# LUMINANCE CONTRAST AND COLOUR CONTRAST RELATED ERRORS IN PSEUDOISOCHROMATIC PLATE IDENTIFICATION

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## SUMMARY

***Purpose:*** **To determine whether differences in luminance contrast and colour contrast are factors in failing to identify American Optical pseudoisochromatic plates (AOPP).**

***Methods:*** **We studied two groups of subjects. In 20 normal test subjects with no errors on the AOPP we used cross-polarising filters to darken and then gradually increase perceived luminance of the AOPP until these normal subjects correctly identified the plate. In a second group, to evaluate the relationship between a luminance contrast sensitivity score using Arden plates and AOPP identification, we tested 37 non-colour-deficient subjects who missed zero to five of the AOPP of low colour and luminance contrast (plates 9–12, 15).**

***Results:*** **Using the cross-polarising filters, we found five plates that required more light to identify (plates 9–12, 15). In the second experiment, we found a significant relationship between the number missed of these five AOPP plates and a decrease in contrast sensitivity ($r = 0.91$, $p<0.001$, Spearman correlation coefficient).**

***Conclusion:*** **Errors in AOPP colour plate detection may be due to loss of ability to perceive colour contrast and possibly luminance contrast.**

Stilling in 1877[1] introduced the first pseudoisochromatic plates. These plates are designed so that the figure and background fall on the same line of colour confusion of the CIE chromaticity diagram.[1] This produces figures that are indistinguishable from the background to a colour-deficient patient. Of the many sets subsequently published, most have been designed to serve as a rapid screening test to detect congenitally colour-deficient patients of the protan or deutan type. The 15 American Optical pseudoisochromatic plates (AOPP), published in 1965,[2] have become a commonly used test. The first plate is taken from the Ishihara set, is not pseudoisochromatic, and functions to detect malingerers. Six other plates are taken from the Ishihara test and seven plates appear to be taken from the Velhagan and Polack tests.[3] The AOPP are designed to separate congenital red–green colour-deficient patients from normals. A subject may miss up to four of the 15 plates and still be considered normal. Misses may occur for many reasons besides congenital colour deficiency. Damage to photoreceptors or to the central nervous system colour vision pathways, poor attention, motivation or concentration, and visual perceptive abnormalities may all be responsible for the inability to correctly identify 'colour' plates. Also, German and Japanese investigators designed some of the AOPP and the different numerical script used for some numerals may be unfamiliar to subjects of other nationalities. Although designed to separate red–green colour-defective subjects, the test is often used in clinical practice to detect patients with acquired colour vision loss.

In our clinical experience, we have noticed that five of the 15 AOPP (plates 9–12, 15) take more time and effort to identify and are commonly missed by patients without detectable ophthalmological disease or congenital colour deficiency. Chiorian and Sheedy's[4] results show the AOPP to vary considerably regarding colour contrast. They also found more variance in the luminance contrast between the figures and the background than expected and concluded the percentage of plates meeting the recommendations for colour contrast and luminance contrast differences is low. This suggests that there may be a gradation in difficulty in these plates that is

Presented at a symposium in London, 29 September 1995, in honour of Professor Geoffrey Arden.

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unrelated to hue perception. Since these colour plates are used in clinical practice not only for detection of red–green colour-deficient subjects but also as a sensory visual function measure, we thought it would be important to analyse subject errors. Since there appeared to be a gradation in difficulty of the plates and differences in luminance and colour contrast, we hypothesised these differences were a factor in identification errors made by subjects.

## SUBJECTS AND METHODS

We performed this study in two groups of subjects. Consent was obtained after the nature of the procedures was explained. Procedures were followed in accordance with the Declaration of Helsinki as revised in 1983. The first group was composed of 20 normal subjects with no misses on the AOPP. In this group, we used cross-polarising filters to increase gradually the perceived luminance until these subjects correctly identified the plates. In the second group of 37 subjects we measured the contrast sensitivity function of those who missed only the plates from the group requiring high luminance for identification.

### *Group I*

Using Sadun and Lessell's method[5] designed for testing brightness sense, we produced conditions of low colour plate luminance in 20 normal volunteers. These 20 subjects ranged in age from 26 to 59 years (mean 39.7 $\pm$ 10.6 years).

