

Perceptually Uniform Hand Painted Color Scales

Ákos Borbély, Ágnes Szűcs

Óbuda University, Faculty of Light Industry and Environmental Engineering,
Hungary, e-mail: Borbely.Akos@rkk.uni-obuda.hu

***Abstract:** Color order systems in art and science utilize color scales and color circles from Antiquity to our times. Albert Munsell made a profound effort to arrange color sequences according to perceived equidistance. Decades later the CIE issued a perceptually uniform color space. The objective of our study was to investigate the ability of young subjects to create uniform color scales along perceptual axis. A group of 52 university students with tested normal color vision took part in our experiments. Their task was to create spatially uniform patches using water-color: to hand paint a color circle according to the geometry and method of Johannes Itten, and a 16 hue color wheel using red, blue and yellow paints only. A requirement for all tasks was, that the created color sequences were equidistant perceptually relying on their own judgment. The subjects were given a brief introduction to color science prior to the experiment. After completing the tasks all samples were measured by a reflectance spectrophotometer. We studied the painted color scales in the CIELAB color space.*

Keywords: perceived equidistance, water-color, color circle, color, pattern, harmony

1 Introduction

In our information society visual culture has an overemphasized role, the amount of visual information young generations receive and have to process is an order of magnitude larger than before the digital age. Designers and creative artists consciously or unconsciously integrate their perceptions and experiences of the virtual worlds into their ideas and works. Color as a cultural and psycho-physical phenomenon is inherently affected by the evolving landscapes of digital media. The theoretical and practical approaches to represent colors show similar patterns throughout history. Color systems were presented in tables and charts or organised in different shapes, from triangular to circular.

A color circle or color wheel is a convenient way to visualize the relationship of different hues, and has become a kind of art standard for this purpose. Early attempts to form a systematic arrangement of colors or hues use round or spherical forms. The first person proven to use this idea to organise colors was Aron Sigfrid

Forsius in 1611, however circular color diagrams had been constructed earlier [1]. Isaac Newton's circular diagram of colors (1704) is chronologically not the first, but is probably the most significant color wheel for science and art. Moses Harris was the first to found his system on the primaries of subtractive color mixing: red, yellow and blue in 1766. His color wheel consisted of 18 segments, two steps of intermediate hues are inserted between the primary and secondary (red, green and blue) colors [2]. The primaries of subtractive color mixing served as the basis for other artists and scientists, who established notable circular arrangements: Johann Heinrich Lambert (1772), Tobias Mayer (1775), James Sowerby (1809), Charles Hayter (1826), Johannes Itten and more.

Albert H. Munsell, college professor and painter invented a perceptually equidistant system of colors with independent perceptual dimensions: hue, chroma and value (lightness). His system was implemented and issued as a set of samples, the Munsell Book of Color. The Munsell color order system is still considered a valuable reference standard by researchers for the comparison of scientific results, especially regarding uniform color spaces [5].

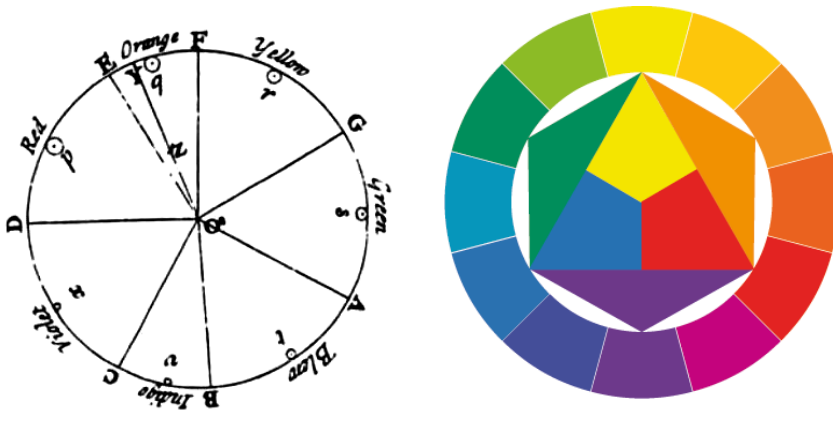


Fig. 1. In the color circle of Isaac Newton (left) hue segments were correlated with music and astronomy, the arrangement of Johannes Itten (right) follows the principles of subtractive color mixing.

For our experiments we have chosen the color circle of Johannes Itten (Fig. 1), who was an expressionist painter and theorist teacher of the Bauhaus school. The colors in his structure are straightforward to create from the artist's point of view. The principal aim of our study was to investigate how the measured color coordinates of painted color wheels are structured in a perceptually uniform color space, such as CIELAB.

2 Method

A group of university students specialized in product design participated in the experiment. The subjects were in the age range of 19-25 years, about 65% of them were female. The task of the participants was to paint two color circles using only the 3 primary colors typical of subtractive color mixing: red, blue and yellow.

The first, 12-segment color circle was designed according to the theory of Johannes Itten [3]. The starting segments of the wheel are the primary colors, two of them are used to mix the secondary colors: green, orange and purple. Tertiary colors are produced as the mixtures of one primary one secondary color (red-orange, yellow-orange, yellow-green, blue-green, blue-violet and red-violet).

The second task of the subjects was to paint a 16 segment color circle. The requirements in this case were to use the three primaries but start with the 2 opponent color pairs: red, green, yellow and blue and paint the intermediate 3 samples so, that they appear perceptually equidistant from their neighbors. The participants were allowed to use their own choice of tempera paint set of the three primary colors, all of them had some experience in subtractive color mixing and creative graphic arts.

