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How to improve computer vision for the color blindness: analytical and experimental approach to color vision of *PIGOP* model

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ABSTRACT

The new theoretical approach on the structure of light radiations [Nie18a] that originated this research and the consequent theoretical description of the mechanisms of colour vision (*PIGOP* model), has produced the possibility of understanding the mechanisms of the formation of colour vision deficits in full agreement with the experimental results, which up to now have not found a coherent theoretical framework. In this article, considerations are made on how to improve computer vision for color blindness persons with the six most common types of colour vision deficiency, thus accommodating the needs of 8 percent of the world's male population.

Keywords

Structure of light radiation, on/off phototransduction of the light signal, additive synthesis, malfunction of photoreceptors, colour blindness, customized colour cards of monitors.

1. INTRODUCTION

In this article, the non-functioning of 1 or 2 of the three human photoreceptors is described, which is why it is considered impossible to produce glasses that can correct color discrimination deficits. It is proposed measures that can improve color discrimination on computer monitors for color blindness, perhaps in the future project of personalized color cards for monitors. To do this, it is necessary to know the mechanisms of color vision, a mechanism that is not intuitive because colors are not perceived immediately but through a code. The human brain does not perceive colors in an analogical way, as the brain of insects does, for example, but is a digital instrument: it identifies the constituent elements of light radiation (magenta, cyan, yellow) through photoreceptors and processes them (additive synthesis, on/off phototransduction) forming all our color sensations.

2. RECENT SOLUTIONS

The proposed research presents a model of color vision and the diagnosis of color discrimination deficits alternative to the RGB model in which it is stated that:

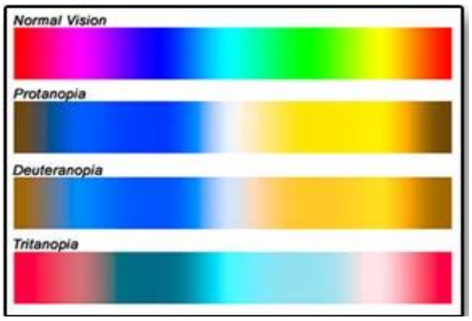
1/ White light only is polychromatic: the visible light waves are countless monochromatic waves between 380-760 nm; [Enc08a]

2/ Human photoreceptors responsible for the distinction of colors (cones) are sensitive to red, green and indigo (RGB); [Enc08a]

3/ Deficit of the discrimination between the colors are due to non-phototransduction by the cones of one of the RGB signals. [Cro01a]

The starting point of the reasoning on the polychromatism of all light radiation has become analysis of the polychromatic composition of the light waves perceived such as red, green and blue revealed by the deficit in the distinction of colors. For this reason, the following table is proposed that illustrates some of these deficits and the citation of how they are explained in literature.

“Protanopia and deuteranopia are various forms of red-green colorblindness, the most common form of dichromia (protanopia is a deficiency in red cells, deuteranopia a deficiency in green; the results are similar because red and green are close in wavelength). Tritanopia is commonly called blue-yellow colorblindness and is less common, with full colorblindness (monochromia) being very rare.” [AVI22a]



3. PROPOSED SOLUTIONS

3.1. The selection of only 4 monochromatic waves as part of the visible: 764 nm, 576 nm, 432 nm and 384 nm

Based on the considerations on the fluctuation of the speed of the propagation of the wave motion [Nie18a] it is deduced that the spectrum of the visible is discontinuous because the frequencies of the visible are only four.

magenta IR 432 THz 768 nm	yellow 576 THz 576 nm	cyan 768 THz 432 nm	*magenta UV* 864 THz 384 nm

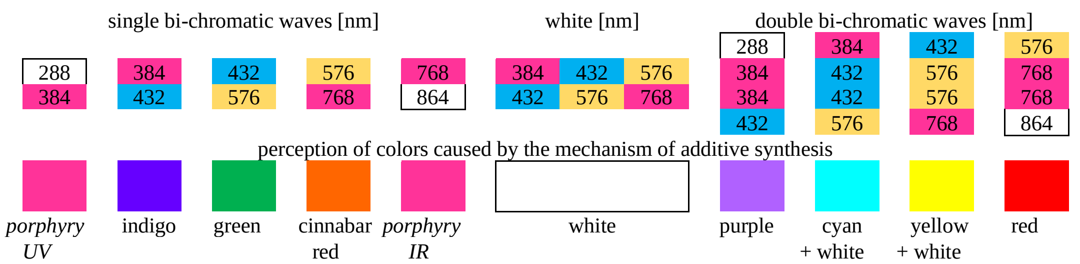
These four frequencies are interpreted by the brain like magenta, yellow and cyan and with these three chromatic sensations (plus black and white) the brain builds all colors through the following mechanisms:

- homologation of frequency multiples,
- additive synthesis,
- on-off phototransduction system of the cones signals that produces 6 chromatic and 2 achromatic information.