All had normal ophthalmological examinations including at least 20/20 visual acuity with their best optical corrections, normal luminance contrast sensitivity by Arden plates, and did not miss any AOPP. Using Macbeth lighting (100 lux), we varied luminance by using spectacles fitted with two cross-polarising filters, one of which was rotated thereby varying light transmission. The subjects viewed each plate monocularly through the cross-polarising filters. The filters were initially set at a 90° angle (zero luminance) and slowly rotated to increase luminance until the subject could correctly identify the numbers on the colour plates. The degree of polarisation necessary to achieve this threshold was measured and recorded three times and the mean was calculated. To calculate the transmitted light intensity we used Mauls' Law: $I_t = I_0 \cos^2 \theta$, where $I_t$ is transmitted light intensity, $I_0$ is initial light intensity (100 lux) and $\theta$ is the polarisation angle in radians.

### *Group II*

Outpatients from the Charity Hospital of New Orleans Ophthalmology Clinic were tested by one of us (P.B.D.) with the AOPP. Inclusion criteria were a best corrected visual acuity of at least 20/20 and normal colour testing using A/O Hardy, Rand, Rittler (HRR) plates and the Farnsworth D-15 test. None of the patients had any history of optic nerve disease or evidence of optic neuropathy on ophthalmological examination. In addition, to be included, patients had to fail to identify all five or fewer of AOPP plates 9–12 and 15, but no other plates. The AOPP test was performed by allowing the patients 4 seconds to identify the numbers presented. Since the numerical script was unfamiliar to some patients and we were interested in whether the patient could discriminate the figure from the background, we allowed tracing of the figure. A Macbeth light (100 lux) was used as illumination and the plates were held at approximately 30 cm from the subject. The patient's best optical correction for near was used and monocular testing was done. Thirty-seven patients met the criteria for the study.

These patients then underwent contrast sensitivity evaluations with the Arden plates. We used the Arden plates produced by the American Optical Company at an illumination level of 100 foot-candles. With the subject at 57 cm from the plates, the spatial frequencies tested were 0.2, 0.4, 0.8, 1.6, 3.2 and 6.4 cycles per degree. All subjects wore their appropriate optical correction if necessary. The plates were presented at a rate of 1 cm/s. Plates 2 to 5 encompassed approximately 30° of visual angle; plates 6 and 7 filled 15° of visual angle. The patients were asked to identify the vertical bars when they perceived them with a pointer. We otherwise performed the testing as suggested in the protocol that accompanies the plates. Arden plates were chosen because they test the low and middle spatial frequencies found on the AOPP and give a global score that is a sum of the results of the various spatial frequencies.

Relationships between variables were tested by linear regression. When criteria for parametric statistics were met, we performed a Pearson correlation; Spearman rank correlation was used for non-parametric data. Differences between groups were considered significant if $p<0.05$.

## RESULTS

### *Group I*

Table I and Fig. 1 show the relative luminance required to identify each of the 15 AOPP of one eye of 20 normal subjects. Plates 11 and 10 required the most luminance followed by plates 9 and 12 and then plate 15. All the remaining AOPP required much less luminance than these five plates, still requiring from 80 to 84 degrees of polarisation (1.3–3.4 lux) to identify the plate.

### *Group II*

The results of group II (AOPP scores and contrast sensitivity scores) are shown in Tables II and III and

**Table I.** Mean minimum polarisation (in degrees) and minimum light intensity transmitted (in lux) necessary to identify each colour plate ($n$ = 20 eyes). Rank is by light intensity transmitted

| Plate no. | Degrees | Luminance transmitted | SD | Rank |
|---|---|---|---|---|
| 1 | 83.4 | 1.6 | 1.4 | 2 |
| 2 | 83.8 | 1.3 | 0.8 | 1 |
| 3 | 80.3 | 3.4 | 3.3 | 10 |
| 4 | 80.8 | 3.2 | 3.8 | 9 |
| 5 | 82.9 | 1.8 | 1.7 | 4 |
| 6 | 81.0 | 3.1 | 4.0 | 8 |
| 7 | 82.7 | 2.2 | 3.5 | 7 |
| 8 | 82.8 | 2.0 | 2.4 | 6 |
| 9 | 62.6 | 24.2 | 20.6 | 13 |
| 10 | 56.0 | 34.4 | 27.1 | 15 |
| 11 | 60.8 | 27.6 | 24.4 | 14 |
| 12 | 65.1 | 20.9 | 19.5 | 12 |
| 13 | 83.0 | 1.9 | 1.9 | 5 |
| 14 | 83.1 | 1.8 | 1.7 | 3 |
| 15 | 66.6 | 19.1 | 18.2 | 11 |

Fig. 2. We found a strong correlation between the total number of plates missed and the Arden contrast sensitivity score ($r$ = 0.91, $p$<0.0001, Spearman rank correlation). Table III lists the most commonly missed AOPPs. Plate 10 was the most frequently missed, closely followed by plates 11, 9, 12 and 15.

