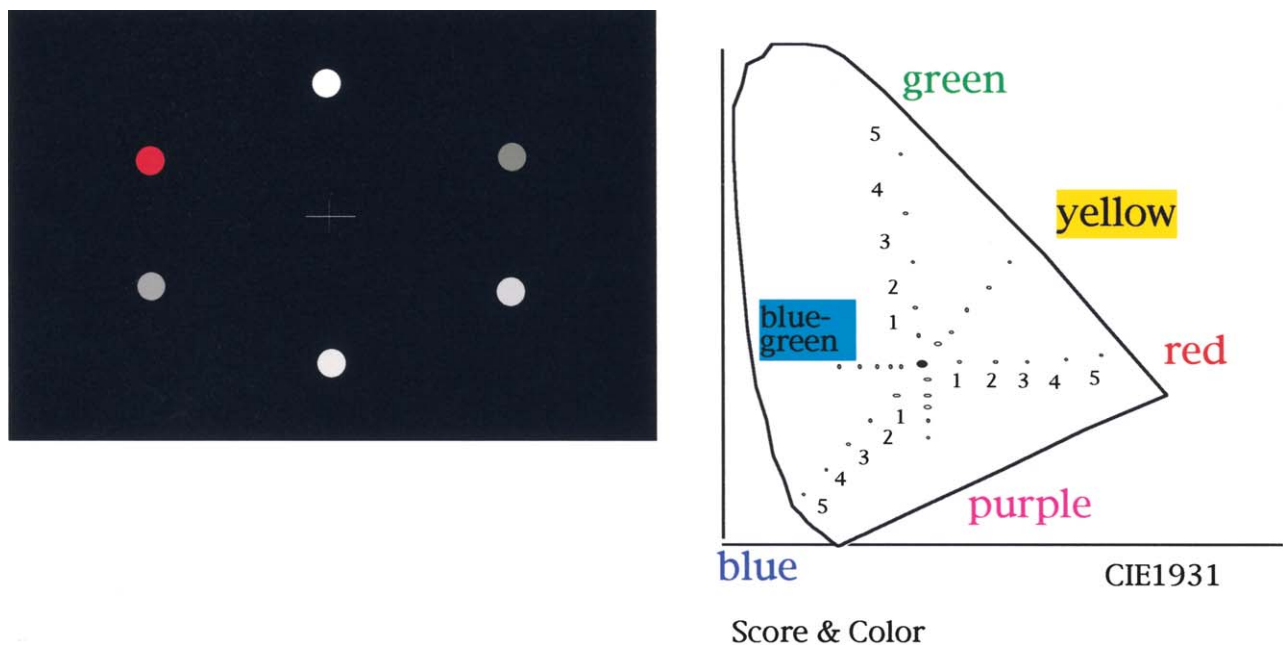
not show the next stimulus. At the first session of this test, the first three answers were ignored to allow the patient to practice. A color target at its highest level of saturation was displayed first in one of the six locations randomly. In each location, the saturation of the chromatic target was decreased when the patient answered correctly. The color saturation threshold of a color was defined as the saturation level at which the patient twice failed to make the correct answer.

The chrominance of chromatic targets was fixed while the thresholds of all six locations were measured. Then the test for the next hue was started. The test was repeated for the six hues (blue, blue-green, green, yellow, red, and purple) with five levels of different saturation for each hue (Figure 3B). The test colors of PCST were selected so as to use the highest saturation colors on the color monitor.

This perimetric color saturation test, which uses colors aligned on protan, deutan, or tritan lines, has been developed by the authors, and will be reported in a future paper.

The result of the PCST was scored into six grades: from 0 to 5, for each hue at each location. A higher score was given for an increase in color saturation. A higher score indicates worse perception of the color.

The chromaticity of the chromatic plates used for PCST was measured with a color meter (Minolta CS-100) and



**Figure 3.** Stimulation pattern and color of perimetric color saturation test (PCST). The stimulation pattern of PCST (left) consists of five achromatic targets and a single chromatic target. Right: these colors are plotted on a chromaticity diagram CIE1931. The numbers indicate increased levels of saturation. A higher score was given for increased color saturation, indicating worse perception of the color.

is displayed on a chromaticity diagram CIE1931 (Figure 3B).