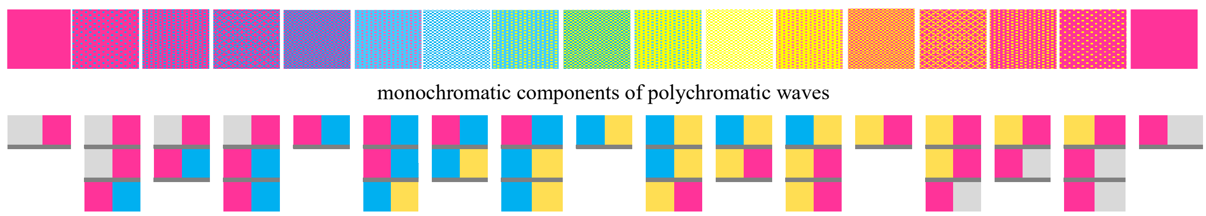
3.2. The luminous wave consists of two heterogeneous monochromatic waves and additive synthesis generates the chromatic content of heterogeneous bi-chromatic waves and their aggregations

According to this thesis with the four monochromatic waves - **cyan** 432 nm, yellow 576 nm, ***magenta UV*** 384 nm and ***magenta IR*** 768 nm - three bi-chromatic bright waves are formed: **cinnabar red**, **green** and **indigo**. In addition, the perceptual system is able to recognize the magenta components in the infrared and ultraviolet waves, present at the two extremes of the visible. To be part of the rose of the visible waves, two half-visible waves also enter for this reason: *porphyry IR* (semi-infrared wave consisting of waves with lengths 768 and 864 nm) and *porphyry UV* (semi-ultraviolet wave composed of waves with lengths 384 and 288 nm).

The light waves thus composed create the light sensations due to the mechanism of additive synthesis.



The following table illustrates the aggregations of the bi-chromatic waves: *porphyry IR* and *UV*, cinnabar red, green, indigo, their monochromatic content and the perception of the main colors of the spectrum through the described mechanism of additive synthesis and the average measure of the lengths of the polychromatic waves.



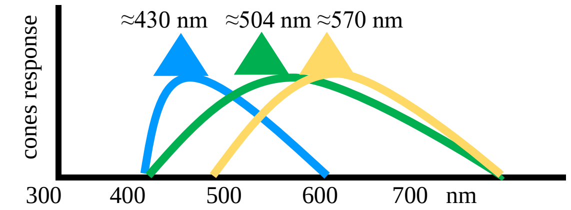
Average measure of the wavelengths of the polychromatic waves consisting of the average of the monochromatic components [nm]																
porphyry UV -1	fuchsia -3	violet -2	plum -3	indigo -1	blue -3	cyan -2	turquoise -3	green -1	lemon -3	yellow -2	orange -3	cinnabar red -1	pumpkin -3	red -2	wine -3	porphyry IR -1
336	360	372	384	408	440	456	472	504	560	588	616	672	720	744	768	816

This model of the structure of light radiation has been named by the author *PIGOP* model from the first letters Porphyry UV, Indigo, Green, Orange, Porphyry IR.

3.3. The peak of the sensitivity of the cones S, M and L corresponds to the cyan, green (cyan + yellow) and yellow respectively

The measurement of the chromatic sensitivity of the three photoreceptors of the human eyes was carried out from which the maximum sensitivity to the following lengths of the light waves is: about 550-580 nm, 500-540 nm and 420-450 nm. These wavelengths correspond to the colors: yellow, green and cyan. [Val06a]

cyan 432 nm	green 504 nm	yellow 576 nm



3.4. ON - OFF process of the phototransduction of light signals

The power of the human brain allows to produce a huge amount of information using the minimum amount of data. In fact, according to the considerations that have been reached during this research, the human photoreceptors (cones and rods) detect only three sensations of color: white, cyan and yellow. The rods detect the presence of light, translated from the visual areas of the brain in the sensation of white. In the presence of the information of the rods on the presence of light, the three cones detect only two information: the presence of the monochromatic waves 432 nm and 576 nm, information translated by the brain respectively in sensations of colors: cyan and yellow.

- the cone S absorbs the monochromatic wave of 432 nm (cyan),
- the cone L absorbs the monochromatic wave of 576 nm (yellow),
- The cone M absorbs a green bi-chromatic wave, consisting of a 432 nm cyan monochromatic wave and a 576 nm yellow monochromatic wave.

cones:							
S			**M**			**L**	

Note that the cones measurement system is binary. It consists in reading only two cyan or yellow stimuli: individually (cones S and L) and together (cones M).

Thanks to the on-off mechanism of phototransduction of the bright signals and the additive synthesis mechanism, the four types of photoreceptors: rods, cones S, L and M are able to provide eight chromatic sensations: as in the figure below + white and black. In this way each cone detects one color and its complementary tint, composing together the white.

Cones: S				**M**				**L**	
monochromatic components of waves									
ON		OFF		ON		OFF		ON	OFF
perception				perception				perception	

3.5. Deficit of color vision due to the dysfunction of the process of phototransduction of light signals

Each color we see produces generic effect on the rods (presence of light) and specific on-off responses from the three cones. The following table illustrates how the colors of the natural spectrum are coded in system shown below. (The natural spectrum differs from the spectrum produced by the RGB system from the different way of generating the purple colors which in the first case are produced by the overlapping of the indigo-1 and *porphyry UV*-1 waves and in the second case by the overlapping of the indigo-1 and red-2 waves.)