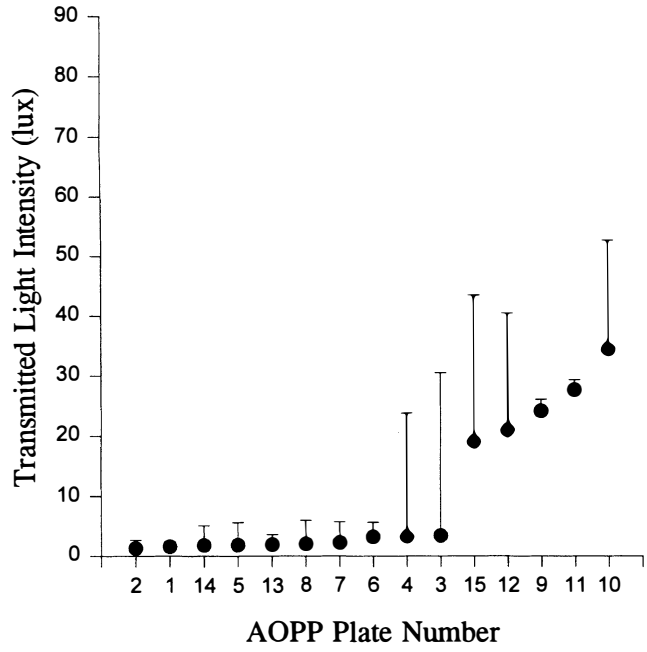


**Fig. 1.** *The relationship between minimum light transmission through the polarised filters necessary for detection of individual AOPP plates. Plate number on the x-axis is ranked by minimum light transmission needed to identify the plate. Note how plates 11, 10, 9, 12 and 15 require much more luminance than the other plates. Error bars represent 1 standard deviation.*

## DISCUSSION

We found five of the 15 AOPP to have different luminance characteristics from the rest of the plates. Colour plates are configured so that their identification is made by detecting differences in colour contrast. Manufacturers of plates attempt to eliminate any luminance cues that could contribute to plate identification. Chiorian and Sheedy[4] used photometry and colorimetry to study the luminance and colour characteristics of the three sets of pseudoisochromatic plates including the AOPP. They point out that if the contrast of the figure on the background is within the patient's range of contrast detection, then a colour-deficient subject might identify the figure even if the colours were appropriately chosen. Chioran and Sheedy grouped similar plates, for example plates 9–12, and measured the average differential luminance between figure and background. They found these plates were of lower luminance contrast than other plates in the set. This corresponds well with our findings of higher luminance needed to identify these plates. We found a good correlation between Chioran and Sheedy's luminance differences and the minimal transmitted light intensity needed to detect these five plates (linear regression, luminance difference = $0.008x$ + 1.1, $r^2$ = 0.50). Chioran and Sheedy also calculated the number of 'just noticeable differences' (JND) from the line of colour confusion for these plates. Again, we found a good correlation between the JNDs and the degrees of polarisation needed to detect these five plates (linear regression, JND = $0.1x$ + 3.3, $r^2$ = 0.59).

Using the plates requiring the highest luminance to be identified, we found a significant direct correlation between the number of plates missed and the total contrast sensitivity score. We also found when normal subjects viewed the AOPP under conditions of increasing luminance and their luminance-associated plate detection thresholds were measured, the plates that appeared to be isochromatic under low luminance conditions were the ones most commonly missed by patients with contrast sensitivity losses.

