Contribution of the S-cones to the perception of the brightness through the achromatic channel

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ABSTRACT

It is well known the contribution of both the M- and L-cones to the luminance. The contribution of the S-cones to luminance has been somewhat contentious but it now seems clear that the S-cones make a small contribution under certain conditions, in particular when the M- & L-cones are selectively adapted to an intense long-wavelength field. In this work we have studied the contribution of the S-cones to the perception of the brightness through the achromatic channel. From the data it can de infered that the contribution of the S-cones to the achromatic channel is clear: it duplicates the contribution of the cones L and M, both with a similar contribution. This fact shows that the achromatic channel in direct heterochromatic brightness matches doesn't match the luminance signal obtained through flicker photometry and conduced by the magno-cellular pathway, and confirm the role of the parvo-cellular pathway conducting both achromatic and chromatic signals.

1. INTRODUCTION

The *Commission Internationale de L'Eclairage* (CIE) in 1978[1] appointed the existent differences among the luminous efficiency function V_λ defined by themselves in 1924[2] being based on results obtained by means of *heterochromatic flicker photometry* (HFP) and the luminous efficiency function $V_{b,\lambda}$ obtained by means of direct heterochromatic brightness matches, being the last one bigger than the first towards both ends of the visible spectrum (figure 1).

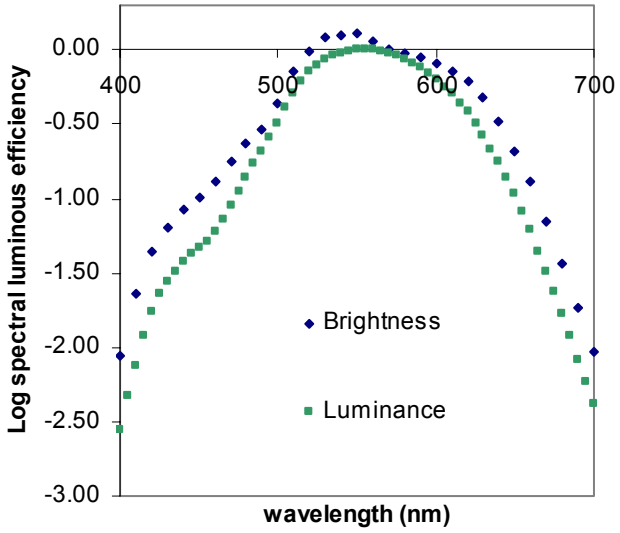

Figure 1: Spectral luminous efficiency curves measured by direct brightness matching (♦) and flicker photometry (■).

Since that moment, the discrepancies between the terms luminance and brightness have been disccused.

These differences are attributable to their definition. The luminance, origin of the photometry, is defined as:

$$L_v = K_m \int L_{e,\lambda} V_\lambda d\lambda \qquad (1)$$

where $L_{e,\lambda}$ is the spectral radiance, V_λ is the CIE photopic luminous efficiency function, and K_m is the maximum spectral luminous efficiency. This CIE luminous efficiency function was obtained using a great number of observers and mainly by means of flicker photometry.

On the other hand, Brightness is the attribute of a visual sensation according to which the area of a visual stimulus presented appears to emit more or less light. This magnitude is usually measured by heterochromatic direct matching.

Important these marked differences made the CIE to separate the application environment of these two magnitudes, the luminance obtained using V_λ and dedicated to photometric measurements since it presented an indispensable characteristic for this type of measurements like the additivity, and the brightness obtained using $V_{b,\lambda}$, and employed to evaluate the attribute of the visual sensation according to which the area in which a visual stimulus is presented appears to emit more or less light[3].

These two magnitudes have been related in the last years, explaining the different values that they present, by means of the neural models of colour vision and the theory of opponents colours. The common denominator of these neural models is the existence of one first stage of processing based on the three types of cones that usually are in the human retina, S- M- and L- cones. One second stage of processing formed by a red-green opponent chromatic channel, or using the terminology of Guth, Tritanopic, an opponent chromatic channel blue-yellow or Deuteranopic and the achromatic non-opponent channel in which the contributions of the cones are added providing the luminance of the stimulus. At this point discrepancies appear among the different authors.

Some authors consider that the achromatic information is only contributed by the magno-cellular pathway, since the luminous efficiency function V_λ was obtained by the minimum-flicker method the magno-cellular pathway has a significant response to a temporal stimulus, corresponding to the parvo-cellular pathway the conduction of the chromatic information in the evaluation of steady stimuli[4]. However, other authors consider that the parvo-cellular pathway contributes to both types, chromatic and achromatic channels, multiplexing both signal[5].

In all the cases, both the M- and L-cones contribute to the luminance. The contribution of the S-cones to luminance has been somewhat contentious[6,7] but it now seems clear that the S-cones make a small contribution under certain conditions, in particular when the M- & L-cones are selectively adapted to an intense long-wavelength field [8,9]. In this work we have studied the contribution of the cone types to the perception of the brightness through the achromatic channel. This would be useful to elucidate the role of both pathways in the perception of brightness.