Codification ON-OFF of cones S, M, L

signal **ON** [nm]

cones: S	M	L
432 cyan	504 green	576 yellow
monochromatic contents		

signal **OFF** [nm]

cones: S	M	L
672 cinnabar red	384, 768 magenta	408 indigo
monochromatic contents		

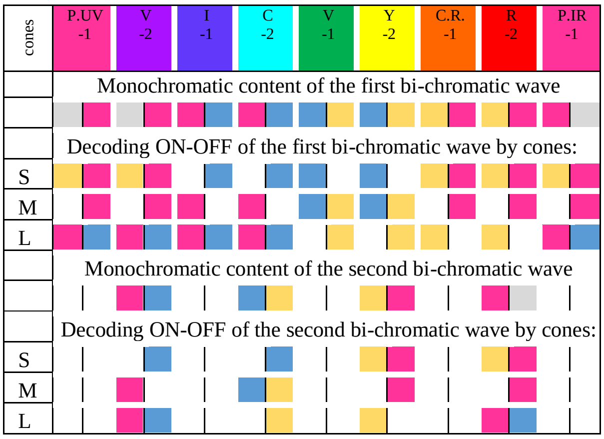
Normal view of natural spectrum

The following tables present:

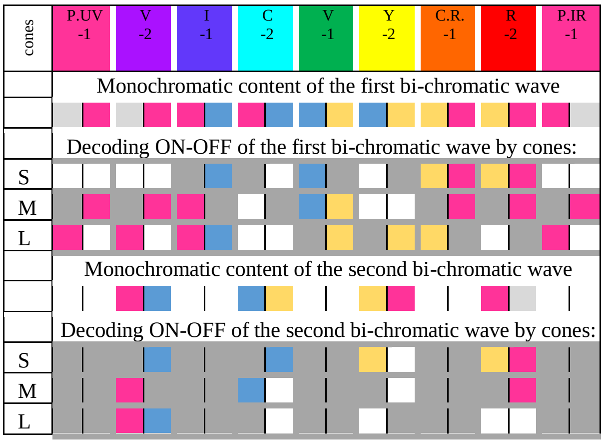
a/ The monochromatic content of the bi-chromatic waves: single and binary of the natural spectrum and their perception;

P.UV -1	V -2	I -1	C -2	V -1	Y -2	C.R. -1	R -2	P.IR -1
Monochromatic content of the first bi-chromatic wave								
Monochromatic content of the second bi-chromatic wave								

b/ Contribution of the three cones in the formation of the chromatic map through the ON-OFF system;

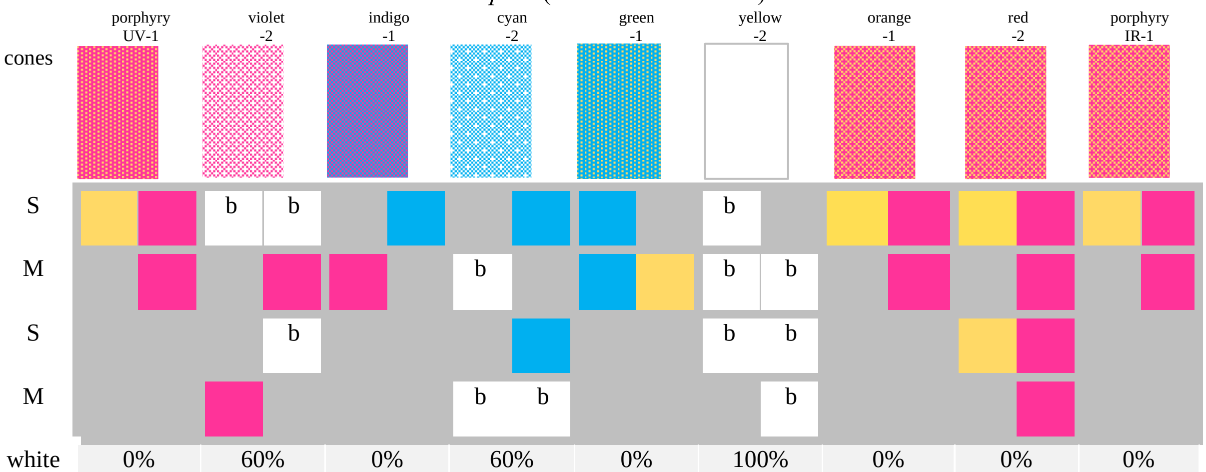


c/ Actually chromatic map generated by the additive synthesis of white.

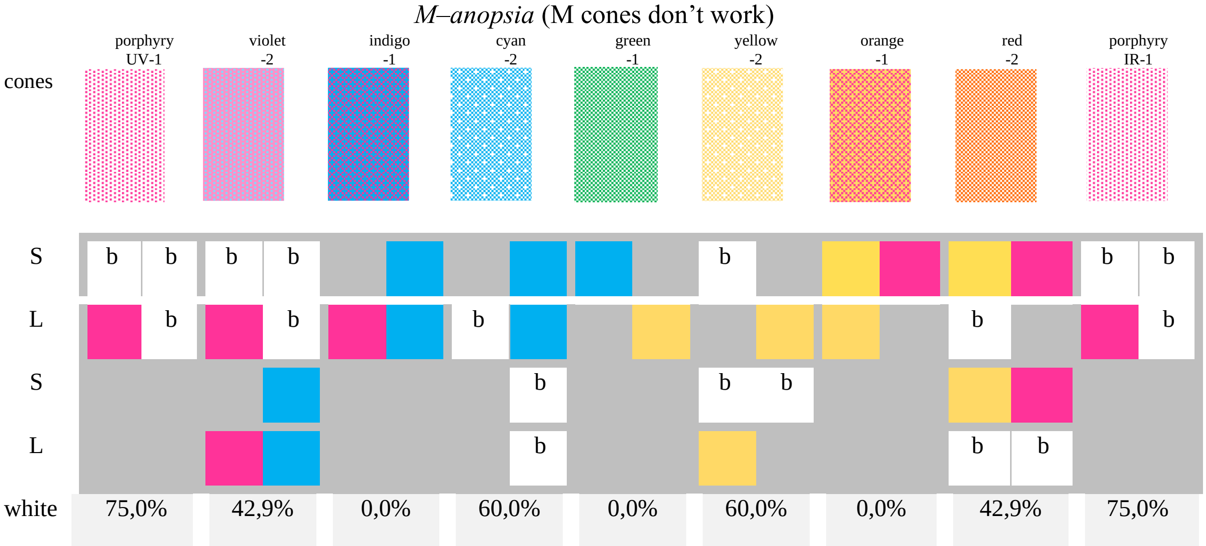


The tables below illustrate the deformation of the vision of the spectrum in the case of the absence of the signals from one of the cones L, M and S.

