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Spacing in the Munsell Color System Relative to the Coloroid Color Systems

Spacing defined by various Munsell hue and chroma steps are analyzed, applying diagrams resulting from transformations between the Coloroid and the Munsell color systems, displaying colors of both color systems with the same Y tristimulus values. After comments on spacings derived from identities, similarities and differences between both color systems, unevennesses uninterpretable from differences of color system constructions are attributed either to uniform variation of color stimuli followed by uneven variation of color perceptions, or to uncertainties of human color perception at several spots of the color space sufficient to be noticeable in spacings in perceptually uniform color systems, such as the Munsell color order system. © *1994 John Wiley & Sons, Inc.*

Key words: color order system, color perception, Munsell color system, Coloroid colour system, aesthetic uniformity

INTRODUCTION

In recent years, Munsell notations of color samples of the Coloroid Colour Atlas[1] have been determined at the Technical University of Budapest. To do this, solutions of the transformation equation between both color systems[2] have been used. Also, spacings of the Munsell color system[3-9] have been investigated. Much investigated unevennesses between spacings of the Munsell color space[10-14] will be assigned a new aspect by being looked at through "eyeglasses" of the Coloroid colour system.[15-17] First, let us have a look at the "eyeglasses" themselves, namely, by comparing essential parameters, aspects in developing the spacings in Munsell and Coloroid colour systems.

IDENTITIES, SIMILARITIES, AND DIFFERENCES

In both color systems, colors are arranged inside a normal circular cylinder in conformity with the principle of cylindrical coordinate systems. Achromatic colors are on cylinder axes so that lightness decreases from the top downward.

In both color systems, hue varies with the angular coordinate. Saturation increases from cylinder axis to cylinder shell. Colors of the same lightness lie in planes normal to the axis.

In both color systems, colors are defined by three data each (in the Munsell system H, C, V; in the Coloroid system A, T, V) referring to hue, saturation, and lightness of the color. In the Munsell color system, hues are marked by letter codes joined by numbers 1–10. The system comprises 10 × 10, that is, a total of 100 hues. In the Coloroid system, the 48 basic hues are marked only by numbers, such as 10–16, 20–26, 30–35, 40–46, 50–56, 60–66, and 70–76. Hues intermediary between basic hues are indicated by decimal fractions joining the number code of the basic hue (e.g., 12.673). Saturation and lightness are indicated in the Munsell system by numbers 1–16, in the Coloroid system by numbers 1–100.

Spacing in the Munsell color system can be expressed by psychometric scales based on perception threshold measurement test results; spacings in the Coloroid colour system rely on harmony threshold measurement test results. Spacings in the Munsell color system resulted from pairwise comparison of self-contained colors of differences exceeding products of sensation thresholds by about the same number, and in the Coloroid system, of neighboring colors belonging to a given group of colors. This is to say that spacing in the Munsell color system is characteristic of the sensitivity of the human eye in adapted condition, while in the Coloroid system, of the human discernment within it, of about the sensitivity of the unadapted human eye. Spacing in the Munsell color system directly rely on repeatedly corrected results of extremely careful tests. Spacing in the Coloroid colour system have been developed in two steps. In the first step, tests, again made with extreme care and involving a great many test subjects, gave a hint that in some places of the color space (in particular, in very saturated and very unsaturated, or very dark and very light domains), our color perception is rather uncertain. Therefore, a compromise was decided. In the second step of developing the spacings, test results have been confined to eliciting stimuli. Final spacings have been deduced from steps of stimuli best fitting test results.

From Coloroid codes (A, T, V) of any color, CIE tristimuli (X, Y, Z) of that color may be calculated, as against those of the Munsell color system (H, C, V). There is linear relationship between excitation purity of any color—corresponding to Coloroid color content and Coloroid saturation. There is no such relationship between Munsell chroma and excitation purity. Another compromise of the Coloroid colour system is that constant Coloroid hue has the same dominant wavelength throughout. This is known not to be valid for the Munsell color system. Tristimulus value Y is in a different relationship to Munsell than to Coloroid lightness (V).

MUNSELL TO COLOROID TRANSFORMATION

Since the Coloroid colour order system is directly transformatable to the CIE XYZ system, it was no problem to locate the 2465 Munsell color samples, each with its XYZ values, in the Coloroid colour space. As a result, the achromatic axes of the two color order systems were brought into agreement.

In the COLOROID colour space, both Munsell and Coloroid colors with the same tristimulus value Y lie in the same plane normal to the achromatic axis. While colors of the same Coloroid hue—with identical dominant wavelengths—are in half-planes fitting the axis, colors of the same Munsell hue compose surfaces fitting the axis, but show a mild curvature, depending on the hue.

While colors of the same Coloroid saturation form coaxial cylindrical shells in the Coloroid space, colors of the same Munsell chroma were found to form conical surfaces of irregular directrices in this space.