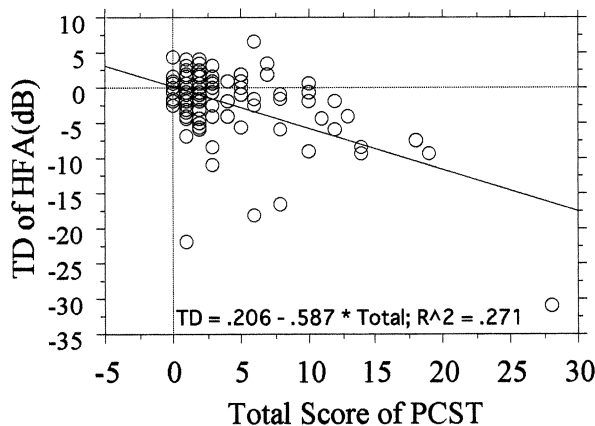
### Results

Twenty-seven patients (27 eyes) were followed up for 3 years. The mean age of the patients was  $55.2 \pm 7.5$  years (range, 40-73 years). The average MD of HFA program 30-2 for these 27 eyes at the baseline measurement was  $-2.33 \pm 3.08$  dB (range, +1.57 to  $-6.49$  dB). The mean refractive error of the 27 eyes was  $-1.15 \pm -1.75$  diopter (range,  $-4.75$  to +2.0 diopter). No patient was taking systemic medication, and none had any ocular disease (ie cataract, age-related macular degeneration) during the study period. The breakdown of the eyes was as follows: 5 normal tension glaucoma (NTG) eyes, 7 ocular hypertension (OH) eyes, and 15 primary open-angle glaucoma (POAG) eyes. The NTG eyes had  $\leq 20$  mm Hg peak ocular pressure; on the other hand, the OH and the POAG eyes had 21 mm Hg or more peak ocular pressure. The OH eyes did not have two adjacent sensitivity loss locations in the 5% or less probability level in tests with the HFA program central 30-2.

In a total of 108 points derived from 4 points in each of the 27 eyes, the correlation between the color saturation thresholds and the TD of HFA was significant for each of the six hues (Table 1).

A higher PCST score means more damage in color sensitivity due to glaucoma. The sum of the PCST scores for all six colors, indicating total color dysfunction, correlates with the total deviation of HFA at the baseline measurement (Figure 4).

Having established that there was a significant correlation between individual measurements of color threshold with our test and the achromatic threshold with the HFA, we determined whether the progress of glaucoma related to changes in the Humphrey threshold measurement could be predicted by the initial color vision test. In order to do this we remeasured Humphrey thresholds after 24



**Figure 4.** Total score of perimetric color saturation test (PCST) and total deviation (TD) of Humphrey Field Analyzer (HFA) at base line measurement. For 108 points of 27 patients, the sum of the scores from six hues on PCST correlated with the TD of HFA. ( $P < .0001$ , Wilcoxon’s signed rank test).

months and 36 months. These were averaged and the result compared to the initial reading. The diagnosing program of HFA decides the TD of  $-5$  dB as the 5% probability abnormal level, and the TD of  $-4$  dB or over as normal in these stimulus locations. To investigate the progression of glaucoma on HFA, only the points with TD of  $-4$  dB or over at initial measurement were included in the comparison. If the TD of HFA was reduced to under  $-4$  dB, the condition was considered progressive. If the TD was unchanged, and  $-4$  dB or over, the condition was nonprogressive. We compared this progress with the initial color thresholds. For statistical purposes, patients were divided into two groups. One group had thresholds determined at levels 0 and 1 (least saturated) and the other at levels 2-5. Thus a  $2 \times 2$  table could be constructed. Figure 5 shows graphically the different color thresholds between the two groups at the initial measurement. Only in 1 case does there seem to be a significant difference of color saturation threshold between the progressive group and the nonprogressive group, and that is for the purple color ( $P = .0004$ , Mann-Whitney *U*-test). Table 2 shows the Fisher’s exact analysis for this data.