L–anopsia (L cones don't work)



M–anopsia (M cones don't work)



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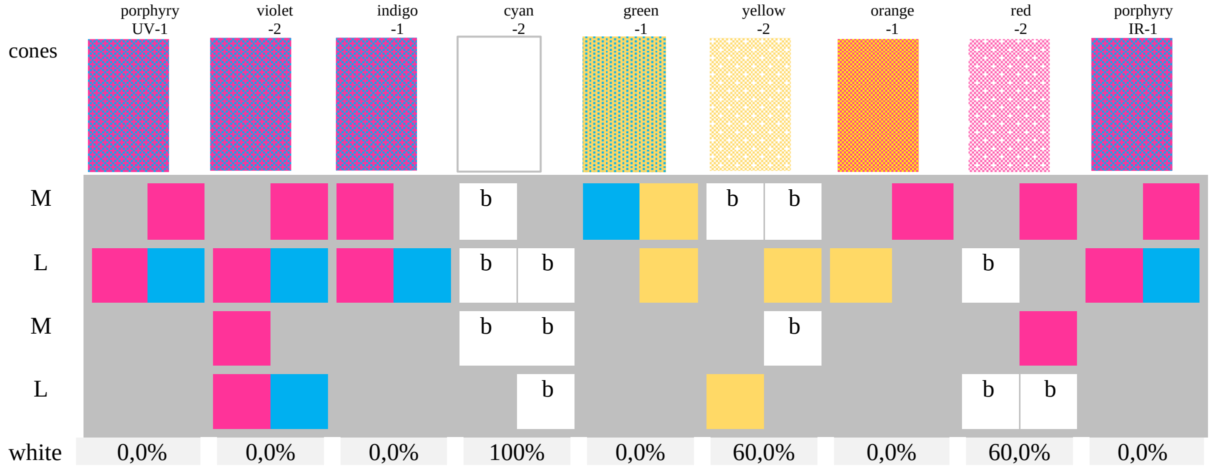
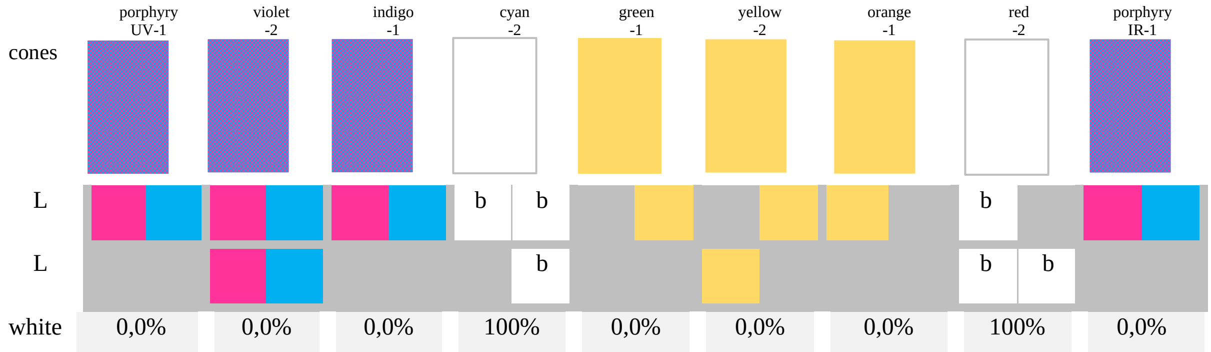
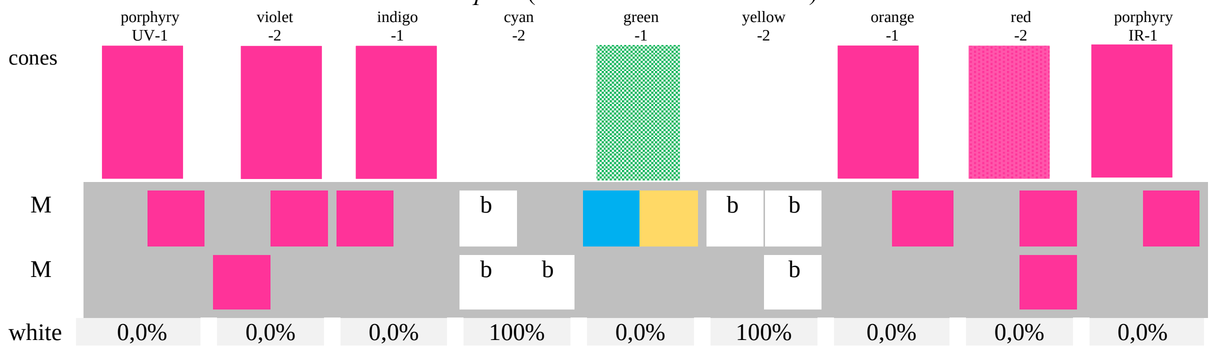
S–anopsia (S cones don't work)