Thereafter, the color space was cut at 14 different levels corresponding to tristimulus values $Y = 4, 6.25, 9, 12.25, 16, 20.25, 25, 30.25, 36, 42.25, 49, 56.25, 64$, and 72.25, by planes normal to the axis, containing colors with equal Y values. Colors of the same Coloroid hue in the sections appear as radii including equal angles with each other, while colors of equal Munsell hues appear as curves, more or less deviating from the radii, here denser, there scarcer. Colors of identical Coloroid saturations in the sections form concentric circles, while those with identical Munsell chroma form irregular, closed curves.

As the next step, circles were cut along some radius to the center, then stretched into a rectangle, with the cut-up radius of the circle as shorter sides, and the perimeter and a straight line of the perimeter length replacing the center as longer sides.

In the new configuration, Coloroid hues and saturations appeared as a rectangular equidistant network. In this network, Munsell hues and chromas appeared as more or less rectangular networks of more or less curved lines.

Coloroid networks result from harmony threshold measurement tests, pointing to a kind of perceptual equidistance; at the same time, they can be expressed in terms of colorimetric magnitudes, namely hue by dominant wavelength, and saturation by excitation purity. Thereby, similarity between Munsell and Coloroid networks offered a new possibility for investigating the Munsell color space. In the following sections, investigation results are presented.

STATEMENTS

Among the fourteen network diagrams obtained in operations described above, three are presented in Figs. 1–3. The scrutinization has led to various statements on spacings in the Munsell color system. Before expanding them the reader will be reminded of the introductory statements, namely, that the rectangular Coloroid mesh does not mean exactly uniform spacings, but only that investigations have been made looking through Coloroid "eyeglasses."

First of all, some comments derived from similarities and differences between the two systems may be made, such as:

- —Lines representing constant Munsell hue more or less consistently deviate from straight lines of constant Coloroid hues, as a function of lightness and saturation in Coloroid space.
- —Save at some spots of the color space, Munsell and Coloroid hue spacings are in about the same relation to each other.
- —In darker ranges, Munsell chroma lines are denser than Coloroid saturation lines. The opposite is true for lighter ranges.
- —In medium-dark or medium-light ranges, spacings of Munsell chroma and of Coloroid saturation are about equal, except at certain spots in the color space.

Further Statements on Hues

- —Irrespective of lightness and chroma, the dominant wavelengths of Munsell hues 1OY and 5P are constant.
- —Passing from hue 1OY toward hue OP (yellow, orange, red, and purple), irrespective of lightness, as chroma increases, dominant wavelengths are shifted toward purple (longer wavelengths).
- —The rate of shifting gradually increases up to hue 1OR, then gradually decreases.

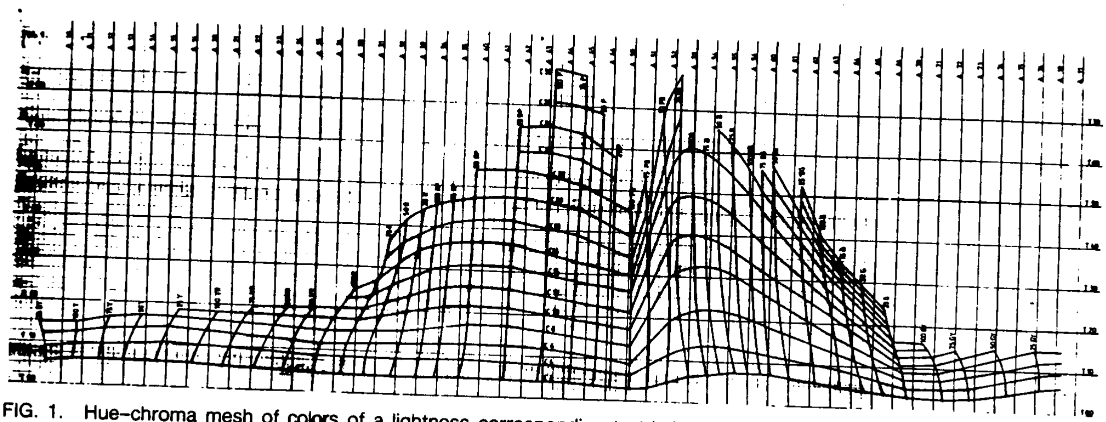

FIG. 1. Hue–chroma mesh of colors of a lightness corresponding to tristimulus value $Y = 16$ in the Munsell color space transformed into the Coloroid colour space. Coloroid hues are on the horizontal axis, Coloroid saturations on the vertical axis.

—Passing from hue OP toward hue 1OY (purple, blue, green, and yellow) irrespective of lightness, as chroma increases, dominant wavelengths are shifted in the purple domain toward dominant complementary wavelength 556 cnm, then toward blues (shorter wavelengths of the spectrum).

