

THE EFFECT OF VARIATIONS OF PILE STRUCTURE
ON THE COLOR RED-PURPLE

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ABSTRACT

THE EFFECT OF VARIATIONS OF PILE STRUCTURE UPON THE COLOR RED-PURPLE

by Anita Marie Fratianne

This research was undertaken to investigate, in detail, the effect of variation of pile structure upon the color, red-purple. Effort was made to determine if a variation of pile height, yarn size, and pile density, and/or an interrelationship of each, affect a pattern of color change on red-purple, and if the behavior of the color red-purple, when affected by texture, is related to its spectral composition. To answer these questions, samples were woven that consisted of three sets of pile structures. One set of samples was woven with red-purple yarn, the color under investigation; the two sets of control samples were woven, one of red and one of purple yarn. The pile structure of each sample varied in size of yarn ply, pile height, and pile density. The combination of variables resulted in a total of 24 samples.

A subjective color analysis was made by three judges by matching the color of each sample with a Munsell color chip. As the pile height and pile density of the samples decreased, the hues, generally, appeared to be warmer, and

the value and saturation levels of the colors decreased. As yarn ply decreased, however, the value and saturation levels of the colors increased.

The objective color analysis was done by the General Electric Recording Spectrophotometer. The data were then substituted in the Nickerson and Stultz color difference formula. Comparisons of the reflectance curves were also made. The Nickerson and Stultz formula showed that the color differences that resulted from a decrease in yarn ply, pile height, and pile density were negligible. Comparison of the reflectance curves showed reduction in size of yarn ply, pile height, and pile density resulted in losses in the percentage of reflectance in the red region of the spectrum. In most cases, the reflectance curves of the red-purple samples more closely matched the curves of the red than the purple samples. As pile structure varied, the color of the red-purple samples reflected nearly the same kind and quality of light as did the red samples.

As pile structures were varied, no regular pattern of color change could be found for the color red-purple. However, the basic hypothesis of this study was proven: the structural variations of the pile samples produced greater patterns of irregularity in red-purple than in either red or purple. The data further indicated that perhaps the influence of the red in the color red-purple was responsible for the difficulty with which red-purple was discerned.

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CHAPTER I

INTRODUCTION

Statement of the Problem

Texture and color are tremendously important to the designer. Knowledge of the effect of texture upon color helps the designer predict the influence of textural change upon the apparent attributes of color, hue, value and saturation.¹

The subject of color modification by texture has been especially interesting to researchers in the Textiles, Clothing, and Related Arts Department at Michigan State University.

Lorraine Gross² showed that texture has a modifying effect upon color. She ascertained that textural change caused perceivable and measurable color changes that could be expressed in Munsell color units. She noted that a

¹Hue, value and saturation is the nomenclature of the Munsell Color System that describes the three attributes of color. Hue is the name of the color, value is the lightness or darkness of the color and saturation is the brightness or chromaticity of the color.

²Lorraine Gross, "The Effect of Height and Yarn Size of a Pile Texture on Color" (unpublished Master's thesis, College of Home Economics, Michigan State University, 1961).

change from a tapestry weave to a pile weave as well as a change in height and yarn size of a pile structure produced color changes in the samples.

The textural changes caused the majority of the colors in the Gross study to change in a consistent direction; however, the blue-green, yellow-green, and red-purple samples exhibited a pattern of color change that deviated from the rest. Gross offered the theory that hand dying had been responsible for the irregular color changes. The yarn of the red-purple sample was commercially dyed and the researcher could offer no other explanation for the deviant color change of the red-purple. Further research was recommended to explain the unique behavior of the red-purple.¹

Focus of the Study

The intent of this research is twofold: (1) to help determine whether variation of pile height, yarn size, and pile density, or an interrelationship of them, affects a pattern of color change in red-purple, and (2) to help determine whether the unique behavior of the color is related to its spectral composition. Because the color red-purple is made of two wavelengths of color, red and purple, the latter two colors were used in this study as control colors.

¹Ibid.

The basic hypothesis of this research is that textural variations upon the color red-purple produce a greater pattern of irregularity than is produced by a textural variation upon either red or purple. This research, while basic in nature, may help establish a practical method to assist designers in predicting the effect of a specific textural change upon a color.

Review of Literature

Color Theory

The literature concerning color theory was studied because of its relevance to the topic analyzed in this thesis.