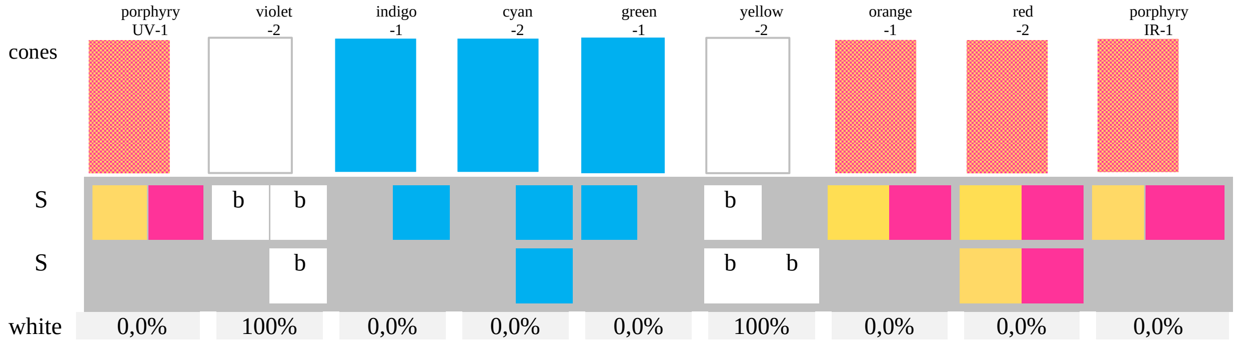
L–monopsia (M and S cones don't work)



M–monopsia (L and S cones don't work)

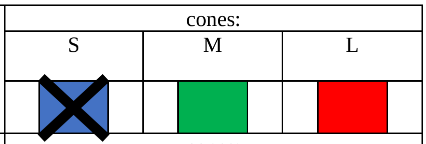
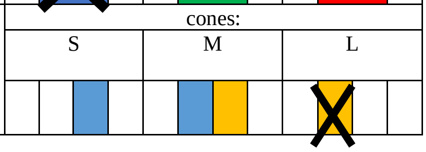


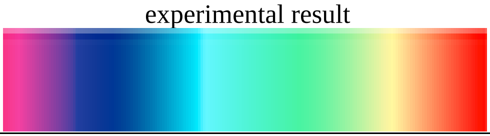
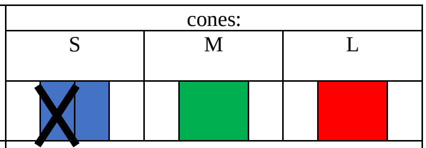
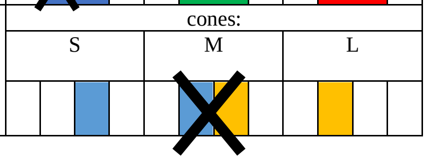
S–monopsia (L and M cones don't work)

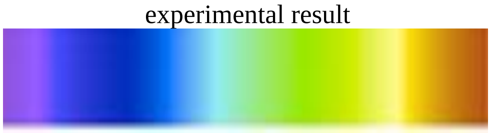
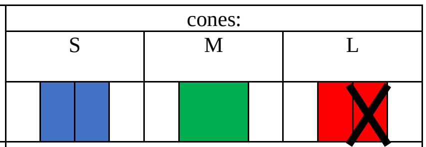
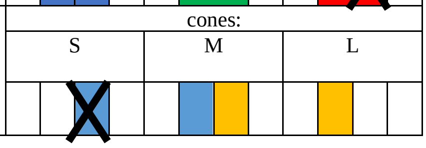


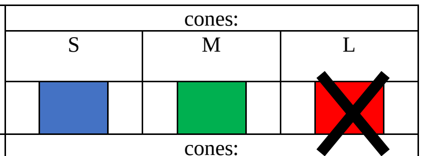
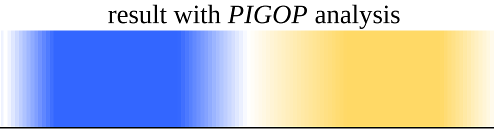
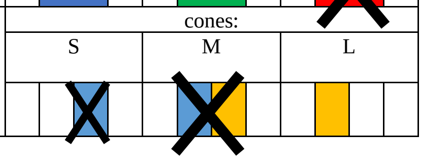
4. COMPARISON OF EXPERIMENTAL RESULTS WITH *PIGOP* MODEL RESULTS

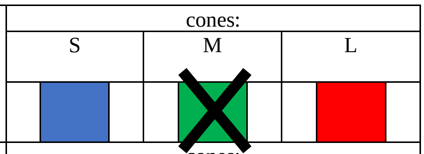
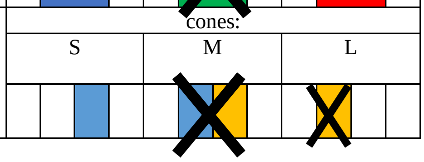
The table compares the spectra of different types of distorted color vision obtained experimentally and through the analytical *PIGOP* method and indicates the diagnoses of the chromatic deficits of both models.

