Dubious Scholarship in Full Colour - Deep Climate

Antecedents of Wegman & Said (2011) and Wegman (2002)

1. Introduction and Summary

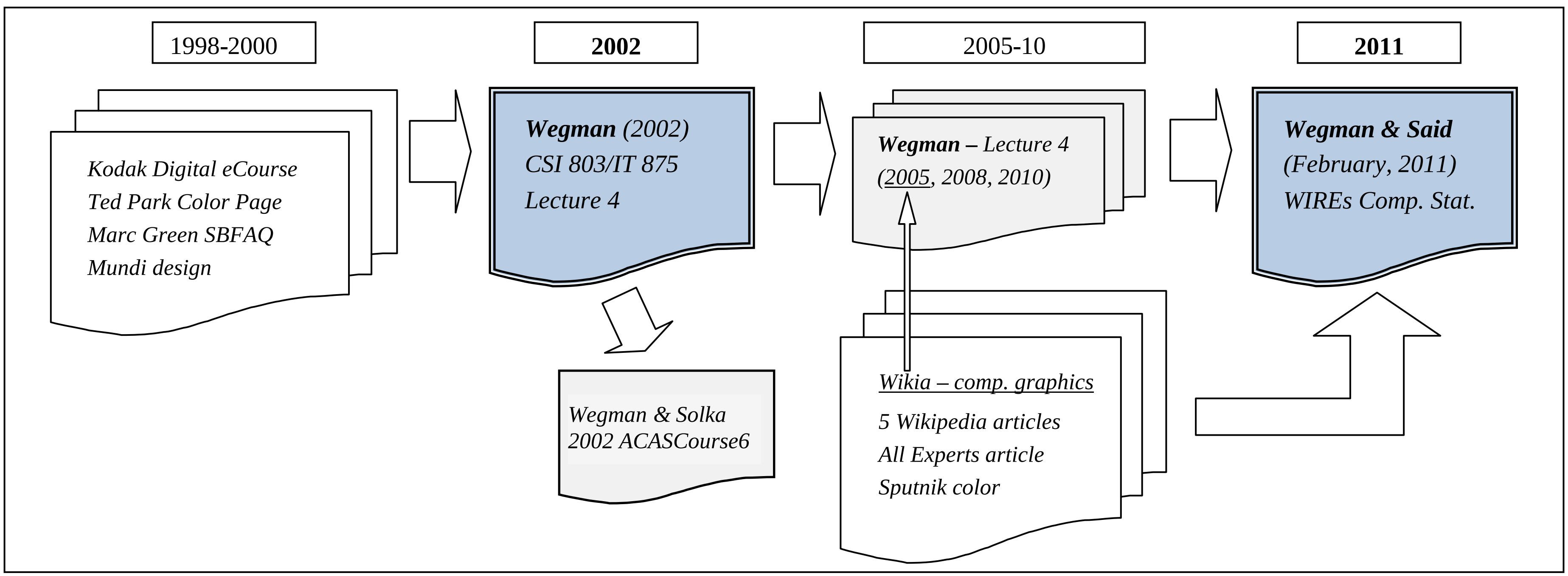
This report examines the antecedents of a recent paper by George Mason University (GMU) statistics professor Edward Wegman and GMU research professor Yasmin Said, "Color Theory and Design" published in the February 2011 *WIREs Computational Statistics*. The paper was acknowledged by Wegman and Said to have been based in large part on a previous course lecture by Wegman, since identified as a PowerPoint lecture note set used in statistical courses at GMU, going back to 2002.

Wegman is best known as the lead author of the "hockey stick" report to the U.S. Congress, commissioned by Rep. Joe Barton in 2005, and released in July 2006. Said was a co-author of that report, as was David Scott of Rice University; the three are also the editors of the *WIREs Comp Stat* journal. Said is a protégé of Wegman, having received her PhD under him in 2005. She went on to become one of Wegman's most frequent co-authors.

Several unattributed verbatim and near-verbatim antecedents of Wegman and Said (2011) have been identified. These fall into two distinct groups:

1. At least 76 out of 83 pages of content in Wegman (2002) are identical to six online sources available at that time, including a Kodak tutorial on digital colour and a page on color theory by Ted Park.
2. In turn, much of this material found its way into Wegman and Said (2011), again unattributed for the most part. Additional unattributed material in Wegman and Said (2011), both text and figures, can be traced to five different Wikipedia articles, as well as other non-academic online sources.

The flow of the main unattributed antecedents has been outlined in the diagram below, and detailed in the following sections.



Here are the full references for the two documents analyzed:

- Edward Wegman and Yasmin Said, "Color Theory and Design", *Wiley Interdisciplinary Reviews: Computational Statistics*, Volume 3, Issue 2, pages 104–118, March/April 2011. Online Feb. 4, 2011.
- Edward Wegman, *Scientific and Statistical Visualization* (Course), Lecture 4. Online version Feb, 2002.

The following table summarizes the "flow" of unattributed antecedents, showing where unattributed antecedents have "ended up" in the two works.

Section 2 breaks down Wegman (2002) page by page; where antecedents have been identified, they were generally used without any change (any exceptions have been duly noted). Section 3 details the evolution of the lecture, through its various versions.

Section 4 shows a detailed side-by-side comparison of Wegman and Said and its antecedents. "Flow through" passages from Wegman 2002 have not been altered from the original sources in most cases. Text from the newer interspersed material from Wikipedia and other sources shows evidence of editing, although substantial identical wording remains.

Year	Source (with hyperlink)	Wegman (2002)	Wegman & Said (2011)
1999	Color Theory Page (Ted Park)	p.2, p. 4, p. 8-13	p. 1, p. 2, p.3
1999	Kodak Digital Color Tutorial, Chapter 2, Digital Color Theory	p. 3, p. 7, p. 15-26	p.2, p.3, p.4, p.5, p. 7
2000, 2004	Marc Green Basic Color & Design SBFAQ (Original at http://www.ergogero.com/FAQ/cfaqhome.html)	p. 6, p. 31-60, p. 62, p. 64	p. 1 *p. 8-14: general acknowledgment and some attribution, 2 charts and some wording without attribution (see Section 3, p. 15-16 below)*
1999	Markemson, 1999	p. 26	p. 7
2000?	Killer sites	p. 65	-
2000	Mundi Design - Principles of Graphic Design	p. 66-84	-
	Antecedents not found.	p. 5, p. 14, p. 28-30, p. 61, p. 63	
		Wegman (2005 ff)	
2001-11	Wikipedia - Eye	-	p.1 (text & figure), p. 2 (text),
2002-11	Wikipedia - Munsell Color System	-	p. 4 (text & figure)
2006-11	Wikipedia - 1931 CIE Color Space	-	p. 4-6 (text & figures)
2005?	Wikia – Computer graphics – Saturation	p. 22-23	p. 6-7 (text & equations)
2004	AllExperts: Genetics/colour blindness and albinism	-	p.9 (text)
2004-11	Wikipedia - RYB Color Model	-	p. 13-14 (paraphrased text, figures)
2005-10	Wikipedia - Normalized Color Co-ordinates	-	p. 14 (figure)
	Sputnik Color Schemes	-	p. 14 (figure)