2. METHOD

The luminous efficiency function $V_{b,\lambda}$ has been obtained by direct heterochromatic matching of three observers, characterized previously as normal trichromats observers through anomaloscopic and colour vision deficiencies tests. A maxwellian-view experimental device built to such effect was used[10], in which to each observer a monochromatic stimulus of variable wavelength in a 2º central circular field surrounded by a 10 cd/m^2 white 15º concentric circular field was showed. Each observer repeated the test in five occasions, registering each 5 nm from 470 to 680 nm the luminance of the necessary monochromatic stimulus to match in brightness the reference target, as well as the tristimulus values L, M, S of this stimulus, obtained directly from the radiance spectrum measured by means of an spectroradiometer PhotoResearch PR-701S and the fundamental response curves of the cones L, M, S proposed by Stockman & Sharpe[11].

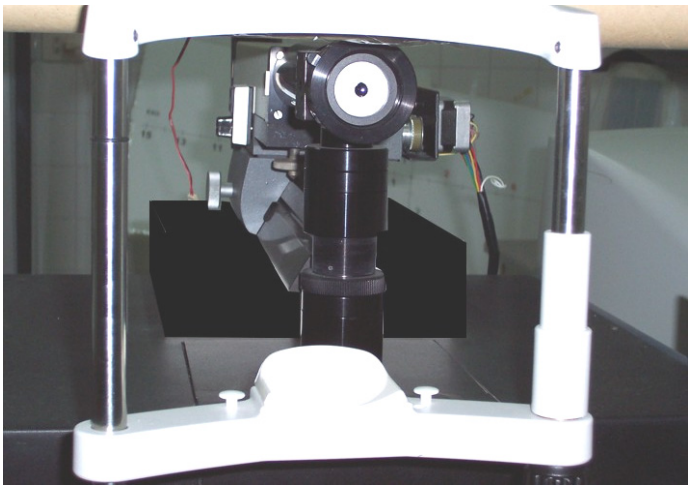

Figure 2: View of the experimental device and the visual field shown to the observers.

Back-propagation neural networks were used for the chromatic characterization to establish the relationship between the each monochromator's input parameters and the tristimulus values LMS of each chromatic stimulus generated[12]. A fit with an average error of less than 1% was achieved with 120 000 epochs. In particular, the average errors made by the network on the complementary set of 108 data pairs were 1.28% for the determination of the L-value, 0.9% for the M-value, and 0.6% for the S-value.

3. RESULTS

The results from each observer were analyzed by principal components analysis (PCA) providing us the directions of the space LMS that explain a bigger percentage of the variance of the experimental results and with a null covariance regarding the other components. Given the characteristics of the visual experience carried out, we can expect that the bigger percent of the explained variance will be due to chromatics variations and, in a second order term, to achromatic variations. In the three cases, the result was the obtaining of three components, the first one explains the 73.5% of the variance belonging to a typical opponent chromatic channel D (blue-yellow), the second component explains the 18% of the variance belonging to an opponent chromatic channel T (red-green) and a third component that explains the 8% of the variance belonging to a non-opponent achromatic channel. Table 1 shows the weights of the L-, M-, S- cones obtained from the PCA for the third component.

Table 1: Weights of the L-, M-, S- cones conforming the third component extracted from the experimental results of the three observers.

Observers	L	M	S
1	0.176	0.191	0.323
2	0.226	0.228	0.408
3	0.176	0.293	0.430

The weights of each cone type for the third component are very similar for all the observers. The absolute values of this weights have not really importance because they are calculated using the Hotelling normalization[13]. In such form, these values are related with the explicated variance of each component. The really important values are the relative values of the weights. These weights, obtained from the three observers experience, shown similar values for the L- & M- cones contributions, but this contributions are duplicated by the contribution of the S-cones to this third component.

As it has been said before, it is well known the contribution of the L- & M- cones to the luminance, and it's clear that the difference between the luminance – obtained by flicker photometry – and the brightness – obtained by direct matching – is due to the contribution of the S-cones. However, it is not quite clear if the contribution of the S-cones to the brightness is made through the chromatic channels T or D, or through the achromatic one. The results obtained in this experience show a clear contribution of the S-cones to the brightness sensation through the non-opponent achromatic channel.

4. CONCLUSIONS

From data we can infer that the contribution of the S-cones to the achromatic channel is clear, duplicating the contribution of the cones L and M, both with a similar contribution. This fact shows that the achromatic channel in direct heterochromatic brightness matches doesn't match the luminance signal obtained through flicker photometry and conduced by the magno-cellular pathway, and confirm the role of the parvo-cellular pathway conducting both achromatic and chromatic signals.

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