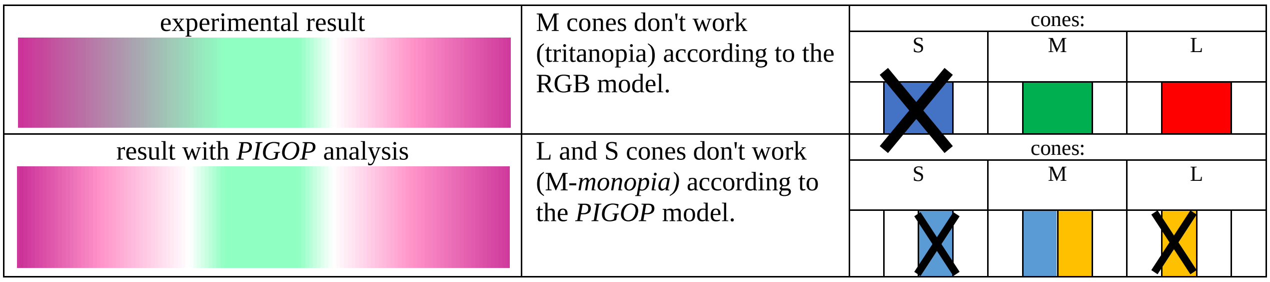
experimental result 	S cones don't work (tritanopia) according to the RGB model.	
result with *PIGOP* analysis 	L cones don't work (*L-anopia)* according to the *PIGOP* model.	

experimental result 	Half of the S cones don't work (tritanomaly) according to the RGB model.	
result with *PIGOP* analysis 	M cones don't work (*M-anopia)* according to the *PIGOP* model.	

experimental result 	Half of the L cones don't work (protanomaly) according to the RGB model.	
result with *PIGOP* analysis 	S cones don't work (*S-anopia)* according to the *PIGOP* model.	

experimental result 	L cones don't work (protanopia) according to the RGB model.	
result with *PIGOP* analysis 	S and M cones don't work (L-*monopia)* according to the *PIGOP* model.	

experimental result 	M cones don't work (deuteranopia) according to the RGB model.	
result with *PIGOP* analysis 	L and M cones don't work (S-*monopia)* according to the *PIGOP* model.	

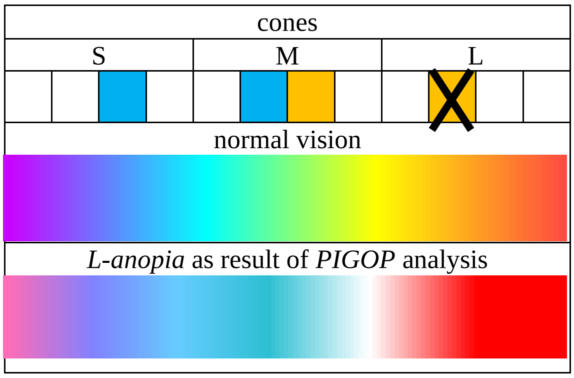


The evident similarity between the experimentally obtained spectra and the spectra obtained as a result of the application of the proposed method of coding chromatic information by the human visual cortex can be considered the experimental confirmation of the *PIGOP* model.

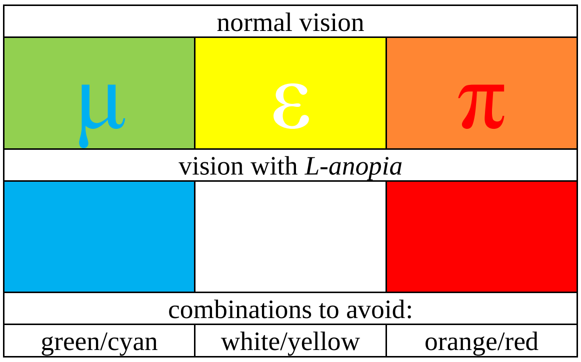
5. COLOR COMBINATIONS NOT DISTINGUISHABLE FOR THE 6 TYPES OF COLOR BLIND PEOPLE

To avoid confusion between the colors of the six types of color blindness described in this work, one must avoid the combinations of these colors whose difference is not perceived as shown in the tables below.

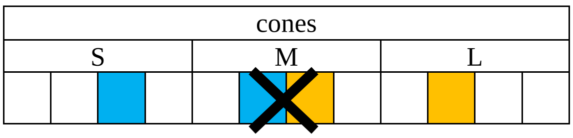
a/ *L-anopia* = L cones don’t work.

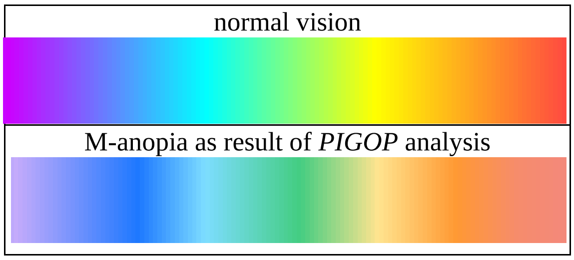


Combinations to avoid:

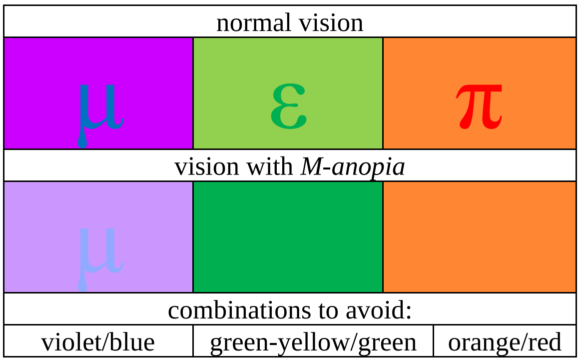


b/ *M-anopia* = M cones don’t work.