2. Detailed antecedents of Wegman (2002)

Page #	Source	Source Details
2	Color Theory Page (Ted Park)	Additive Primary Colors, para 1 (verbatim, one sentence added: "There are about 10^7 foveal cones.")
3	Kodak, Chapter 2, Digital Color Theory	Lesson 1, p. 1 (first figure)
4	Color Theory Page (Ted Park)	Color Theory Page (Ted Park) Additive Primary Colors, para 2 (verbatim, added phrase "A somewhat simple interpretation is that")
5		*Antecedent not found.*
6	Marc Green Basic Color & Design SBFAQ (Orig. http://www.ergogero.com/FAQ/cfaqhome.html)	Verbatim (Includes "actually hue" instead of "actual hue")
7	Kodak, Chapter 2, Digital Color Theory	Lesson 1, p. 1, para 3 – Verbatim, added "because cones dominate". Figure 2.
8-13	Color Theory Page (Ted Park)	Additive Primary Colors - para 2 (verbatim, word order slight change), right-hand figure,. Subtractive Primary Colors - para 2 (verbatim), absorption chart table, para 5 (verbatim), chart.
14		*Sam Wilks – no antecedent found.*
15-26	Kodak, Chapter 2, Digital Color Theory	Lesson 1, p.7-8, all figures and text. Lesson 1, p. 9, fig 2-3 and all text. Lesson 1, p. 10, all figures and almost all text (slight omissions).
27	Markemson, 1999	Phrase added (intervening source?): "Basically, how much of the hue is identifiable".
28-30		*Gamma – no antecedents found (includes original photo)*
31-37	Marc Green Basic Color & Design SBFAQ	Part 4: Color Blindness 4.1: Slight order changes and omissions
38-40	Marc Green Basic Color & Design SBFAQ	Part 4: Color Blindness 4.2 para 2-3, 4.3 Fig 1, para 4.2, para 4
41-43	Marc Green Basic Color & Design SBFAQ	Part 4: Color Blindness 4.7 Question (rephrased as stmt), all para (slight omissions)
44-48	Marc Green Basic Color & Design SBFAQ	Part 5: Using Color Effectively 5.1 (slight omission); 5.2 Para 3, 5.3 (slight omission), 5.5
49-57	Marc Green Basic Color & Design SBFAQ	Part 5: Using Color Effectively 5.5 Para 1-2 (slight addition "12 colors …" 5.6 Para 1, 8, 10 (slight omission), Fig 1 5.7 Para 4 (slight omission), Fig 1 5.12 (slight omission)
58-60	Marc Green Basic Color & Design SBFAQ	Using Color Effectively 5.13 (list only)
61		*Antecedent not found*
62	Marc Green Basic Color & Design SBFAQ	Using Color Effectively 5.13 (fig only)
63		*Antecedent not found*
64	Marc Green Basic Color & Design SBFAQ	Using Color Effectively 5.15 (fig only)
65	Killer sites	Killer sites – Netscape browser palette with diagram
66-84	Mundi Design - Principles of Graphic Design Flash interactive (rollover); also as zipped SWF. (Org at mundidesign.com/presentation/index2F.html) Described at: 1, 2)	Verbatim slides from section 3 on Composition and Layout **3a**: 1, 6, 2, 5, 8. **3b**: 1-5. **3c**: 1-3. **3d**: Grids (sole slide); Root rectangle 2, 9, 10; Golden mean 2, 10.

3. Evolution of Color Theory course lecture

Over the years, Wegman's lecture notes have changed remarkably little, beyond formatting and changes in graphic template. However some changes are worth noting, especially in the list of "resources" appearing at the end of the lecture. In initial versions, these were the actual sources, although not identified as such. In the latest version in 2010, all traces of references to the actual sources had disappeared.

The following table lists five different versions and details changes in the "resources" list, as well as any significant changes in content or format. (Note that that the "resources" links given here are the original ones found in the lectures, and no longer function for the most part. Currently available online links to the "resources" are given in the tables in sections 2 and 3).

Year	Course/Version	"Resource" list	Other Changes	Comments
2002	CSI 803/IT 875 Scientific and Statistical Visualization CSI803-Lecture4.pdf 85 pages	Color Theory http://www.beer.org/~tpark/color.html *[Ted Park Color Page]* http://www.kodak.com/US/en/digital/dlc/book3/chapter2/index.shtml Color Design http://www.ergogero.com/FAQ/cfaqhome.html *[Marc Green SBFAQ]* http://www.killersites.com/1-design/ *[Killer sites]* Graphic Design http://www.mundidesign.com/presentation/index2F.html [Mundi] http://www.graphicdesignbasics.com/		
2002	Statistical Data Mining: A Short Course for the Army Conference on Applied Statistics ACAS Course6.pdf 86 Pages	Same as above	p. 2 lists topics No accent graphics	Jeffrey Solka was course co-author, but apparently had nothing to do with this lecture. Colours washed out (ironically).
2005	Statistical Data Mining IT 871, Lecture 4 SDM2005_4.pdf 87 pages	Same as above	pp.22-23 on saturation from Wikia Graphics. No accent graphics	
2008	Statistical Data Mining IT 871, Lecture 4 SDM2008_4.pdf 86 pages	Color Theory http://en.wikipedia.org/wiki/Color_theory http://graphics1.kodak.com/documents/Introducing Color Theory.pdf Graphic Design http://en.wikipedia.org/wiki/Graphic_design http://www.graphicdesignbasics.com/principles-of-design	p. 67 – Killer Site web color design removed (had mentioned Netscape browser)	Use of bullet points to break up copied text.
2010	Statistical Data Mining IT 871, Lecture 4 SDM2010_4.pdf 67 pages	Color Theory http://en.wikipedia.org/wiki/Color_theory Graphic Design http://en.wikipedia.org/wiki/Graphic_design	Mundi design slides removed (19 slides).	

4. Detailed comparison of *Color Theory and Design* (Wegman & Said, 2011) and antecedents

The following table shows identified unattributed antecedents of Color Theory and Design, page by page, followed by detailed side-by-side comparison

Page	Source (with hyperlink) Flow Through	
1	Color Theory Page (Ted Park) Wikipedia - Eye Marc Green SBFAQ	Weg2002, p.2, 4 - Weg2002, p. 6
2	Wikipedia - Eye (fig, txt) Kodak Tutorial Digital Color Color Theory Page (Ted Park)	- Weg2002, p.7 Weg 2002, p. 8,10,12
3	Color Theory Page (Ted Park)	Weg2002, p. 12
4	Color Theory Page (Ted Park) Kodak Tutorial Digital Color Wikipedia - Munsell Color System	Weg2002, p. 9, 13 Weg2002, p. 15-20 -
5	Kodak Tutorial Digital Color Wikipedia - 1931 CIE Color Space (fig, txt)	Weg2002, p. 21 -
6	Wikipedia - 1931 CIE Color Space (fig, txt)	-
7	Wikia – Computer graphics – Saturation (fig, txt) Kodak Tutorial Digital Color Markemson, 1999	Weg2005, p.22-3 Weg2002, p. 25-6 Weg2002, p. 27
8	*No unattributed antecedents found*	
9	Marc Green SBFAQ	Weg2002,p. 42-3
10	AllExperts: Colour blindness/albinism	-
11	Marc Green SBFAQ (fig)	Weg2002,p. 53-4
12	Wikipedia - RYB Color Model	-
13	Wikipedia - Normalized Color Co-ordinates (fig) Sputnik Color Schemes (fig) Marc Green SBFAQ	- - -
14	*No unattributed antecedents found*	-

Colored regular font indicates substantially close wording between the article and its antecedent sources (identical in cyan, slight variation in yellow), *italic* represent paraphrased sections, **bold** represents significant departures of Wegman & Said 2011 from sources. A few short sentences of unknown provenance added in Wegman 2002 are highlighted in grey; these may be original. Paragraphs have been reformatted for ease of comparison. Passages with changes that introduce various issues have been underlined, but for the most part not analyzed at present.