The reflectance spectra of all painted samples were measured by a spectrophotometer with $45^\circ\text{a}:0^\circ$ measurement geometry. CIE Lab tristimulus values were calculated using D50 illuminant and 2° standard observer, ΔE_{ab}^* color differences were evaluated between the samples.

3 Results

Table 1. Mean, std. deviation and maximum values of the measured ΔE_{ab}^* color differences between patches of the 12-segment, Itten-type color wheel

a.)	B-BG	BG-G	G-YG	YG-Y	Y-YO	YO-O
Mean	56,8	28,9	33,2	42,1	30,9	21,9
Std. dev.	16,8	15,6	11,3	14,0	12,3	8,4
Max.	103,6	103,5	60,4	67,7	62,1	45,2

b.)	O-RO	RO-R	R-RV	RV-V	V-BV	BV-B
Mean	19,8	16,1	43,5	21,0	15,2	39,6
Std. dev.	7,0	8,4	14,9	13,3	6,5	13,8
Max.	38,4	48,5	67,9	73,2	35,3	75,5

Table 2. Mean, std. deviation and maximum values of the measured ΔE^*_{ab} color differences between patches of the 16 segment color wheel, painted by the subjects

a.)	B-BBG	BBG-BG	BG-GBG	GBG-G	G-GYG	GYG-YG	YG-YYG	YYG-Y
Mean	47,3	14,3	14,5	17,2	17,0	18,6	19,9	24,0
St. dev.	16,8	7,6	7,7	10,6	6,4	6,7	6,5	11,7
Max.	82,8	48,2	47,6	51,6	40,1	30,5	38,4	55,5

b.)	Y-YO	YO-O	O-RO	RO-R	R-RV	RV-V	V-BV	BV-B
Mean	26,5	22,9	20,2	17,6	41,7	18,7	14,6	39,8
St. dev.	10,5	8,1	7,1	8,6	15,1	7,6	5,7	13,3
Max.	63,5	47,5	34,0	45,9	70,3	41,1	29,7	82,6

The mean, standard deviation and maximum values of calculated ΔE^*_{ab} color differences between patches of the color wheels for all subjects are shown in tables 1-2, notations indicate the hue of the actual two patches, eg. YO-O stands for the color difference between the yellow-orange and orange samples. The individual (intra-subject) mean color differences between adjacent patches ranged from 26,3 to 41,6 units for the Itten types, from 19,1 to 28,9 units in case of the 16-segment wheel. The mean a^*, b^* coordinates of the samples for all subjects are shown in Fig. 2. It is important to note that this representation of CIELAB coordinates have only demonstration purpose, for thorough analysis the L^* value has to be accounted for as well.

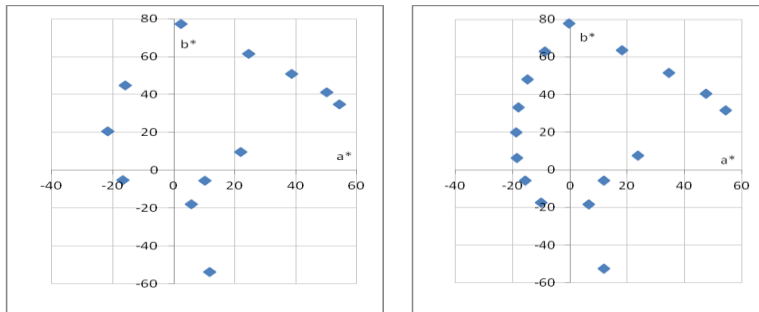


Fig. 2. Mean coordinates of all subjects' painted color circles projected onto the a^*, b^* plane of the CIELAB color space (left: 12-segment, right: 16-segment).

4 Discussion and Conclusion

Measured color coordinates of painted color circles showed large inter-subject variations in our experiment. This result was expected: the task of the subjects was not the reproduction, but the individual creation of circular arrangements of color samples based on theoretical instructions by their own chosen primaries. No perceptual dimension was kept constant, unlike in the studies of Munsell.

The perceptual uniformity of the painted colour circles as the distribution of the colour differences between the hue steps is demonstrated in Fig. 3. The relative area and arc length of each segment of the wheels were calculated to correspond to the average of the mean color difference of all subjects between the neighboring sample patches.

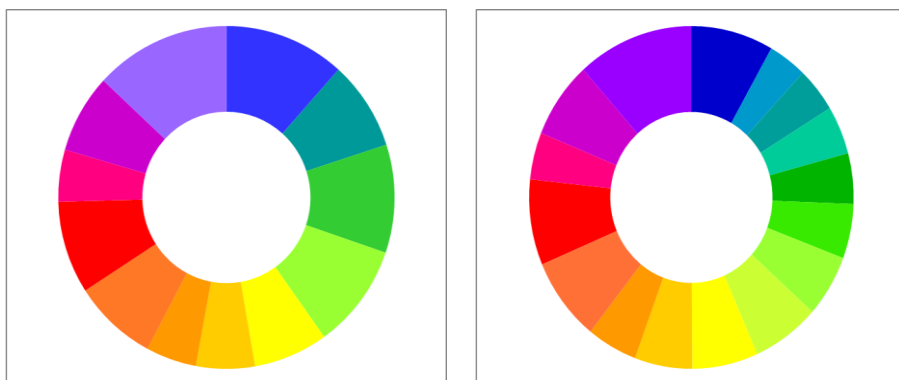


Fig. 3. Computed color wheels (left: 12-segment, right: 16 segment) representing measured ΔE_{ab}^* metric color differences between the segments of the painted color circles. The arc length of each segment is proportional to the sum of the color differences from the two neighboring segments.

Results of our study indicate that in case of a color wheel the perceptual uniformity of the sample scales is far from the artist's concept. The introduction of green as a basic color in the 16-segment circle affected primarily the distribution of blue-green region.

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