Among the 91 points with TD of  $-4$  dB or better at the baseline HFA, the PCST score for purple was 0 or 1 for 67 points and 2 or greater for the remaining 24 points. The latter points, representing the worse perception of the color, showed a greater tendency to become “progressive” (TD would decrease below  $-4$  dB in the follow-up period) than the former ( $P = .0028$ , Table 2).

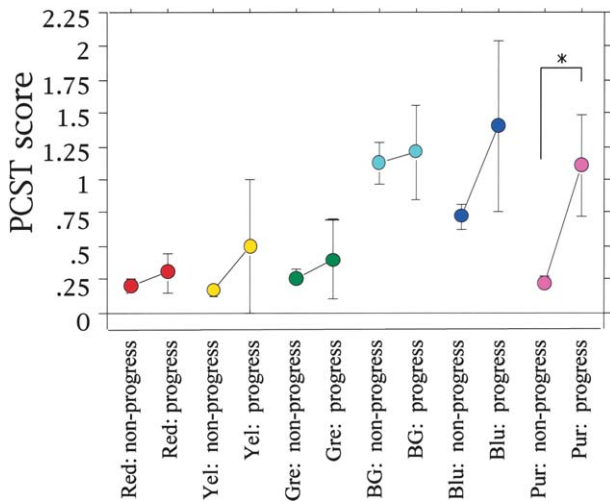
The Fisher’s exact results for other colors were not significant.

**Table 1.** Correlation Coefficient Between Humphrey Field Analyzer (TD\*) and Perimetric Color Saturation Test at Baseline Measurement

Colors	Spearman’s Correlation	P-value
Red	-0.279	.0039
Yellow	-0.197	.0411
Green	-0.321	.0009
Blue-Green	-0.233	.0159
Blue	-0.313	.0012
Purple	-0.460	<.0001
Total of 6 colors	-0.428	<.0001

\*TD: Total deviation.





**Figure 5.** Perimetric color saturation test (PCST) score between “progressive” points and “nonprogressive” points. Ten of 91 normal points progressed to abnormal on Humphrey Field Analyzer. The PCST score of each hue at baseline measurement was compared between 81 nonprogressive points and 10 progressive points. Red, Yellow (Yel), and Green (Gre) had a low PCST score; on the other hand, Blue-green (BG), Blue (Blu), and Purple (Pur) had a higher PCST score. While there was no difference between “progressive” points and “nonprogressive” points on the PCST score of BG, “progressive” points had a significantly higher PCST score with Purple. (\* $P = .0004$ , Mann–Whitney  $U$ -test, Bar = 1 standard error).

### Discussion

In this study, the predictive power for a future decrease in Humphrey sensitivity was greatest for purple test objects. There was a difference in predictive power among the six colors.

Although there are some reports of glaucoma eyes with red-green dyschromatopsia, the majority of glaucoma eyes have blue-yellow dyschromatopsia.<sup>6</sup> Our previous study also reported the blue color saturation discrimination inadequacy of glaucoma eyes.<sup>15,26</sup> In this study, there is a difference of color vision damage detected by the six colors. Although the color saturation discrimination threshold correlates with the TD of HFA in all six colors,

**Table 2.** Purple Score at Base line measurement and Progression on Humphrey Field Analyzer

	Score of Purple		Total
	0–1	2–5	
Progression group	3	7	10
Nonprogression group	64	17	81
Total	67	24	91

$P = .0028$ , Fisher’s Exact Test.

the color vision damage is detected earlier with PCST than with conventional perimetry in purple, blue, and blue-green colors. This suggests the advantage of using these colors for early glaucoma detection. On the other hand, the damage reflected by red, yellow, and green dyschromatopsia was found only where glaucoma damage was found using conventional perimetry. These findings are in agreement with previous reports in which acquired dyschromatopsia generally begins with the blue cone system, and later extends to the red cone system.<sup>27</sup> Therefore, the damage to red color perception means serious and irreversible damage.