Section 1 – HUMAN VISUAL SYSTEM (p.1 – p.2)

Para 1 – No antecedent found

Para 2

Human vision relies on light sensitive cells in the retina of the eye. There are two basic kinds of sensors. These are rods and cones. Rods are cells which can work at very low light intensity (*scotopic)*, but cannot resolve sharp images or color.

The rods contain a pigment, rhodopsin, also called visual purple, which saturates at higher levels of light.

Cones are cells that can resolve sharp images and color, but require much higher light levels to work.

Figure 1 illustrates the major components of the human eye. Both the rod cells and the cone cells are located on the retina. The central part of the retina is called the *fovea*, which is where cells responsible for vision are most densely located.

There are about 10^7 foveal cones.

The combined information from these sensors is sent to the brain and enables human vision.

Wegman (p. 2) - Color Theory Page (Ted Park)

Human vision relies on light sensitive cells in the retina of the eye. There are two basic kinds of sensors. These are rods and cones. Rods are cells which can work at very low intensity , but cannot resolve sharp images or color.

Wikipedia - Eye

Rods ~~cannot distinguish colours, but are responsible for low-light~~ (scotopic) ~~monochrome (black-and-white) vision; they work well in dim light as they~~ contain a pigment, rhodopsin (visual purple), which ~~is sensitive at low light intensity, but~~ saturates at higher ~~(photopic)~~ intensities.

Wegman (p. 2) - Color Theory Page (Ted Park)

Cones are cells that can resolve sharp images and color, but require much higher light levels to work.

Wegman (p. 2) – no antecedent found

There are about 10^7 foveal cones.

Wegman (p. 2) - Color Theory Page (Ted Park)

The combined information from these sensors is sent to the brain and enables us to see.

Para 3
There are three types of cones.

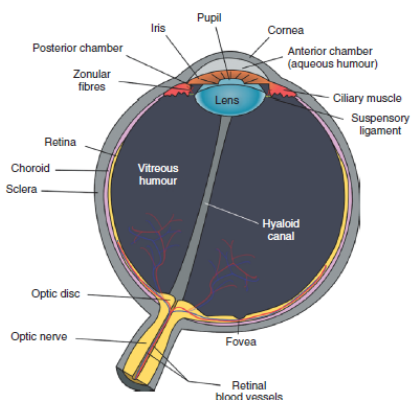
A somewhat simplistic interpretation is that

red cones are sensitive to red light, green cones are sensitive to green light, and blue cones are sensitive to blue light.
More precisely, the cones are sensitive to long, medium, and short wavelengths of light. The peak response of the cones do not actually occur precisely in the red, green, and blue color bands, but the perception of color depends on contrast among the stimulation levels of the different cell types.

Para 4
[Omitted – virtually identical to Wegman p. 5]

Para 5
The relationship between wavelength and actual hue is roughly:
- 620–730 nm: red
- 590–610 nm: orange
- 550–580 nm: yellow
- 490–540 nm: green
- 450–480 nm: blue
- 380–440 nm: violet.

FIGURE 1 (Creative Commons license without specific attribution)
Schematic diagram of the **human** eye.



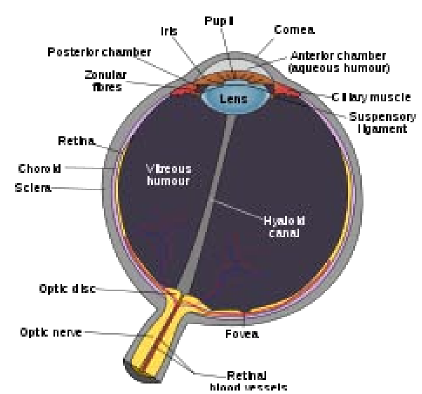
Wegman (p. 4) - Color Theory Page (Ted Park)
There are three types of cone.
Wegman (p. 4) – added phrase
A somewhat simple interpretation is that
Wegman (p. 4) - Color Theory Page (Ted Park)
Red cones are sensitive to red light, green cones are sensitive to green light, and blue cones are sensitive to blue light.

Wegman (p. 4) - Color Theory Page (Ted Park)
The perception of color depends on an imbalance between the stimulation level of the different cell types.

Wegman (p. 5) – no antecedent found

Wegman (p. 6) – Marc Green SBFAQ
The relationship between wavelength and actually hue is roughly:
620-730 nm: red
590-610 nm: orange
550-580 nm: yellow
490-540 nm: green
450-480 nm: blue
380-440 nm: violet

Figure 1 from Wikipedia – Eye
Schematic diagram of the vertebrate eye.



Para 7

The colors we see are affected by the intensity of light and by its spectral content. At low levels of illumination, objects are less colorful because rods are dominant. In bright daylight, we see more color, contrast, and saturation because cones dominate.Figures 2 and 3 illustrate these effects.

Section 2 - COLOR THEORY (p. 2-8)
Para 1
[*Two sentences omitted.*]
Indeed, the pigments in the eyes can vary from one animal group to another and can be used to tell the evolutionary distance between animal groups.
[*One sentence omitted.*]

Para 2
Additive color processes, such as television, work by having the capability to generate an image composed of red, green, and blue light. Because the intensity information for each of the three colors is preserved, the image color is preserved as well. The spectral distribution of the image will probably be wrong, but if the degree of intensity for each of the primary colors is correct, the image will appear to be the right color. Red, green, and blue are the additive primary colors because they correspond to the red, green, and blue cones in the eye.

Para 3
Subtractive color processes work by blocking out parts of the spectrum. The idea of subtractive color is to reduce the amount of undesired color reaching the eye. If, for example, one had a yellow image, one would want to have a dye that would let red and green reach the eye, and block out blue. The additive secondaries become the subtractive primaries, because each of the additive secondaries will reflect two of the additive primaries, and absorb one of the additive primaries (Figures 4 and 5). See also Table 1.

Wegman (p. 7) – Kodak, Chap 2, Digital Color Theory (Lesson 1, p.1, para 3)
The colors we see are affected by the intensity of light and by its spectral content. At low levels of illumination, objects are less colorful because rods are dominant. In bright daylight, we see more color, contrast, and saturation because cones dominate.

Wikipedia – Eye (Pigmentation)

The pigment molecules used in the eye are various, but can be used to define the evolutionary distance between different groups

Wegman (p. 8) - Color Theory Page (Ted Park)
Additive color processes, such as television, work by having the capability to generate an image composed of red, green, and blue light. Since the intensity information for each of the three colors is preserved, the image color is preserved as well. The spectral distribution of the image will probably be wrong, but if the degree of intensity for each of the primary colors is correct, the image will appear to be the right color. Red, green, and blue are the additive primary colors, because they correspond to the red, green, and blue cones in the eye.