Color and Light

Color is the aspect of radiant energy of which the human observer is aware through the visual sensations which arise from the stimulation of the retina of the eye.¹

Color exhibits such a multidimensional nature that scholars with varied interests study color sensations within the structures of their own disciplines. To the physicist, color is a study of light; to the physiologist, color is a study of vision; to the chemist, color is a study of dyes

¹Ralph M. Evans, "Variables of Perceived Color," Journal of the Optical Society of America, Vol. LIV, No. 12 (December 1964), 1467-1474.

and pigments; and to the psychologist, color is a study of sense perceptions.

Color is a function of the physical quality of light. Visible light is a small portion of the electromagnetic radiation band which includes all forms of radiant energy. This band is divided into sections, each section being specified by difference in wavelength. The wavelength associated with visible light falls in a region approximately midway in the energy band.

Light, as does all electromagnetic radiation, travels in transverse waves. These waves can vary in frequency of oscillation, thereby giving characteristic colors.¹ The frequency may be expressed directly in terms of cycles per second. Another method of expressing color is in terms of the wavelength² which is a measure of the distance between wave crests.³ Since this distance is extremely small, the measurement is usually given in units of millimicrons (symbol $m\mu$), 0.0000001 centimeters, or in Angstroms (symbol $\text{\AA}$), 0.00000001 centimeters.⁴

¹Maitland Graves, Color Fundamentals (New York: McGraw-Hill Book Co. Inc., 1952), p. 5.

²Deane B. Judd and Günter Wyszecki, Color in Business, Science, and Industry (2d ed.; New York: John Wiley and Sons, Inc., 1963), p. 28.

³W. D. Wright, The Measurement of Colour (London: Helger and Watts, 1958), p. 1.

⁴Martin Koblö, World of Color, trans. Ian. F. Finlay (New York: McGraw-Hill Co., 1956), p. 9.

The color spectrum ranges from blue light whose wavelength is approximately $400 \text{ m}\mu$ ($4000 \text{ \AA}$) to red light whose wavelength is about $700 \text{ m}\mu$ ($7000 \text{ \AA}$). All color perceived by the human eye lies between $400 \text{ m}\mu$ to $700 \text{ m}\mu$.

The divisions of the spectrum occur at the following wavelengths.¹

<u>Color</u>	<u>$\text{m}\mu$</u>
Violet	400-450
Blue	450-500
Green	500-570
Yellow	570-590
Orange	590-610
Red	610-700

Color and Texture

Color results from the selective absorption and reflection of light at different wavelengths by the surface structure of a material. When light encounters a medium, some wavelengths of light are absorbed and others are reflected. Generally, it is the reflected wavelengths of light which we perceive as the color of the material.

The characteristic of a material such as texture, luster, or transparency have the capacity to reflect, refract, and absorb light, thereby determining the perceived

¹A. C. Hardy, Handbook of Colorimetry (Cambridge: Technology Press, 1936), p. 2.

color to the degree that the surface structure modifies the light which falls upon it.

When light falls upon the surface of a material and encounters a boundary between media,¹ for example, a ray of light between air and a cotton fiber or between air and a pigment particle, then the reflection of the light occurs; next, refraction occurs when the ray of light bends as it encounters the medium; and finally, reflection reoccurs when the light passes from the medium back to the air. Four per cent² of the initial beam of light is reflected upon each encounter of light and the medium. When light meets a granular or fibrous structure, the beam of light meets with new interference every few millionths of an inch. These repeated encounters result in a thorough diffusion of the light.

It should be emphasized that specular reflections occur at the surface of a material, and that diffuse reflections occur beneath the surface in materials that have a granular or pigmented material structure. After specular reflections occur, the remaining light penetrates the surface of the granular or pigmented structure. It is absorbed while scattering multiple reflections beneath the surface,

¹Richard S. Hunter, "Those Other Aspects of Appearance," Color Engineering, Vol. 1, No. 2 (June 1963), 8-14.