**Table II.** Relationship between Arden plate score and number of AOPP missed

| | | Contrast scores | | Subject's age (years) | |
|---|---|---|---|---|---|
| No. of plates missed | No. of eyes in group | Mean ± SD | Range | Mean ± SD | Range |
| 0 | 29 | 60.4 ± 3.8 | 53–73 | 30.9 ± 5.13 | 24–41 |
| 1 | 17 | 66.4 ± 3.3 | 62–77 | 35.1 ± 9.5 | 27–54 |
| 2 | 9 | 72.3 ± 3.2 | 68–76 | 48.6 ± 14.1 | 30–73 |
| 3 | 6 | 75.0 ± 2.3 | 72–78 | 52.0 ± 11.8 | 38–69 |
| 4 | 10 | 82.1 ± 6.1 | 74–91 | 66.1 ± 8.25 | 51–74 |
| 5 | 3 | 91.7 ± 2.1 | 90–94 | 72.7 ± 1.5 | 24–71 |

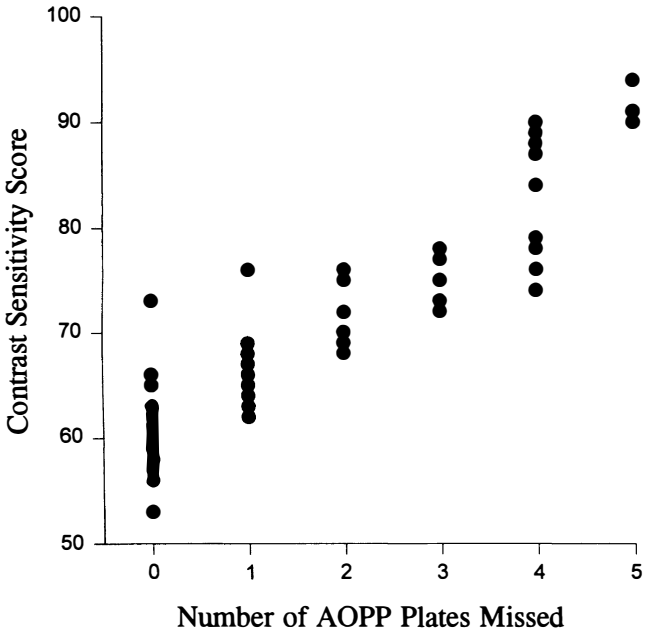


**Fig. 2.** *The relationship between contrast sensitivity score with the Arden contrast test and the number of AOPP missed.*

Long and associates[6] noted the number of errors made on the AOPP with 90 college-age volunteers with presentation times of 1, 3 and 5 seconds at various distances. At 76 cm with 3 and 5 second presentation times, the most frequently missed plates were numbers 4, 10, 12 and 15. Frequent errors were also made on plates 6 and 11. This correlates well with our results, but few errors were made in their series on plate 9. Some differences probably relate to technique, as we asked our patients to trace any figures they could not identify. In a related study, Long and colleagues[7] showed that the number of plates missed increased under conditions of low illumination (75 lux). Since relative luminance contrast decreases with illumination, contrast difference was probably a factor in explaining both their results and ours.

Conditions of low luminance affect not only luminance contrast differences of the plates but also colour contrast differences. Hart[8,9] has demonstrated that loss of colour contrast sensitivity occurs early in disease of the optic nerve. It is well known that luminance contrast sensitivity loss is an early indicator of disease of the sensory visual system. Although our normal subjects made errors with both the AOPP and contrast sensitivity testing, their error scores on the two tests were highly correlated. This suggests that subjects who miss the AOPP plates requiring higher levels of luminance to be identified correctly, are using neurosensory elements common to both the luminance contrast and colour contrast systems. Since luminance and colour contrast losses are correlated with sensory visual system damage, there is some rationale for using these plates as a screening test for acquired disease of the sensory visual system. However, missing these plates may reflect loss of colour contrast and luminance contrast rather than loss of hue discrimination.

**Table III.** AOPP missed by patients, by plate number

| Plate no. | Total plates missed | % of total |
|---|---|---|
| 9 | 12 | 16.2 |
| 10 | 27 | 36.5 |
| 11 | 22 | 29.7 |
| 12 | 10 | 13.5 |
| 15 | 3 | 4.1 |

In summary, it has been suggested that failure to identify pseudoisochromatic plates properly may be due to visual processes other than colour vision.[7] Our results show that differences in colour contrast and possibly luminance contrast may be added to the list of these factors. When using the AOPP in a clinical setting adequate lighting is important to avoid false positive errors in plate identification.

Key words: Contrast sensitivity, Colour vision testing, Pseudoisochromatic plates, Colour plates.

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