Wegman (p. 10) - Color Theory Page (Ted Park)
Subtractive color processes work by blocking out parts of the spectrum. The idea of subtractive color is to reduce the amount of undesired color reaching the eye. If, for example, you had a yellow image, you would want to have a dye that would let red and green reach the eye, and block out blue. The additive secondaries become the subtractive primaries, because each of the additive secondaries will reflect two of the additive primaries, and absorb one of the additive primaries.

Para 4

With this information, in a subtractive color system, such as printed documents that reflect light, if we wanted red, we would mix magenta and yellow. Magenta would absorb green, and yellow would absorb blue, leaving only red to be reflected back to the eye. For black, a combination of all three would be used, which should, in principle, block out all light. In practice, printers use black as well, because the dyes used in printing are not perfect, and some light from other parts of the spectrum still is reflected.

TABLE 1

Additive Secondaries/Subtractive Primaries Absorption Chart

Color	Reflects	Absorbs
Yellow	Red and green	Blue
Magenta	Red and blue	Green
Cyan	Green and blue	Red

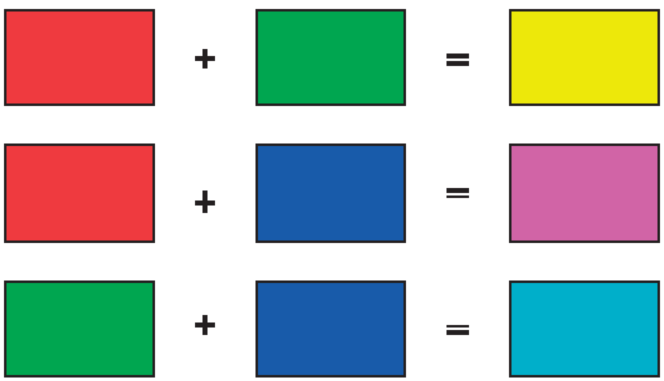


FIGURE 4 | Additive secondaries are derived by combining primary colors.

Wegman (p. 12) - Color Theory Page (Ted Park)

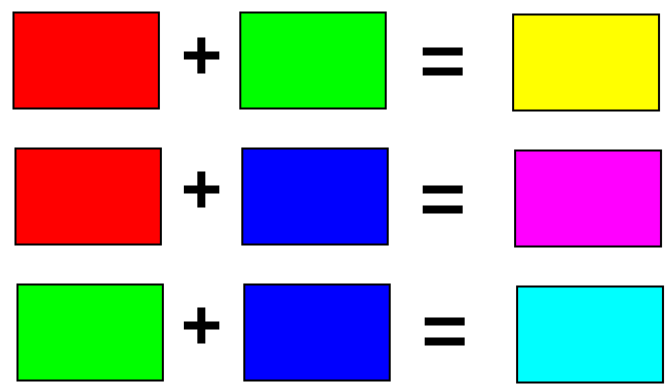
With this information,
if we wanted red, we would mix magenta
and yellow. Magenta would absorb green, and yellow would absorb blue, leaving only red to be reflected back to the eye. For black, a combination of all three would be used, which should
block out all light in theory. Printers use black as well, since the dyes used in printing are not perfect, and some light from other parts of the spectrum gets through.

Wegman (p. 12) - Color Theory Page (Ted Park)

Additive Secondaries/Subtractive Primaries Absorption Chart

Color	*Reflects*	*Absorbs*
Yellow	Red and Green	Blue
Magenta	Red and Blue	Green
Cyan	Green and Blue	Red

Wegman (p. 9) - Color Theory Page (Ted Park)



Derivation of Additive Secondaries from ~~Additive~~ Primary Colors.

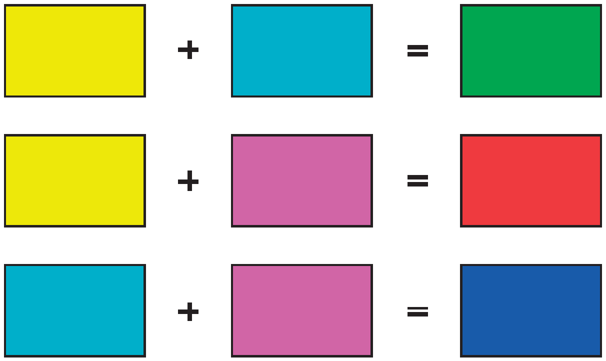


FIGURE 5 | Subtractive primaries mixing chart.

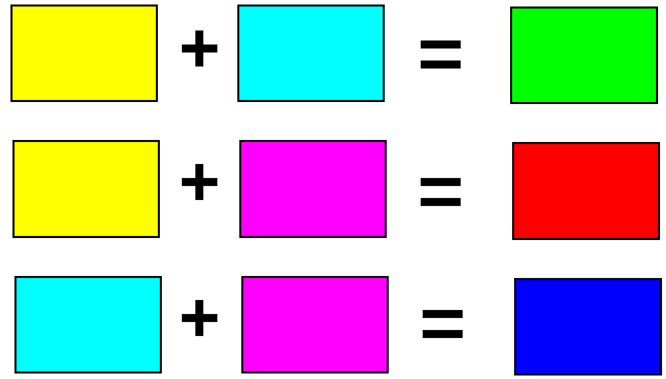
Para 5 [*Omitted*]

Para 6

Color can be defined by three properties: hue, saturation, and lightness or brightness. When we call an object 'red,' we are referring to its hue. Hue is determined by the dominant wavelength.

The saturation of a color ranges from neutral to brilliant.
Colors are desaturated by mixing in white or gray or black.
Lightness or brightness refers to the amount of light the color reflects or transmits.

Wegman (p. 13) - Color Theory Page (Ted Park)



Subtractive Primaries Mixing Chart

Wegman (p. 15-17) – Kodak, Chap 2, Digital Color Theory (Lesson 1, p.7)

Color can be defined by three properties: hue, saturation, and lightness or brightness. When we call an object "red," we are referring to its hue. Hue is determined by the dominant wavelength.

The saturation of a color ranges from neutral to brilliant.

Lightness or brightness refers to the amount of light the color reflects or transmits.

Sub-section: The Munsell System (p. 4)
Para 1
Color ordering systems, such as the Munsell System, use the three properties of color to identify unique colors. Notice that colors are distributed in three dimensions: *hue*, *chroma* (saturation), and *value* (lightness).
We commonly see colors arrayed in two dimensions. This is a useful, but incomplete representation.

Value is the third dimension that is not shown in two-dimensional color wheels, **but is** often used in image editing software.

Professor Albert Munsell's (1885–1918) description of the color system was published in Refs 2,3.

Munsell's system was based on rigorous experimental research with careful measurements of human visual responses to color (Figure 7).

It persisted for many decades, eventually being superseded by systems such as the CIE (in French, Commission Internationale de l'Eclairage).