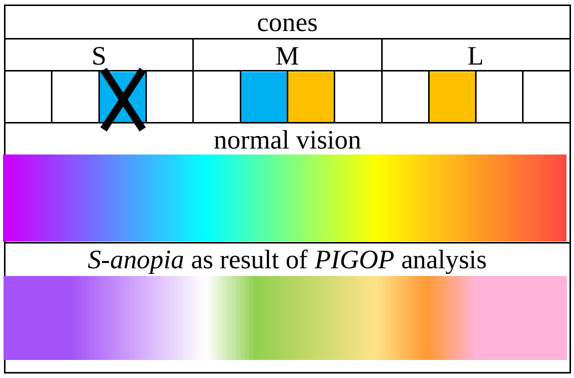




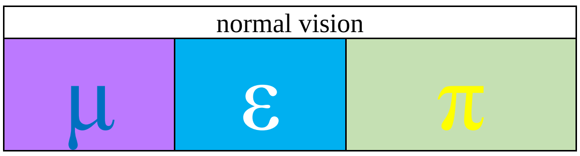
Combinations to avoid:

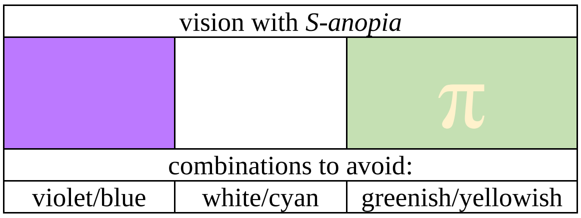


c/ *S-anopia* = L cones don’t work.

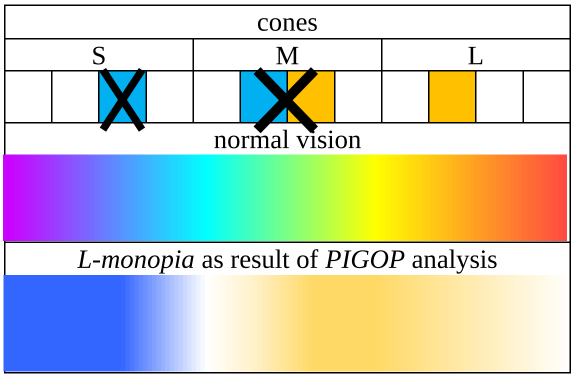


Combinations to avoid:

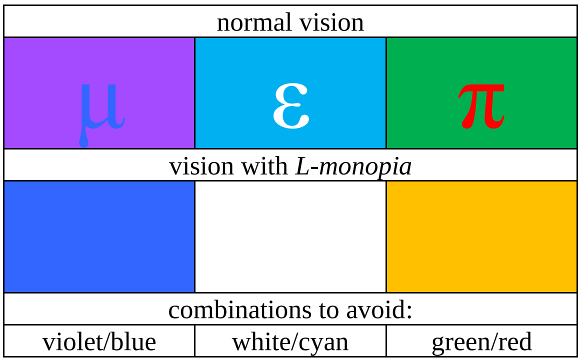


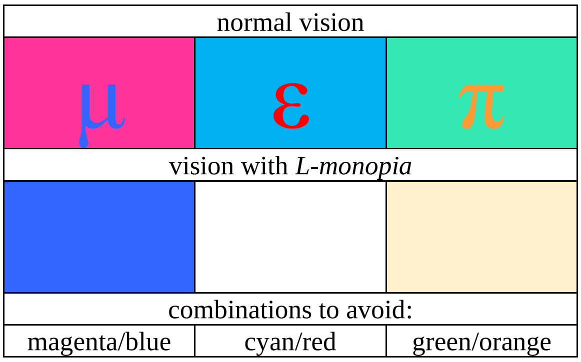


d/ *L-monopia* = S and M cones don't work.

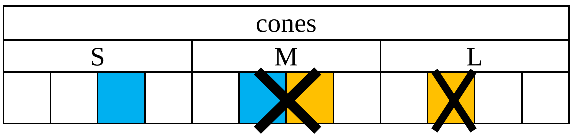


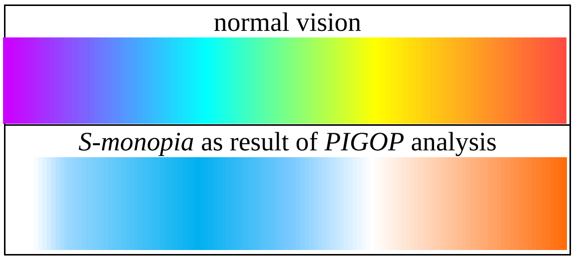
Combinations to avoid:



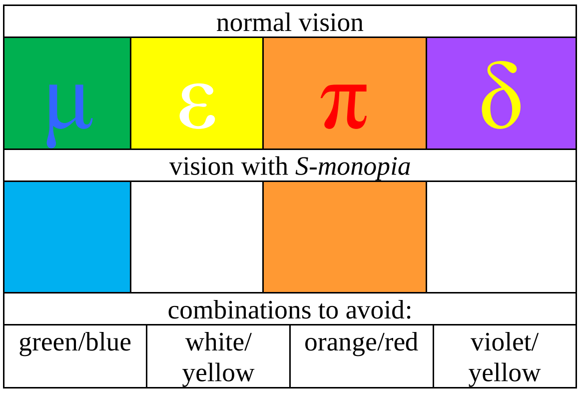


e/ *S-monopia* = L and M cones don't work.

