# What a statistician might want to know about human color vision, but was afraid to ask!

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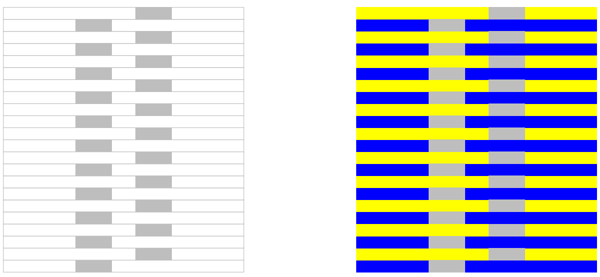
The use of color can provide a powerful and effective means to enhance the salience of graphical displays. Misused, however, it can also mask the message that the author intends. Within the base package **grDevices** in R [5], there can be found several sophisticated facilities for manipulating the color of graphics. In addition, several add-on packages extend these capabilities. For those who might lack an artistic sense of how best to use color in data displays or for the roughly 8% of the population (mostly males) with abnormal color vision, it can be useful to understand some basic aspects of human color vision.

A number of confusions can be avoided by making a distinction between the concepts of *coding* and *appearance*. Coding concerns how the physical stimulus (e.g., light intensity, spectral distribution, etc.) is sampled by the visual system and transduced into neural activity; appearance concerns what a stimulus looks like. In this talk, I will highlight display issues with respect to these two concepts and some of the facilities available in R for dealing with them. While there is certainly a relation between the coding of light by the visual system and its color appearance, such a relation is complex and remains a research topic. As shown below, for example, lights that are encoded identically by the visual system can appear very differently as a function of context.



*The two columns of small grey boxes in the left image appear quite different in the context of the alternating blue and yellow slats in the right image but are physically identical in both images (i.e., specified in each case by the argument* col = "grey"*) and therefore encoded identically at the visual input.*

The trichromatic model of human color vision describes how chromatic differences are encoded in three spectrally different channels in the visual system. Color matching experiments that support the model have led to color specification systems for the spectral coding of lights by an average normal, observer (e.g., the CIE 1931 $xy$ diagram) These systems, however, do *not* represent color appearance! For example, the grey boxes in the above figure have the same tristimulus values in the left and right images independently of the color of the adjacent slats.

Chromatic discrimination experiments demonstrate that the CIE $xy$ diagram is anisotropic. This has led to the development of so-called uniform chromaticity diagrams (e.g., $L^*u^*v^*$ and $L^*a^*b^*$) that are, in fact, not uniform. The **colorspace** package facilitates specifying lights in R with respect to these different spaces [2]. Chromatic discrimination across the $xy$ chromaticity diagram can be explained by a decorrelation of the signals at the retinal output [3].

It is estimated that about 1.3% of the population have dichromatic color vision, i.e., color matching behavior that depends on only two instead of three variables. The loss of one of the normal spectral channels leads to a collapse of the normal space to a two-dimensional subspace. There are three types of dichromacy (each corresponding to loss of one of the normal spectral channels). The **dichromat** package [4] provides color palettes that can be used to modify a graphic so that a color normal observer can appreciate for a given graphic display the loss of salience experienced for an observer with a particular type of dichromacy.

Recent work suggests how models of coding might be used to predict the salience of lights in a multicolor display. Salience can be gauged operationally by the reaction time to detect a particular color target in a field of distractor colors. Under some conditions, reaction time is independent of the number of distractors, suggesting high salience while under others, reaction time increases with the number of distractors, suggesting low salience with respect to the distractors. These results can be explained by models in which observers use a linear classifier to search for the target color [1].

What about appearance? The appearance of lights can be represented by coordinates along three perceptual dimensions that code opponent pairs of colors: red-green, yellow-blue, white-black. This opponent color coordinate system, however, is not related linearly to the spaces described above that encode identity between lights. Such appearance diagrams suggest useful color scales for graphics. Nevertheless, care must be taken in their use, as color appearance, unlike spectral coding, depends strongly on the spatial configuation of lights (as shown in the image above) and the adaptation state of the observer (e.g., for a transient effect of adaptation, stare at a fixed point on the right image above for 30 seconds and then move your gaze to the left image).

**Références**

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