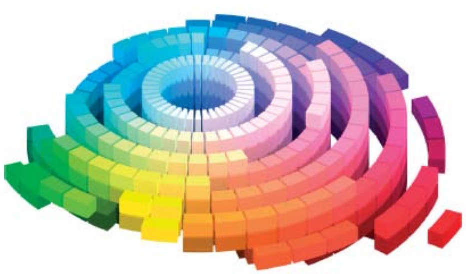
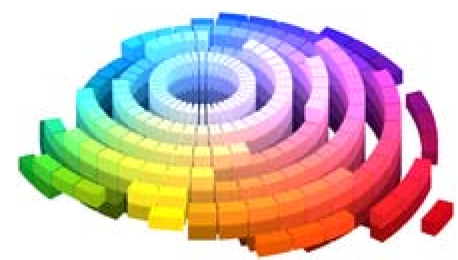


FIGURE 7 | Illustration of the Munsell color system. The vertical direction represents value or lightness. The radial direction represents Chroma or Saturation. The angular direction represents Hue. This image is used under the Creative Commons Attribution-Share Alike 3.0 License. Details are at http://creativecommons.org/licenses/by-sa/3.0/legalcode. [No attribution]

Wegman (p. 18-20) – Kodak, Chap 2, Digital Color Theory (Lesson 1, p.8)
Color ordering systems, such as the Munsell System, use the three properties of color to identify unique colors. Notice that colors are distributed in three dimensions.

We commonly see colors arrayed in two dimensions. This is a useful, but incomplete representation. ~~Colors actually occupy a three dimensional space~~.
Lightness is the third dimension that is not shown in color wheels often used in image editing software.

Wikipedia – Munsell Color System (para 2)
Munsell's system, ~~and particularly the later renotations~~, is based on rigorous measurements of human subjects' visual responses to color, putting it on a firm experimental scientific basis~~. Because of this basis in human visual perception, Munsell's system has outlasted its contemporary color models~~, and though it has been superseded ~~for some uses by~~ models such as CIELAB (L*a*b*) and CIECAM02, ~~it is still in wide use today~~.



Three-dimensional representation of the 1943 Munsell renotations.

Sub-Section: CIE Models (p. 5)
If the Munsell system established the three dimensional nature of color perception, the CIE models attempt to establish numerical values.[4,5]
To measure and predict the appearance of a particular color, we need a way to link perception to numbers and formulas. Scientific color values were established earlier this century by the CIE group. CIE models for defining color space all rely on the same basic numbers.

[*5 sentences omitted*]

It is, of course, possible for two sources of light with distinctly different spectral distributions to combine to present a tristimulus value to the eye and be recorded as a certain color. It is possible for another two sources of light with different spectral distributions from the first two to combine and present the same tristimulus value to the eye, which would therefore be recorded as the same color even though the combined spectrums are distinctly different. This effect is called metamerism.

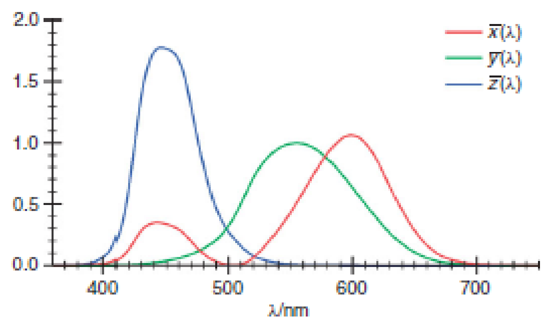
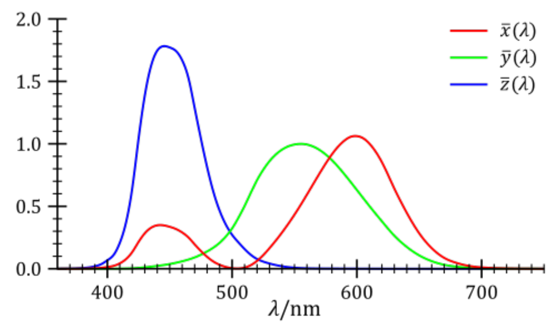


FIGURE 8 | XYZ Color matching functions as described in the text. This image is used under the Creative Commons Attribution-Share Alike 3.0 License. Details are at http://creativecommons.org/licenses/by-sa/3.0/legalcode. [No attribution]

Wegman (p. 21) – Kodak, Chap 2, Digital Color Theory (Lesson 1, p.9)

To measure and predict the appearance of a particular color, we need a way to link perception to numbers and formulas. Scientific color values were established earlier this century by the CIE group. CIE models for defining color space all rely on the same basic numbers.

Wikipedia – CIE 1931 Color Space
The CIE Standard Observer (para 2)
Two light sources, made up of different mixtures of various wavelengths, may appear to be the same color; this effect is called metamerism. Two light sources have the same apparent color to an observer when they have the same tristimulus values, no matter what spectral distributions of light were used to produce them.



The CIE standard observer color matching functions

CIE Models (cont.)
Para 2
Because of the distribution of cone cells on the retina, color perception depends on the field of view with each individual having different distribution and different field of view. The CIE sought to eliminate this variability be defining a standard colorimetric observer. With the belief that most cones are located within 2° of the fovea, the chromatic response of the standard colorimetric observer was taken to be the response of the average human within 2°.

Based on extensive experimentation,[6,7] the standard colorimetric observer is characterized by three color matching functions.

The color matching functions are a numerical description of the chromatic response of the standard colorimetric observer, which is, of course, the average chromatic response of a number of humans. The CIE defines the color matching functions as x(λ), y(λ), and z(λ) where λ is the wavelength in nanometers.

Para 3
The tristimulus values *X*, *Y*, and *Z* for a color with spectral power distribution $f(\lambda)$ are given in terms of the standard colormetric observer as

$$X = \int_0^\infty f(\lambda)\overline{x}(\lambda)d\lambda$$

$$Y = \int_0^\infty f(\lambda)\overline{y}(\lambda)d\lambda$$

$$Z = \int_0^\infty f(\lambda)\overline{z}(\lambda)d\lambda.$$

Wikipedia – CIE 1931 Color Space
Section: The CIE Standard Observer (para 2)
Due to ~~the nature~~ of the distribution of cones in the eye, the tristimulus values depend on the observer's field of view.

To eliminate this variable, the CIE defined the standard (colorimetric) observer. Originally this was taken to be the chromatic response of the average human ~~viewing~~ through ~~a~~ 2° ~~angle~~, due to the belief that the ~~color-sensitive~~ cones resided within ~~a~~ 2° ~~are~~ of the fovea.

[*Two sentences omitted*]

Para 4
The standard observer is characterized by three color matching functions.

Section: Color Matching functions
The color matching functions are the numerical description of the chromatic response of the observer (described above).

The CIE has defined a ~~set of three~~ color-matching functions, called x(λ), y(λ), and z(λ), ~~which can be thought of as the spectral sensitivity curves of three linear light detectors that yield the CIE XYZ~~ tristimulus values X, Y, and Z.

The tristimulus values for a color with a spectral power distribution $I(\lambda)$ are given in terms of the standard observer by:

$$X = \int_0^\infty I(\lambda)\,\overline{x}(\lambda)\,d\lambda$$

$$Y = \int_0^\infty I(\lambda)\,\overline{y}(\lambda)\,d\lambda$$

$$Z = \int_0^\infty I(\lambda)\,\overline{z}(\lambda)\,d\lambda$$

where λ is the wavelength ~~of the equivalent monochromatic light (measured~~ in nanometers).

CIE Models (cont.)
Para 4-5

The CIE xyY color space is a derived color space. The Y value was designed to reflect the overall luminance (brightness, lightness). *The remaining to dimensions are characterized* by the x and y and are used to specify colors. Here the normalized values are given by

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}.$$

The values *x* and *y* specify the chromaticity diagram, independent of luminance. This diagram is illustrated in Figure 9.

