Compensation of white for macular filtering

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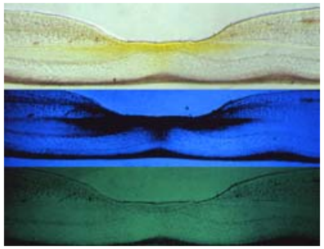
1 Introduction

S cone excitation is lower in the fovea because short wavelength light is filtered by the yellow macular pigment. Despite this reduced S cone excitation, white fields appear uniform -- there is no yellow spot in the center of the visual field.

This could be due to filling-in across space of the macular shadow. Or it may be that neurons receiving from the macula are compensating their responses to match that of extra-macular neurons.

We measured macular pigment density and achromatic white points by showing subjects stimuli at various eccentricities. These were presented in isolation in a black surround to prevent filling-in across eccentricity.



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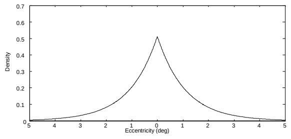
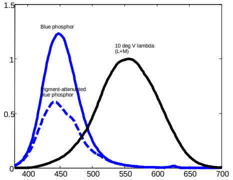
Approximate macular pigment profile



2 What Is The Spatial Profile of Macular Pigment?

- Macular pigment reduces the intensity of blue CRT phosphor light, and to a much lesser extent green phosphor light, on the retina (Figure 1).
- Subjects set motion nulls to measure blue phosphor to green phosphor luminance ratios for centrally presented disks (1, 2 deg diameter) and peripherally presented rings (2-4 deg, 4-6 deg, 6-8 deg, 8-10 deg diameter). See Demo.
- Reduction in blue to green luminance ratio compared to a standard 10deg observer indicates selective filtering of the blue phosphor by macular pigment. Assuming no other differences in pigmentation from the standard observer, the luminance ratio can be used to calculate macular pigment density at each stimulus location on the retina (Figure 2).
- Additional lens pigment can also alter the blue to green phosphor luminance ratio, but affects all eccentricities equally. A model of macular and lens pigment fit to our data indicates our subjects' lens pigment density is very similar to the standard observer's.

Figure 1



See minimum motion demo

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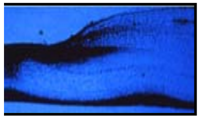
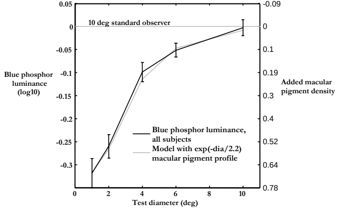
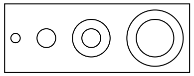


Figure 2

Macular pigment density
measured by change in blue phosphor luminance



3 Achromatic White Settings



- Subjects made achromatic settings by changing the chromaticity of centrally presented disks or peripheral rings (same dimensions as in section 2) using the mouse.
- These stimuli were presented in isolation on a black background to prevent filling-in across space as a mechanism for achieving an achromatic percept.
- The macular pigment alters the effective cone sensitivities for stimuli presented in the central retina (Figure 3, lower dashed lines).
- To achieve a percept of uniform white across the visual field, cone sensitivities in the macula may be neurally scaled up to match the rest of the retina (Figure 3, upper dashed line).
- There is a dramatic difference in achromatic settings predicted with or without this neural compensation, particularly for S cone chromaticity (Figure 4).

Figure 3

Cone signals can be scaled to compensate for macular pigment
For example, they can be scaled to keep equal-energy white, white

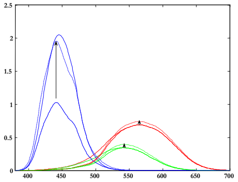
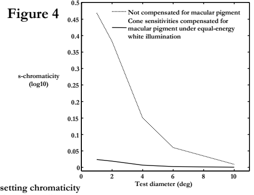


Figure 4

Predicted s-chromaticity of white
based on measured macular pigment profile

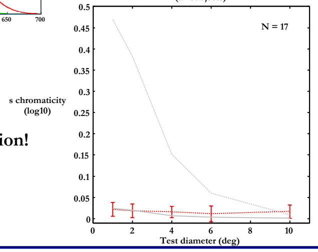


Our subjects show:

Complete Compensation!