—The rate of shifting gradually increases up to hue 2,5G, then it gradually decreases.

—For the same chroma increase, dominant wavelengths of dark colors vary more than do those of light colors.

—There is hardly a single hue for which its dominant wavelength varies evenly as chroma increases.

—Colors of hues YR, 2.5YR, and 7.5YR vary nearly linearly.

—Colors of hues 2.5R, 1ORP, 7.5RP, 5RP, 7.5B, 5B, 2.5B, and 1OBG vary next to logarithmically.

—Colors of hues 1OGY, and 7.5GY display variations of a different kind, but of a definite trend.

—For part of the hues, near the achromatic axis, hence for low chromas, dominant wavelengths are less shifted—that seems to be reasonable—while for the others, the opposite is true. Such a variation was found for hues 5R, 1ORP, 2.5PB, 1OB, 7.5BG, 5BG, 1OG, 7.5G, 5G, and 2.5G, contradicting laws of color vision by assuming that variation of hues of low chroma is more perceptible than of hues of high chroma.

—Several changes of the rate of wavelength variation with chroma increase within a hue are frequent. Such variations occur for, e.g., hues R, 1OR, 2.5BG, and 2.5G.

Further Statements on the Chroma

—Throughout the Munsell color space, chroma steps match about uniform color content variations.

—Chroma steps of adjacent hues from 1ORP–1OPB match about equal color contents.

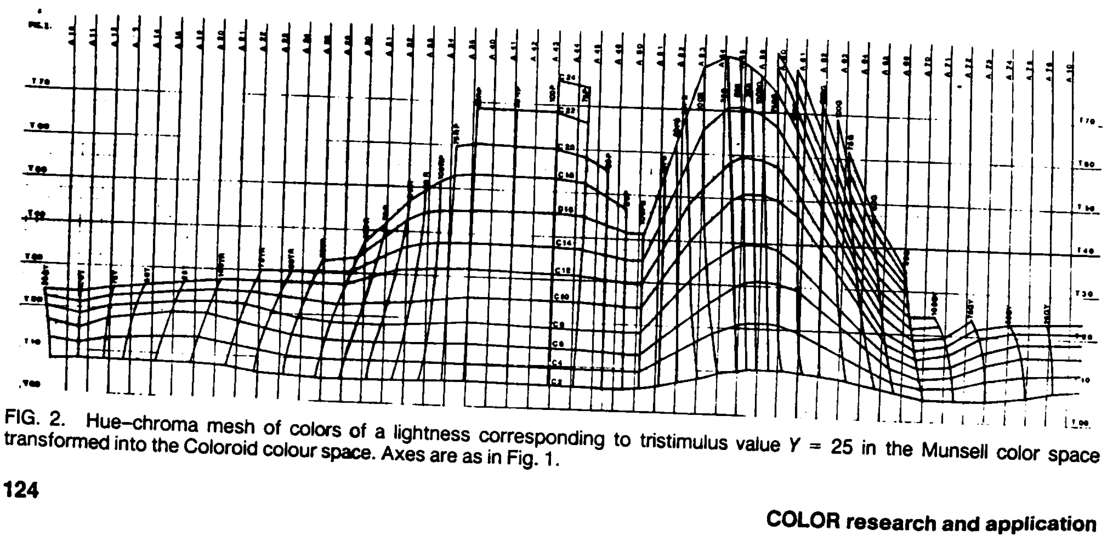

FIG. 2. Hue–chroma mesh of colors of a lightness corresponding to tristimulus value $Y = 25$ in the Munsell color space transformed into the Coloroid colour space. Axes are as in Fig. 1.

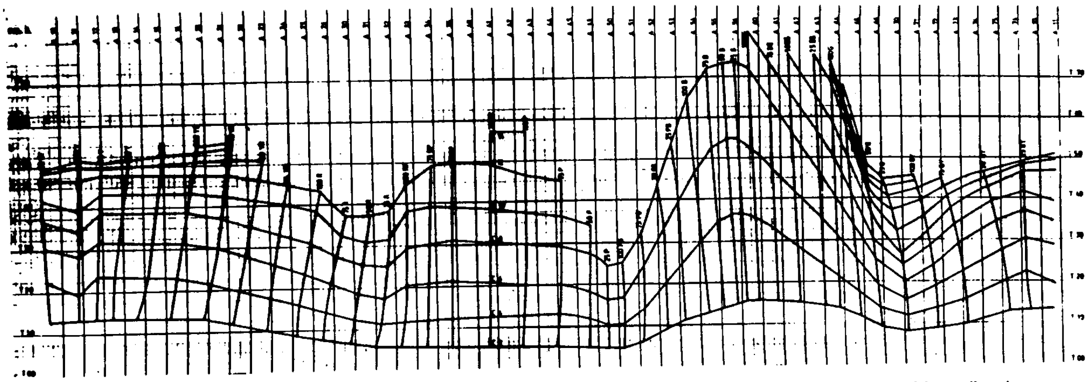

FIG. 3. Hue–chroma mesh of colors of a lightness corresponding to tristimulus value $Y = 49$ in the Munsell color space, transformed into the Coloroid colour space. Axes are as in Fig. 1.