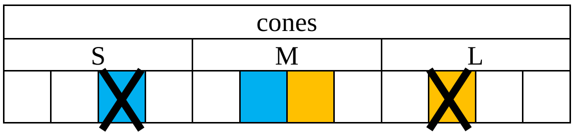


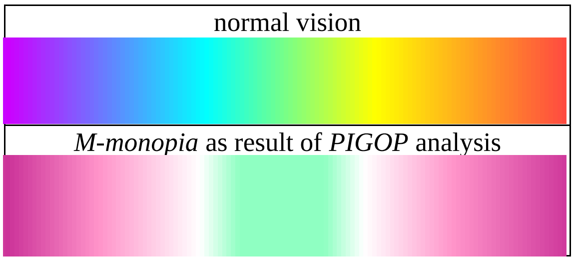


Combinations to avoid:



f/ *M-monopia* = L and S cones don't work.





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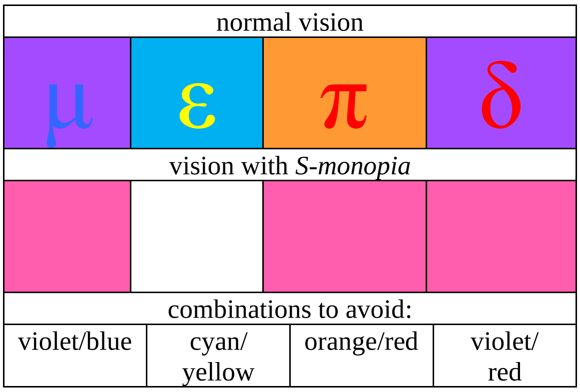
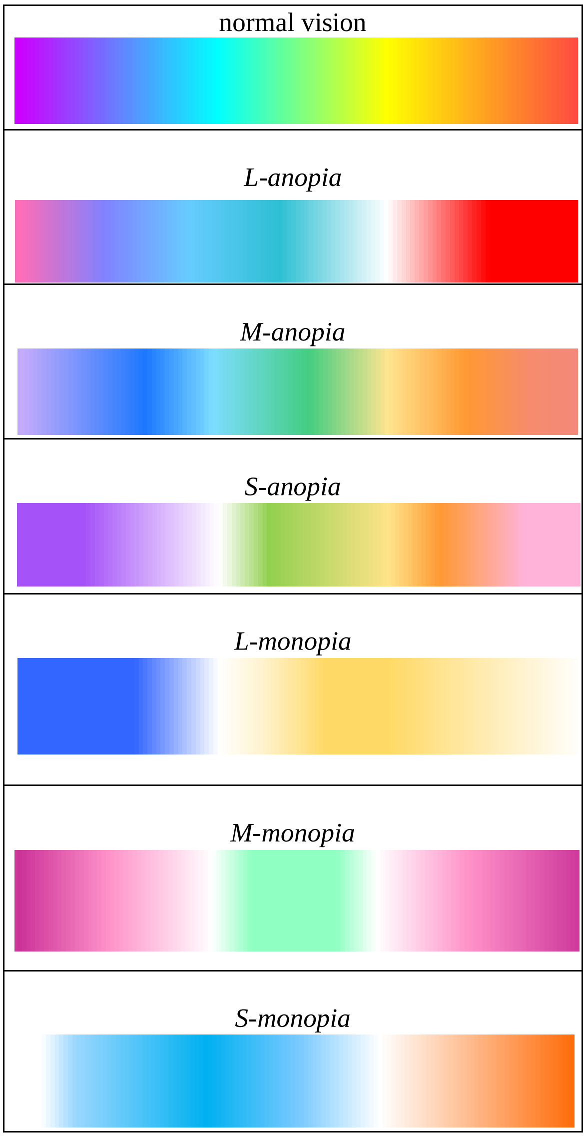


CONCLUSIONS: HOW TO IMPROVE COMPUTER VISION FOR THE COLOR BLINDNESS?

To conclude the reasoning presented, it is proposed to compare the 6 spectra produced by the 6 types of color blindness described in order to identify the combinations both those to be avoided most and those most universally effective for distinguishing colors from each other.

The table below compares the spectra produced by 6 types of color blindness with each other and with the spectrum produced by normal vision.



The following two tables illustrate the combinations to avoid the most.

Do not combine with white: violet, cyan, yellow, red.

normal vision			
μ	ε	π	δ
vision with:			
S-monopia	*S- monopia* *L-monopia* *S-anopia*	*L-anopia* *M-monopia* *S-monopia*	*L-monopia*

Do not combine yellow with: white, cyan, green and red/orange.

normal vision			
μ	ε	π	δ
vision with:			
L-anopia *M-monopia* *S- monopia*	*M-monopia*	*L-monopia*	*L-monopia*

The most effective combinations are:

- indigo and orange,

normal vision					
μ	ε	π	δ	α	θ
vision with:					
μ	ε	π	δ		θ
L-anopia	*M-anopia*	*S-anopia*	*L-monopia*	*M-monopia*	*S-monopia*

- green and red,

normal vision					
μ	ε	π	δ	α	θ
vision with:					
μ	ε	π		α	θ
L-anopia	*M-anopia*	*S-anopia*	*L-monopia*	*M-monopia*	*S-monopia*

- violet and orange.

normal vision					
μ	ε	π	δ	α	θ
vision with:					
μ	ε	π	δ		θ
L-anopia	*M-anopia*	*S-anopia*	*L-monopia*	*M-monopia*	*S-monopia*

A desirable future solution to help color blind people (that is, 8 percent of the world's male population, or billions of people) to better distinguish colors from each other could be the design of color cards for monitors customized for the six types of color blindness.
The formation of reds and violets is different in the RGB and PIGOP models, which describe the spectral composition of light radiation. These differences from a perceptual point of view are negligible for the purposes of this research. They will be addressed in the new research project on the possibility of optimizing the production of colors offered by the PIGOP model compared to the RGB model.

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