²Ibid., p. 8.

and is finally readmitted into the air in a nearly diffuse state.¹

Thus, the material structure of an object modifies light and determines color by reflecting, refracting, and absorbing light. Particle size, and distribution and continuity of pigment or fiber are important structural factors of materials that modify light. The effects of such physical phenomena as material structure upon light are explained by Luckiesh:

The character of the surface of a pigment and the density of coloring matter influences the appearance of color. If a red aniline dye solution be deposited upon a fabric by means of an air brush, the pigment under some conditions will be deposited in the form of fluffy powder whose appearance is deep velvety red. The purity of the red is largely due to the multiple reflections, for the light is able to penetrate an appreciable distance into the medium, and at each reflection it becomes purer, that is, more nearly monochromatic. If the solution were applied by means of an ordinary brush, the deposit would not have been so porous and the appearance of the color would not have been such a deep red.²

Color and Vision

The appearance of color is a function of the physical process involving the retina of the eye and the brain, as well as the observer's psychological interpretation of the physiological response. The observer's color sensation

¹Judd and Wyszecki, p. 97.

²Mathew Luckiesh, Light, Vision and Seeing (New York: D. Van Nostrand Co. Inc., 1944), p. 36.

is, therefore, dependent upon the quality of light, the proper functioning of the eye and the brain, and the accurate interpretation as a result of the observer's psychological process.

The sensation of color is determined to a great extent by eye function. Evans clearly recognized that "variations in the human eye from one observer to another are simply part of the subject of color."¹ In the properly functioning eye, the conversion of light energy into nervous energy takes place in the retina of the eye. The actual receptors are the rods and the cones, containing a photochemical substance which decomposes because of the action of the light and reforms in the dark. Wright states that rods are responsible for the detection of weak light, and the cones, which function under higher illumination, are responsible for the perception of detail and color.² An observer with normal trichromatic color vision is able to perceive basically red, green, and blue light. Such observers, as Judd explains, may differ considerably in their ability to make fine color distinctions but this is a difference in degree not in kind of color discrimination.³ However, as a result of talent and training, the experienced observer is

¹Ralph M. Evans, Introduction to Color (New York: Wiley and Sons, Inc., 1954), p. 117.

²Wright, pp. 28-29.

³Judd and Wyszecki, p. 71.

able to discriminate and recognize colors that often remain hidden to the less experienced observer.¹

When nervous impulses from the retina reach the brain what color is seen also depends upon the consciousness of the observer; and, as a result, a whole new series of phenomena must be included in the subject of color vision. Depending upon the color of the surrounding areas, an observer with normal color vision may view a wavelength of light, for example, blue light, as a different color than it actually is. Evans says that the effect of surrounding areas are just as much properties of the eye as any of its other characteristics, but they are usually considered part of psychology.²

The sense of vision is curiously involved in a number of illusions and phenomena, due largely to the fact that the eye does not merely record the objects before it but actually creates effects in and of itself. Color perception is not determined solely by the amounts and quality of the light rays that reach the eye, but involves the total situation in which the color is seen.³

The psychophysical adaptations of the eye to one color, and the resulting effect of the ability of the eye to perceive the color's complementary hue, should be recognized as important influences upon color perception. Such color

¹Koblo, p. 16.

²Evans, Introduction to Color, p. 117.

³Frederick M. Crewdson, Color in Decoration and Design (Illinois: Frederick J. Drake and Co., 1953), p. 48.

phenomena as successive and simultaneous contrast of colors are also important influences upon color perception.

Fortunately, however, Wright has assured color researchers that while these forestated influences upon color must be considered, their effect upon accuracy of color match remains nominal:

Experiments show that colour match remains valid over a remarkably wide range of adaptation levels and conditions of contrast.¹

Color Measurement

"For years color matching has been an art. Now there is a need for an orderly scientific approach to the solution of color problems. Instrumentation could complement the practical experience of the colorist."²

Macbeth,³ in "Color Matching," states that researchers are all too familiar with the discontinuities which continually arise between subjectively perceived and objectively measured colors. Standardization depends on finding a proper balance between human and technical color evaluation. In order to keep a proper balance between the two, neither aspect of colorimetry, subjective or objective, should be

¹Wright, p. 51.

²Douglas Graham, "Color Measurement and the Colorant Mixture Computer in the Textile Industry," American Dyestuff Report, Vol. LIII (August 3, 1964), 673-678.

³Norman Macbeth and Warren B. Reese, "Color Matching," Illuminant Engineering, Vol. LIX (June 1964), 461-471.

ignored in a comprehensive study of color. Each form of colorimetry has specific advantages and disadvantages. The eye is the final arbiter of color because, in the final analysis, the color that is actually seen is most important. However, as is continually stressed in the literature, instrumental measurement is also extremely important. Hunter states that although the eye is an agile comparator, it is a relatively poor memorizer. The eye is a relatively poor memorizer because it contains no meters and cannot assign numbers to the color impressions that it perceives. Instrumental color measurement and color specifications are necessary in color research so that investigators everywhere can communicate intelligently about important characteristics of the appearance of color.¹ Instrumentation should not replace what the human eye can do but should complement it with numerical and graphical expressions of sense impressions.²

Objective Color Measurement

Wright³ has encouraged the use of spectrophotometry by color researchers because spectrophotometric measurement of energy distribution does not depend on visual peculiarities of the experimenter; thus the color specification is

¹Hunter, p. 9.