Before this study, we expected that the blue-green color would predict future glaucoma damage, because the ocular hypertension eye had a larger blue-green abnormal score in PCST testing. However, it was not blue-green that predicted future glaucoma damage but purple.

We speculate that the reasons for this result are as follows:

- Damage to blue and blue-green color perception is frequent in glaucoma eyes but it takes a long time for these visual field changes to appear in conventional perimetry testing.
- Damage to red, yellow and green perception usually appears after damage detected by conventional perimetry, due to the redundancy of red and green cones in the retina.
- Damage to purple perception has intermediate effects on the other five colors due to damage to both the red and blue cone systems, and occurs before any changes are detected in conventional perimetry.

Clinically, we often observe that a progressive glaucoma patient had successful treatment. If the glaucoma damage is determined at an early stage, we can evaluate glaucoma treatment correctly and decrease unnecessary medications. If it were possible to use PCST to achieve an early stage prediction, this would be very beneficial. The evaluation of many visual functions has great potential for changing glaucoma treatment. In the present version of PCST, there is not sufficient sensitivity and specificity to predict early glaucoma damage. Previous studies indicated that certain types of color sensitivity damage varies with the glaucoma type and that color damage varies with the visual field location.<sup>28,29</sup> To improve the sensitivity of the PCST, we might need to choose other hues, different brightness for the test stimulus, and other stimulus locations in the visual field. It is not known which is more advantageous for glaucoma prediction, testing in the photopic condition or testing in the mesopic condition. The present PCST uses a dark background, and might be reflecting both rod and cone

function. If we want to isolate the cone function, we might need to use a bright background.

In this study, we found that there are differences between the six hues for early glaucoma damage prediction. The PCST using the purple color saturation threshold is suitable for early glaucoma diagnosis, because only purple would predict future sensitivity loss from glaucoma.