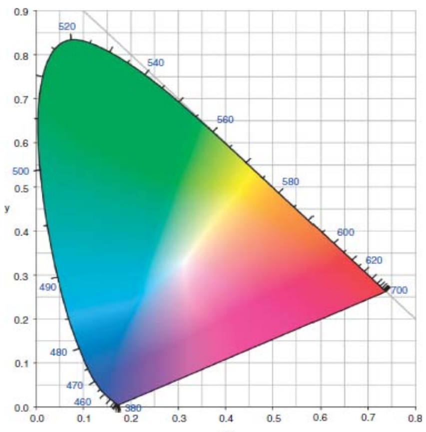


FIGURE 9 | CIE xyY Chromaticity Diagram as a function of x and y. The range 380 to 700 nm represents the range of perception of visible light for humans. Saturation as well as chroma are represented in this diagram. This image is used under the Creative Commons Attribution-Share Alike 3.0 License … [No attribution]

Wikipedia – CIE 1931 Color Space
Section: The CIE xy chromaticity diagram and the CIE xyY color space (para 2)

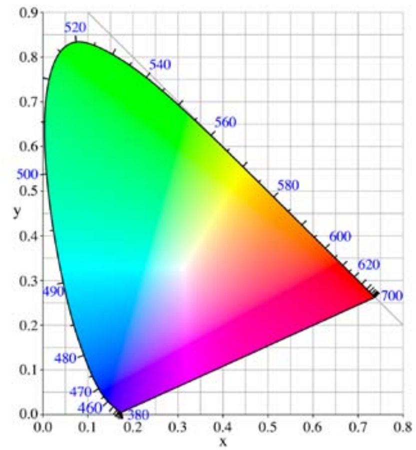
The CIE XYZ color space was deliberately designed so that the Y parameter was a measure of the brightness or luminance ~~of a color. The chromaticity of a~~ color was then specified by the ~~two~~ derived ~~parameters~~ x and y, two of the three normalized values which are functions of all three tristimulus values X, Y, and Z.

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$

The derived color space specified by x, y, and Y is known as the CIE xyY color space and is widely used to specify colors in practice.



The CIE 1931 color space chromaticity diagram. … This diagram displays the maximally saturated bright colors that can be produced by a computer monitor or television set.

CIE Models (cont.)
Para 6-7 (p. 6-7)

In the CIE XYZ color space, the saturation (chroma in Munsell, purity in CIE) is the Euclidean distance between the position of one color (x, y) and the illuminant's reference white (x_w, y_w), i.e. that set of three chromaticity values that determines the reference white in the xy plane divided by the same distance for a pure (monochromatic) color with the same hue $(x_c, y_c) = \rho_{max}(x - x_w, y - y_w) + (x_w, y_w)$ where ρ_{max} is the maximum in the chromaticity diagram. Then purity is defined as

$$p = \frac{\sqrt{(x - x_w)^2 + (y - y_w)^2}}{\sqrt{(x - x_c)^2 + (y - y_c)^2}}.$$

In an RGB space, saturation can be thought of as the standard deviation, σ, of the color coordinates R (red), G (green), and B (blue). Letting μ be the luminance, then

$$\sigma = \sqrt{\frac{(R-\mu)^2 + (G-\mu)^2 + (B-\mu)^2}{3}}.$$

Para 8 (p. 7)
[*Two sentences omitted*]

Measuring color allows us to compare the color gamut, or range of colors produced by different methods (Ref 8, Section 18.7). Color transparency film produces a wide range of colors including some a monitor cannot display. Color printers and printing presses have different color gamuts.

[*One sentence omitted*]
These systems can never capture all the colors that the eye can see, but they can simulate the appearance very successfully if color reproduction is understood and controlled.

Wegman 2010, Wikia – Computer graphics – Saturation
Purity in CIE 1931 XYZ color space

In the CIE XYZ color space, the purity or saturation is the Euclidean distance between the position of the color (x, y) and the illuminant's white point (x_I, y_I) on the CIE xy ~~projective~~ plane, divided by the same distance for a pure (monochromatic, ~~or dichromatic on the purple line~~) color with the same hue $(x_P, y_P) = \rho_{\max}(x - x_I, y - y_I) + (x_I, y_I)$:

$$p = \sqrt{\frac{(x - x_I)^2 + (y - y_I)^2}{(x - x_P)^2 + (y - y_P)^2}}$$

and $\rho_{\max}$ maximal within ~~the boundary of~~ the chromaticity diagram.

Saturation in RGB color space
In an RGB color space, saturation can be thought of as the standard deviation σ of the color coordinates R(red), G(green), and B(blue). Letting μ represent the brightness, then

$$\sigma = \sqrt{\frac{(R-\mu)^2 + (G-\mu)^2 + (B-\mu)^2}{3}}.$$

Wegman (p. 25-26) – Kodak, Chap 2, Digital Color Theory (Lesson 1, p.10)

Measuring color allows us to compare the color gamut, or range of colors produced by different methods. Color transparency film produces a wide range of colors including some a monitor cannot display.Color printers and printing presses have different color gamuts.

They can never capture all the colors that the eye can see ~~or that are in an original transparency~~, but they can simulate the appearance very successfully if color reproduction is understood and controlled.

CIE Models (cont.)
[*Para 9 and Figure 10 omitted*]

Para 10 (p. 7)
To summarize the color concepts:

- Hue: color with no black, white or gray added
- Tint: hue + white
- Shade: hue + black
- Tone: hue + gray or hue + varying degrees of its complementary color
- Value or Lightness or Brightness or Luminosity:
how light or dark a color appears
- Intensity or Purity: how bright or dull a color appears, also called saturation and/or chromaticity. Basically, how much of the hue is identifiable.

Grays are achromatic, meaning no hue/color.

[*Sub-section: Digital Colors (2 para) – omitted*]

Wegman (p. 27) - Markemson, 1999

Hue: color with no black, white or grey added
Tint: hue + white
Shade: hue + black
Tone: hue + grey or hue + varying degrees of its complementary color
Value:
how light or dark a color appears
Intensity: how bright or dull a color appears, also called saturation and/or chromaticity. Basically, how much of the hue is identifiable.

Greys [Grays] are achromatic, meaning no hue/color ~~and are therefore low in intensity. The hue yellow would be completely saturated, high in chromaticity and extremely intense.~~

Artsmartnewmedia, 2010:
Intensity: Refers to how bright or dull a color appears; also called saturation and/or chromaticity. Basically, how much of the hue is identifiable. Grays are achromatic, meaning they have no hue or color ~~and are therefore low in intensity~~
[I*ndicates possible missing intermediate antecedent between Markemson and Wegman*]

Section: COLOR DEFICIENCIES IN HUMAN VISION (p. 8-10)

[***Note: This and the following section is acknowledged to be based mainly on the Marc Green SBFAQ. Only particularly egregious examples of close, unattributed wording and images from Green, or those from other sources, are given.]***

Sub-section: The Elderly (p. 9)
[*Two sentences omitted*]

Deficiency of vision in the elderly is a result of yellowing and darkening of the lens and the shrinking of pupil size. Yellowing of the lens has the result of blocking short wavelength (blue) light so that the intensity of bluish colors is diminished.