(Figure 5)

Figure 5 White setting chromaticity
as function of test diameter
(all subjects)



4 Is fast scaling of S-cone sensitivity responsible?

- At 1/100 of maximum CRT intensity (~ 0.8 cd/m^2) and below, the S-cone increment threshold changes little with pedestal intensity, indicating that stimuli in this range will not scale S-cone sensitivity appreciatively (Figure 6).
- Subjects made white settings at this low luminance.
- The compensation for macular pigment remained complete, indicating that fast scaling of cone sensitivities is not responsible (Figure 7).

Figure 6

S-cone increment threshold on equal-energy white pedestals

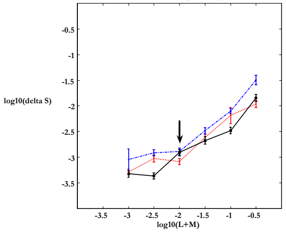
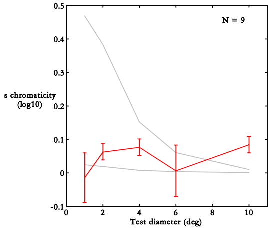


Figure 7

White setting chromaticity
at low luminance



5 What is White?

- The roughly 1000 settings made by our subjects lie close to the black-body locus (near 6000K), and also close to the slightly greener daylight locus (not shown). On this evidence, equal energy white (EEW, Figure 8) is slightly reddish and yellowish.
- Much to our surprise, the dispersion of the settings is not along the tritan axis, as is characteristic of most discrimination ellipses, but along the red/green equilibrium axis of Hering, which is also the black body locus for low saturation colors. Individual subjects' data show this consistently (Figure 9). Subjects were successful in avoiding reddish or greenish tints but were less concerned bluish or yellowish deviations.

Figure 8 White setting chromaticity
19 subjects, 50 settings each

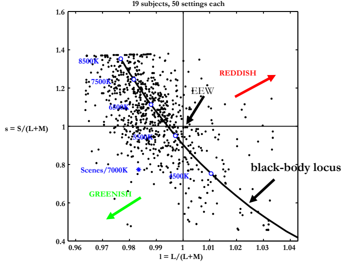
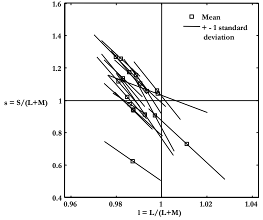


Figure 9

White setting chromaticity
subjects' means and direction of maximum variance



6 Achromatic Centroid Principle

It is plausible that the achromatic sensation is associated with stimuli that fall at the **centroid** of the surface chromaticities (cone excitations per unit luminance) provided by the observer's environment. Long-term adaptation in color appearance could lead to such a result.

Our results provide **limited support** for this. Natural daylights do span the achromatic region, though often bluish. But natural reflectances are not uniform, and the daylight reflected from natural scenes, such as those of Ruderman et al. in the Figure 8 above, is on average slightly greenish (and for most daylights, yellowish as well.)

On this evidence, the centroid principle is only approximately valid. But sampling difficulties, notably the question how to treat the sky itself as a stimulus, make it difficult to evaluate rigorously.

7 Conclusions

- The perception of white is locally neurally compensated for reduced foveal S-cone excitation due to macular pigment. Since the compensation is found even at low intensities, it is apparently not due to retinal sensitivity regulation.
- Somewhat fortuitously, a degree of compensation that is appropriate for broadband whites also happens restores precise uniformity in perception of CRT whites.
- In two-dimensional settings, the subjective achromatic points fell close to the black body locus, not far from equal-energy white.
- Surprisingly, the major axis of the distribution of settings deviated consistently from the tritan axis. Instead, settings were mainly dispersed along the Hering red/green equilibrium axis.
- This pattern of dispersion implies that the cone outputs were observed not directly but through an opponent representation in which the S and L cones operate antagonistically to the M cones.
- Although daylights are often nearly white, reflected light from surfaces is on average slightly yellowish and greenish.

8 References

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