²Graham, pp. 673-678.

³Wright, p. 130.

not subject to error from this cause. Because of the great advantages of using the spectrophotometer, Wright feels that this instrument will be adopted as the ideal method of color measurement.

The spectrophotometer measures in absolute terms and with adequate precision the energy distribution, wavelength, reflectance, and transmission factors of lights. With many spectrophotometers, the tristimulus X Y Z factors, or the amounts of red, blue, and green light present in a color, are automatically integrated. Spectrophotometric data provide a fundamental basis for an absolute language of color.

In an article entitled "Current Practical Use of Instrumental Color Matching,"¹ Frank J. Rizzo notes the importance of spectrophotometry in that the industrial use of spectrophotometers is increasing for color matching dye-stuffs in all stages of production, for predicting fiber blends, for measuring color degradation, and for color fastness evaluations. Rizzo concludes that "all our efforts in objective color measurement are to replace visual assessment."²

¹Frank J. Rizzo, "Current Practical Use of Instrumental Color Matching in Industry," American Dye Reporter, Vol. LII (April 13, 1963), 365-369.

²Ibid., p. 366.

In an experiment measuring the color of small patterns on cloth, P. R. Bunkall¹ states that he prefers to use a spectrophotometer in which X Y Z readings are integrated, because he feels that previous limitations in color measurement are overcome with the application of the new technique.

Hardy² stresses that because of the spectrophotometer, experiments are repeatable with adequate precision and provide the fundamental color language so important to color research. Judd, like Hardy, approves the use of spectrophotometric techniques for color measurement: "The spectrophotometer is the most important basic tool for the evaluation of color of industrial products as well as for fundamental research in colorimetry."³

Fred W. Billmeyer,⁴ in an article concerning research in colored plastics, states that the complete information given by the spectrophotometer in absolute terms is most useful where detailed information is needed, as in color matching.

¹P. R. Bunkall, "Measuring the Color of a Very Small Pattern," Society of Dyers and Colourists Journal, Vol. LXXX (May 1964), 255-256.

²Hardy, p. 9.

³Judd and Wyszecki, p. 98.

⁴Fred W. Billmeyer, "Color and the Coloring of Plastics," Color Engineering, Vol. I, No. 3 (September 1963).

Spectrophotometry was listed by the respected International Commission on Illumination as one of the methods by which the international standard observer was derived. The standard observer gives the exact amounts of color mixture necessary to reproduce any wavelength of color in the spectrum.¹

Recently, it was reported in the Society of Dyers and Colourists Journal that the recording spectrophotometer had been used successfully to measure the color of dyed carpet yarns. In the paper, "Use of Instrumental Match Prediction for Recipes for Wool-Nylon Carpet Yarn,"² the author explained that yarns colored with different dye formula were mounted in 20mm internal diameter cardboard tubes at a density of 192 yarns per tube and were cut flush with the tube. This method of representation of the yarn gave a reproducible surface for color measurement similar in character to the cut tufts by which carpet yarns are normally assessed visually. The color of each mounting was measured on the recording spectrophotometer and the resulting reflectance curves and tristimulus values were used in specification for dye recipes.

¹Wright, p. 130.

²R. Walton, "Use of Instrumental Match Prediction for Recipes for Wool-Nylon Carpet Yarn," Society of Dyers and Colourists Journal, Vol. LXXX (August 1964), 429-430.

Dorothy Nickerson, in research that concerned color measurement in textiles, converted spectrophotometric results into Munsell notations in order to give the results a visual referent. She also stressed the importance of the study of color differences based upon different sets of measurement. "It is evident that very precise measures of color are necessary if small color differences are ever to be as satisfactorily studied by instruments as they are by the eye."¹

The spectrophotometer can precisely measure small color differences, and judgments based upon such instrumental measurements appear to be somewhat more accurate than judgments made by experienced observers, and much more accurate than judgments made by the less experienced observer.²

Subjective Color Measurement

When an observer is asked to compare colors and to evaluate color difference, there may be as many different answers as there are observers.³ Recognizing this fact is

¹Dorothy Nickerson, "The Illuminant in Textile Color Matching," Illuminant Engineering, Vol. XLIII (January-December 1948), 416-467.