Of course, colors that have a blue component will shift in the perception of the elderly so that cyan, blue-gray, light blue, magenta will be affected and more difficult to distinguish.

Because of the shrinking of the pupil size, less light will reach the photoreceptors in the eye so that colors generally appear darker that they would for younger individuals with similar illumination.

For example, yellows may appear brown and blues may appear black.

Of course, when considering color design for the elderly, these effects must be considered. More saturated primary colors are thus recommended.

Wegman (p. 42-43) – Marc Green SBFAQ

Vision declines with age ~~in several ways, but the most relevant for color design is~~ the yellowing and darkening of the lens ~~and cornea~~ and the shrinking pupil size. Yellowing ~~selectively~~ blocks short wavelength light, so blues look darker.

Moreover, the elderly have difficulty discriminating colors which differ primarily in their blue content: blue-white, blue-gray, green-blue green, redpurple, etc.

Aging also reduces the amount of light reaching the photoreceptors compared to the young viewer. All colors will be dimmer and visual resolution lower.

For example, ~~a moderately bright~~ yellow may appear brownish and ~~dimmer~~ blues will appear black.

When designing for the elderly, use bright colors ~~and make sure that brightness contrast is especially high (and text larger) to help compensate for acuity loss.~~

SubSection: ColorBlindness (p.9-10) - Para 7

One interesting situation is the case of albinism, lack of the pigment melanin. This is a genetic disorder called
oculocutaneous albinism.

In order to exhibit albinism, one must inherit a mutant allele from both the mother and the father,
thus males and females are affected
equally for autosomal disorders. The disease is characterized either by the failure to synthesize pigment proteins or the failure of integratory proteins to implement them into tissue.

.Section: COLOR DESIGN (p. 10-14)
Sub-section Hard-Wired Perception (p. 11)

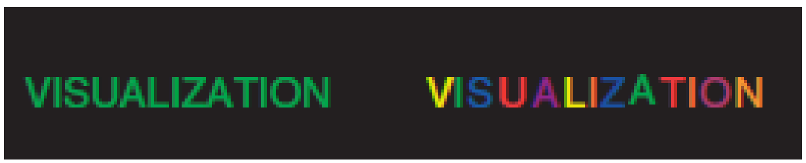


Figure 12: [no attribution]

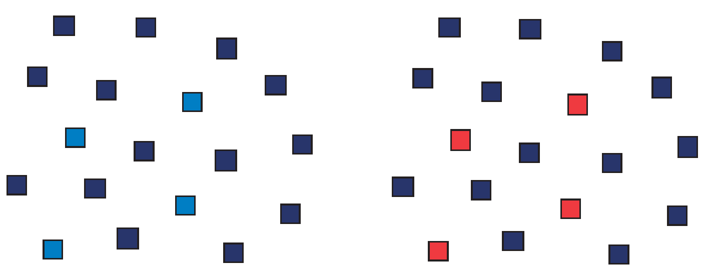


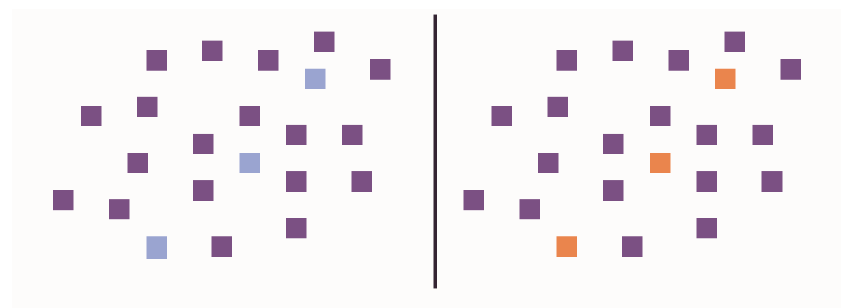
Figure 13: [no attribution]

All Experts: Genetics/colour blindness and albinism

Albinism is somewhat different--there is not a single gene 10 or so different types of
oculocutaneous albinism.

But, in order to exhibit albinism, one must inherit a mutant allele from both the mother and the father (~~whereas males only receive an X chromosome from the mother~~), thus males and females are affected equally for autosomal disorders. The disease is characterized either by the failure to synthesize pigment proteins or the failure of integretory proteins to implement them into tissue.

Wegman (p. 53-54) – Marc Green SBFAQ (5.6)



Subsection: Color Design Based on the Color Wheel (p. 12-14) - Para 2

The RYB color wheel was originally described by Isaac Newton in his 1704 treatise on Opticks.[14]

The 18th century understanding of color vision was predicated on the idea that red, yellow, and blue were the primary colors.

The use of the RYB color wheel as a model for complementary colors and as a basic tool for art and printing became well established.

Two documents, Goethe[15] *and Chevreul,*[16] *became the handbooks for color theory.*

Wikipedia – RYB Color Model - History

In his *Opticks*, Newton published a color wheel to show the geometric relationship between these primaries.

Wikipedia – Color Theory

… [A] tradition of "color theory" on began in the 18th century, initially within a partisan controversy around Isaac Newton's theory of color (Opticks, 1704) and the nature of so-called primary colors. Color theory was originally formulated in terms of three "primary" or "primitive" colors—red, yellow and blue (RYB).

Wikipedia – RYB Color Model - History

The RYB model was used for printing, by Jacob Christoph Le Blon, as early as 1725.

The RYB primary colors became the foundation of 18th century theories of color vision, as the fundamental sensory qualities that are blended in the perception of all physical colors and equally in the physical mixture of pigments or dyes. These theories were enhanced by 18th-century investigations of a variety of purely psychological color effects, in particular the contrast between "complementary" or opposing hues that are produced by color afterimages and in the contrasting shadows in colored light.

These ideas and many personal color observations were summarized in two founding documents in color theory: the Theory of Colours (1810) by the German poet and government minister Johann Wolfgang von Goethe, and The Law of Simultaneous Color Contrast (1839) by the French industrial chemist Michel Eugène Chevreul.

Subsection: Color Design Based on the Color Wheel (p. 13-14) - Figures

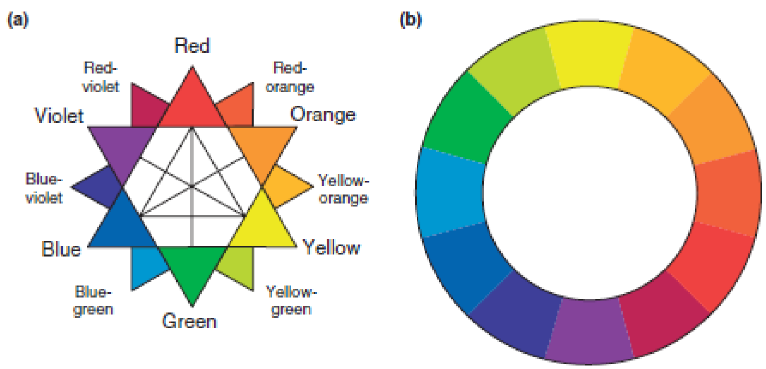


FIGURE 16 | The RYB color wheel. These images are used under GNU Free Documentation License**. [no attribution**]