## References

- Lakowski R, Bryett J, Drance SM. A study of colour vision in ocular hypertensives. *Can J Ophthalmol* 1972;7:86–95.
- Adams AJ, Rodic R, Husted R, Stamper R. Spectral sensitivity and color discrimination changes in glaucoma and glaucoma-suspect patients. *Invest Ophthalmol Vis Sci* 1982;23:516–524.
- Flammer J, Drance SM. Correlation between color vision scores and quantitative perimetry in suspected glaucoma. *Arch Ophthalmol* 1984;102:38–39.
- Airaksinen PJ, Lakowski R, Drance SM, Price M. Color vision and retinal nerve fiber layer in early glaucoma. *Am J Ophthalmol* 1986;101:208–213.
- Kurata K. Study on the color discrimination of subjects with acquired anomalous color vision; Report 1, On the hue confusion of the glaucoma. *Nippon Ganka Gakkai Zasshi (Acta Soc Ophthalmol Jpn)* 1965;69:1998–2006.
- Drance SM, Lakowski R, Schulzer M, Douglas GR. Acquired color vision changes in glaucoma. *Arch Ophthalmol* 1981;99:829–831.
- Abe H, Sakai T, Yamazaki Y. The selective impairment of the three color mechanisms (red-, green-, and blue-sensitive mechanisms) isolated by the new color campimeter in pathological eyes with fundus disease: studies of static threshold campimetry in early glaucoma. *Nippon Ganka Gakkai Zasshi (Acta Soc Ophthalmol Jpn)* 1983;87:950–957.
- Hart WJ, Silverman SE, Trick GL, Neshet R, Gordon MO. Glaucomatous visual field damage. Luminance and color-contrast sensitivities. *Invest Ophthalmol Vis Sci* 1990;31:359–367.
- Sample PA, Weinreb RN. Color perimetry for assessment of primary open angle glaucoma. *Invest Ophthalmol Vis Sci* 1990;31:1869–1875.
- Johnson CA, Adams AJ, Casson EJ, Brandt JD. Blue-on-yellow perimetry can predict the development of glaucomatous visual field loss. *Arch Ophthalmol* 1993;111:645–650.
- Johnson CA, Adams AJ, Casson EJ, Brandt JD. Progression of early glaucomatous visual field loss as detected by blue-on-yellow and standard white-on-white automated perimetry. *Arch Ophthalmol* 1993;111:651–656.
- Logan N, Anderson DR. Detecting early glaucomatous visual field changes with a blue stimulus. *Am J Ophthalmol* 1983;95:432–434.
- Yu TC, Falcao-Reis F, Spileers W, Arden GB. Peripheral color contrast. *Invest Ophthalmol Vis Sci* 1991;32:2779–2789.
- Felius J, de Jong LAMS, van den Berg TJTP, Greve EL. Functional characteristics of blue-on-yellow perimetric thresholds in glaucoma. *Invest Ophthalmol Vis Sci* 1995;36:1665–1674.
- Kogure S, Saitou S, Chiba T, et al. A new perimetric color saturation test for glaucoma eyes. *Atarashii Ganka (J Eye)* 1995; 12:829–832.
- Kogure S, Iijima H, Tsukahara S. A perimetric color saturation test in eyes with glaucoma and ocular hypertension. *Invest Ophthalmol Vis Sci* 1996;37:S508.
- Arden GB, Gunduz K, Perry S. Colour vision testing with a computer graphics system. *Clin Vis Sci* 1988;2:303–320.
- Gunduz K, Arden GB, Perry S, Weinstein GW, Hitchings RA. Colour vision defects in ocular hypertension and glaucoma: quantification with a computer driven colour television system. *Arch Ophthalmol* 1988;106:929–936.
- Arden GB, Gunduz K, Perry S. Color vision testing with a computer graphics system: preliminary results. *Doc Ophthalmol* 1988;69: 167–174.
- Gunduz K, Arden GB. Changes in colour contrast sensitivity associated with operating argon lasers. *Br J Ophthalmol* 1989;73:241–246.
- Berninger TA, Canning C, Strong N, Gunduz K, Arden GB. Using argon laser blue light reduces ophthalmologists' color contrast sensitivity. *Arch Ophthalmol* 1989;107:1453–1458.
- Falcao-Reis F, O'Donoghue E, Bucetti R, Hitchings RA, Arden GB. Peripheral contrast sensitivity in glaucoma and ocular hypertension. *Br J Ophthalmol* 1990;74:712–716.
- Tak Yu V, Arden GB, Hogg CR, O'Sullivan F, Spileers W, Falcao-Reis F. New colour vision test of retinal periphery: very high sensitivity and selectivity for damage in glaucoma prior to field loss. *Invest Ophthalmol Vis Sci* 1991;32. ARVO abstract 2158.
- Devos M, Devos H, Spileers W, Arden GB. Quadrant analysis of peripheral colour contrast thresholds can be of significant value in the interpretation of minor visual field alterations in glaucoma suspects. *Eye* 1995;9:751–756.
- Devos M, Spileers W, Arden GB. Colour contrast thresholds in congenital colour defectives. *Vision Res* 1996;36:1055–1065.
- Kogure S, Iijima H, Tsukahara S. Assessment of potential macular function using a color saturation discrimination test in eyes with cataract. *J Cataract Refract Surg* 1999;25:569–574.
- Schwartz SH. Anomalies of color vision. In: Schwartz SH, ed. *Anomalies of color vision*. Norwalk, CT: Appleton & Lange, 1994: 135–167.
- Yamazaki Y, Lakowski R, Drance SM. A comparison of the blue color mechanism in high- and low-tension glaucoma. *Ophthalmology* 1989;96:12–15.
- Falcao-Reis FM, O'Sullivan F, Spileers W, Hogg C, Arden GB. Macular colour contrast sensitivity in ocular hypertension and glaucoma: evidence for two types of defect. *Br J Ophthalmol* 1991; 75:598–602.