²Hugh R. Davidson and Marvin Taylor, "Prediction of the Color of Fiber Blends," Journal of the Optical Society of America, Vol. LIV, No. 54 (April 1964), 250.

³Judd and Wyszecki, p. 111.

necessary in any color research; however, one should also remember Wright's statement that if a practical system of subjective color measurement were eventually developed, its most widespread application would probably be found in the realm of design.¹

Keeping in mind the number of variables present when judgments are made by a human observer, such as eye adaptation, color contrasts, and psychological interpretation, it would seem advisable to limit, as much as possible, the variable conditions of the environment in which the color judgments are made. Suggestions concerning methods of presenting textile samples to human observers were given in two studies.² The suggestions included use of a standard illuminant and standard angle conditions for presentation of the samples.

Artificial light is preferred to natural daylight because the artificial lights' irradiance and spectral distribution can be defined sufficiently, as well as can be made independent of time.³ In 1931, the International

¹W. D. Wright, "The Needs and Prospects of Subjective Colour Measurement," National Physical Laboratory Symposium, No. 8 (Stationery Office, 1958).

²Olsen Bent Buchmann, "The Objective Measurement of Colour Changes," Danish Institute for Textile Research, XI (1950), 128-159.

³Y. Nayatani and S. Sysyechi, "Color of Daylight from North Sky," Journal of the Optical Society of America, Vol. LIII, No. 5 (May 1963), 626-629.

Commission on Illumination adopted a light source having a certain energy distribution as an internal standard of illumination to be used for the purpose of colorimetry. This standard light is called illuminant "C" and is equal to the average daylight of noon in the north sky. The source is a tungsten lamp operated at a temperature which approximately averages daylight, and is supplied with a suitable filter.¹ The angular conditions recommended for the measurement of color of an opaque surface are that the light should strike the surface at a 45° angle, and that the light should be viewed along the perpendicular to its surface.²

For visual matching, care should be taken that the surface of the sample is in a horizontal plane and that the standard should be close to the sample and in the same plane of the sample. Errors in Munsell values by as much as one whole step are possible by the inadvertent tilting of the sample's surface.³

¹Hardy, p. 4.

²Deane Judd, "Colorimetry," National Bureau of Standards, United States Commerce Circular 478 (Washington: U.S. Government Printing Office, 1950), p. 6.

³"The ISCC Method of Designating Colors and a Dictionary of Color Names," National Bureau of Standards, United States Commerce Circular 533 (Washington: U.S. Government Printing Office, 1955), p. 7.

Color and Texture

The literature was reviewed to investigate the relationship of color and texture. Theoretical material and recent research developments concerning the effect of texture on color provide a helpful background for the understanding of the material being studied in this paper.

Evans defines texture as the "visible nonuniformities in the reflectance of the surface which are obviously a physical property of the surface."¹ David Katz² described the effect of texture surface conditions upon color as Erscheinungsweisen, or modes of appearance. According to Katz, modes of appearance are surface attributes such as luster, film, or sheen, which integrate with the surface color and influence the way in which a color is seen.

Recently, Frank Rizzo and Alvin O'Ramsley³ noted that for samples where the same fiber and dyes are used, the essential difference between the color of the two textile samples was solely due to their surface texture. Thus,

¹Evans, Introduction to Color, p. 122.

²David Katz, The World of Color (London: Keegan, Paul, Trench, Trubner and Co., Ltd., 1955), p. 1.

³Frank J. Rizzo and Alvin O'Ramsley, "New Color-Measurement Instruments for Use by the Textile Industry," American Dye Reporter (May 15, 1961), pp. 374-384.

these authors help establish the fact that surface texture may help account for color change.

Warburton and Lund¹ also reported that color may be modified by the textural quality of a surface.

Gross² established that change in variation of pile structure of a texture had a modifying effect on color. In her limited experimentation, variations in the height of pile and size of yarn proved to be causal factors in the variations in the samples' colors.

A theory has evolved to explain why texture effects color. Luckiesh³ states that when the ends of a nap surface face the light, the light is able to penetrate the fabric to a considerable depth; thus the color of the texture appears deeper, due to multiple reflections. If, however, the nap ends are away from the light there is more specular reflection away from the surface and less penetration of the light into the surface. The result is less color change.