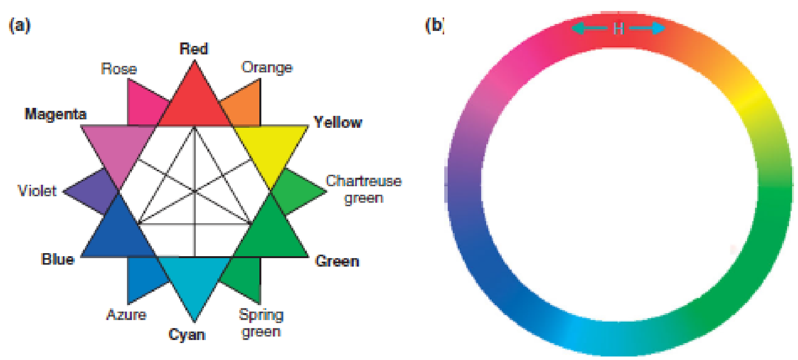
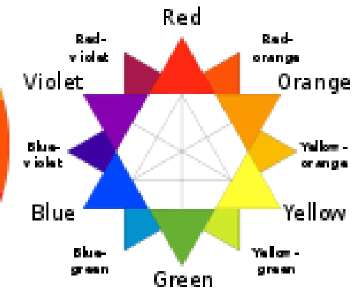


FIGURE 17 | HSV color wheel based on RGB primaries. The left image shows primary, secondary and tertiary hues. The right image show a more continuous version of the hues. These images are used under GNU Free Documentation License. **[no attribution**]

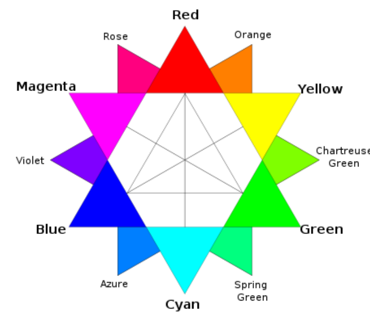
Wikipedia – RYB Color Model

RYB color wheel



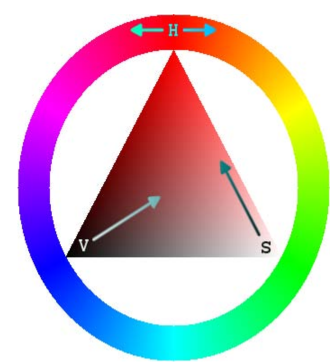
RYB color star

Wikipedia – Normalized color co-ordinates



Primary, secondary, and tertiary colors on the RGB (HSV) color wheel.

Sputnik – Color Schemes



Subsection: Color Design Based on the Color Wheel (p. 12-14)
p. 13 para 2

In general, color design principles suggest a number of different strategies for using color.

The simplest strategy would be to choose a monotone achromatic scheme. Such a scheme would not employ any color at all, but use black, white, and shades of gray. This kind of color scheme is sometimes used by interior designers, but while it can be dramatic, it also risks being boring.

A related scheme is a monotone chromatic scheme. Here, a single hue is chosen, which is varied in lightness and saturation. Again, this type of scheme can be boring.

Another scheme is an analogous hues scheme. In such a use of color, two or three hues close together in color space are used. For example, shades of green or blue greens can be used effectively.

A more daring use of color is a complementary color scheme. Here complementary colors on the color wheel are used. An example using the RYB color wheel would be blue and orange or the Christmas colors of red and green.

Another color scheme is the split complementary color scheme. Instead of choosing the exact complementary color, choose colors that are adjacent to the complementary color. So that opposite to orange would be blue, but a split complementary scheme might choose blue–green and blue–violet. Usually one would want the split complementary hues to be also different in brightness and somewhat desaturated.

A final strategy is a triad color scheme.Here one can choose three colors equally spaced around the color wheel. As with the split complementary scheme, two of the hues should be desaturated.

Marc Green SBFAQ (5.13)

There are several types of color schemes. Some are simple while others are complex and should be left to the experts:

- Monotone achromatic: neutral colors only, white, black gray. Easy to use but requires expert care to avoid complete boredom. ~~See the Next interface as an example of how effective a neutral design can be.~~
- Monotone chromatic: a single chromatic color ranging in brightness and saturation: red, pink, rose, etc. Easy to use but again risks monotony.
- Analogous hues: two or three colors close to each other in color space: blue-greens, etc. Easy to use.
- Complementary hues: contrasting hues: blue-orange, red-green. Requires care since it can appear garish and unbusinesslike. ~~Works best when the two differ significantly in brightness and one is relatively desaturated, , e. g., a dimmer, desaturated red and a brighter saturated green.~~
- Split complementary hues: uses three colors, one base color plus two, near, but not directly across, color space: orange with blue-greens. Works best when colors from opposite sides differ significantly in brightness and color(s) from one side is/are desaturated. Usually produces a less garish feeling than a simple complementary scheme.
- Triad hues: uses three hues ~~approximately~~ equidistant in color space: red-yellow-blue. Desaturate at least two hues. ~~Triad schemes are often embedded in a generally neutral field, so it would work well on a typical Windows gray background.~~

5. References and further reading

Edward Wegman and Yasmin Said, "Color Theory and Design", *Wiley Interdisciplinary Reviews: Computational Statistics*, Volume 3, Issue 2, pages 104–118, March/April 2011. Online Feb. 4, 2011.

Edward Wegman, Statistical *Data Mining: A Short Course for the Army Conference on Applied Statistics*. (Color Theory, Color Design, Graphic Design). Online at ACASCourse6, along with the proceedings of ACAS 2002.

Wegman (2002) - Antecedents

Color Theory Page (Ted Park)

Kodak, Chapter 2, Digital Color Theory

Marc Green Basic Color & Design SBFAQ (Orig. http://www.ergogero.com/FAQ/cfaqhome.html)

Markemson, 1999

Killer sites

Wegman and Said (2011) - Additional antecedents

Wikipedia - Eye http://en.wikipedia.org/wiki/Eye

Wikipedia - Munsell Color System http://en.wikipedia.org/wiki/Munsell_color_system

Wikipedia - 1931 CIE Color Space http://en.wikipedia.org/wiki/CIE_1931_color_space

Wikia – Computer graphics – Saturation http://graphics.wikia.com/wiki/Saturation

AllExperts: Genetics/colour blindness and albinism http://en.allexperts.com/q/Genetics-1795/colour-blindness-albinism.htm

Wikipedia RYB Color Model http://en.wikipedia.org/wiki/RYB_color_model

Wikipedia Color Theory http://en.wikipedia.org/wiki/Color_theory

Wikipedia - Normalized Color Co-ordinates http://en.wikipedia.org/wiki/Wikipedia:WikiProject_Color/Normalized_Color_Coordinates

Sputnik Color Schemes http://sputnik.freewisdom.org/en/Color_Schemes

Further Reading

Discussion of the above analysis is given at:

- Deep Climate, *Wegman and Said 2011: Dubious Scholarship in Full Colour, part 1*.

An overview of scholarship issues in the Wegman report is found in:

- John Mashey, *Strange Scholarship in the Wegman Report*, 2010.
- The SSWR Executive Summary is also available on its own as a separate document.

There is much more at DeepClimate.org, including:

- *George Mason University's Endless Inquiry* [overview of plagiarism inquiry by GMU into Wegman Report and Said et al (2007) in CSDA.
- Wegman Report Update, part 2: GMU Dissertation Review
- Here is a list of related Deep Climate posts.