—In other parts of the color space, chroma steps of adjacent hues correspond to gradually increasing color content. The distance between these steps varies with location in color space. For instance, while color content increases slightly between hues 7.5Y and 5Y, it increases markedly from 7.5PB to 5PB.

—For the rate of color content increase, hues 10PB and 2.5G act as dividing lines.

—Chroma steps match equal color content variations exclusively for hues 5R, 2.5R, and 10RP, but even here only in lighter ranges.

—For hues 5OY, 2.5Y, 5GY, and 2.5GY, chroma steps /2, /4 match greater color content variations than do chroma steps /8, /10, /12.

—On the contrary, in other parts of the color space, e.g., for hues 5RP, and 2.5RP, chroma steps /2, /4 correspond to lesser color content variations than to chroma steps /8, /10, /12, /14, etc.

—Sometimes, for instance, for hues 7.5R, 5R, or 5BG, and 2.5BG, chroma steps correspond either to lesser or to greater color content variations.

—There are hues where color content differences between chroma steps gradually but markedly decrease with increasing chroma. For instance, in hue 5Y, for colors with tristimulus value $Y = 50$, color content differences in the chroma range of /2 to /4 are six times those for colors in the chroma range of /14 to /16.

CONCLUSION

Comparison of the diagrams leads to the following conclusion: similarities and differences between spacing in both color systems mostly reflect similarities and differences between constructions of both color systems.

Two assumptions are offered to explain differences between spacings in the two color systems at several regions of the color space. Either uniform variation of color stimuli at several regions of the color space elicit uneven variation of color perception, or human color perception is uncertain in these regions of the color space, and this manifests itself also in the spacing of perceptually uniform color systems such as the Munsell color system.

1. A. Nemcsics, *Coloroid Colour Atlas*, Innofinance, Budapest, 1985.
2. A. Nemcsics, *Coloroid to Munsell transformation*, in Hungarian, Research Report Budapest, 1985.
3. S. N. Newhall, The ratio method in the review of the Munsell colors, *Am. J. Psych.* **52**, 394 (1939).
4. Sidney N. Newhall, Preliminary report of the OSA Subcommittee on the spacing of the Munsell colors, *J. Opt. Soc. Am.* **30**, 617–695 (1940).
5. K. S. Gibson and D. Nickerson, An analysis of the Munsell colour system based on measurements made in 1919 and 1926, *J. Opt. Soc. Am.*, **3**. 30, 591 (1940).
6. Sidney N. Newhall, Dorothy Nickerson, and Deane B. Judd, Final report of the OSA Subcommittee on the spacing of the Munsell colors, *J. Opt. Soc. Am.* **33**, 385–418 (1943).
7. D. Nickerson, Munsell renotations used to study color space of Hunter and Adams, *J. Opt. Soc. Am.* **40**, 85–88 (1950).
8. D. B. Judd and G. Wyszecki, Extension of the Munsell renotation system to very dark colors, *J. Opt. Soc. Am.* **46**, 281 (1956).
9. D. B. Judd and G. Wyszczki, *Color in Business, Science and Industry*. Wiley, New York, London, 1963.
10. T. Indow, Multidimensional studies of the Munsell color solid, *Psychol. Rev.* **95**, 456–470 (1988).
11. Tarow Indow and Nanoko Aoki, Multidimensional mapping of 178 Munsell colors, *Color Res. Appl.* **8**, 145–152 (1983).
12. Tarow Indow and Melvin L. Morrison, Construction of discrimination ellipsoids for surface colors by the method of constant stimuli, *Color Res. Appl.* **16**, 42–56 (1991).
13. R. S. Berns and F. W. Billmeyer, Jr, Development of the 1929 Munsell Book of Color: A historical review, *Color Res. Appl.* **10**, 246–250 (1985).
14. T. Indow, Indiscriminable regions, color differences, principal hue vectors in Munsell space, *Colour 93 Proceedings*, Budapest, **1**, 3–7 (1993).
15. A. Nemcsics, The Coloroid Colour System, *Color Res. Appl.* **5**, 113–120 (1980).
16. A. Nemcsics, Color space of the Coloroid Color System, *Color Res. Appl.* **12**, 135–146 (1987).
17. A. Nemcsics, *Colour Dynamics—Environmental Colour Design*, Ellis Horwood, New York, London, Toronto, Sydney, Tokyo, Singapore, 1993.