Luckiesh⁴ also describes the effect of certain fibers upon color. The reflected color of a textured

¹P. Warburton and G. V. Lund, "Colour and Textiles," The Journal of the Textile Institute Experiments in Colour, Vol. 47, No. 5 (May 1956), 315-318.

²Gross, p. 40.

³Luckiesh, p. 309.

⁴Ibid., p. 309.

material is the color of the incident light after it has been altered by the selective absorption of the fabric. In a loose fabric with a porous surface, the light is able to penetrate more deeply and the reflected color is the result of multiple reflections. Wool fibers are more transparent than cotton fibers and therefore permit the deeper penetration of the light and a greater number of multiple reflections. The light reflected from less porous fibers or fabrics is just slightly changed because it does not allow multiple reflections. "This tends to dilute the colored light and to make it appear less saturated."¹

The ultimate concern in the study of textural modification of color is not whether texture modifies light and therefore color, but rather to what extent it does and whether predicable limits can be set as to how much texture does affect color. In order to set predictable limits, exact quantitative measures of color change due to textural variation should be made. Present researchers in the area of color and texture seem most often to describe the qualitative change in color that results from textural variation. For example, in the work completed by Warburton and Lund,² changes in hue as well as changes in value were described by observers looking at $4\frac{1}{2}$ denier material, 3 denier material,

¹Ibid., p. 308.

²Warburton and Lund, p. 315.

and finally $1\frac{1}{2}$ denier material. The investigators stated that the green fabrics appeared a little more yellow and the purple fabrics appeared bluer as the fiber size decreased.

This researcher believes that the tendency to present results of research in a descriptive manner rather than to state quantitative results is not unique to the Warburton and Lund experiment, but is, in general, the trend in research concerning the modifying effect of texture upon color. Considering the newness of this field of investigation, it is perhaps a prudent approach for research to be presented in such a manner. At some future time, the quantitative results of various investigators may be compiled and then practical limits may be set as to the extent texture does affect color.

Summary

In recent years, more investigators have become interested in studying the effect of texture upon color. Color theory indicates that there is a physical explanation for the modification of color caused by texture. Researchers, however, are left with the task of developing effective color experimentation that results in precise quantitative and qualitative measurement of color change.

Because of the present interest in exact color measurement, leading color researchers suggest the use of

instrumental color measurement to complement the work done by human observers. The increasing effectiveness of research in the area of color and texture indicates that, in the future, predictable limits may be established concerning the extent of the influence of texture on color.

CHAPTER II

METHODOLOGY

Research Design

This study was designed to describe and evaluate the effect of three structural variables of a pile texture (pile height, size of yarn ply, and pile density) upon the color red-purple. The study utilized both subjective and objective methods of investigation.

Samples

Twenty-four pile samples used for analysis in this study were made from three colors of yarn: red-purple, red, and purple. The red-purple samples were the major concern of this study, while the red and the purple samples were used as controls.

Each of the colors of yarn were woven into eight possible combinations of the three structural variables, pile height, yarn ply, and pile density (see Table 1).

Thus, each sample with a certain pile structure matches another sample exactly, except for the alteration of one variable factor. For example, number one sample matches number three sample except in pile height. Later,

Table 1. Research design for samples: combinations of variables

Combination	Variables		
	Pile (P)	Density (D)	Ply (PL)
1	high (HP)*	high (HD)*	three-ply (3PL)*
2	high (HP)	low (LD)*	three-ply (3PL)
3	high (HP)	high (HD)	one-ply (1PL)*
4	high (HP)	low (LD)	one-ply (1PL)
5	low (LP)*	high (HD)	three-ply (3PL)
6	low (LP)	low (LD)	three-ply (3PL)
7	low (LP)	high (HD)	one-ply (1PL)
8	low (LP)	low (LD)	one-ply (1PL)

*Letter codes used throughout study to identify the variable.

it will be shown that analysis of the data was done with one variable at a time. By matching the samples into pairs, and then studying the color differences between such pairs, any color change between them was judged to be the result of the one variable that made the samples different.

The pile samples were woven in the following manner: the red-purple, red, and purple yarn used was three ply "Z" twist construction, in which each single ply was a combination of two yarns in an "S" construction. The warp was a heavy 5/10 medium twist, linen yarn. The weft was the previously described red-purple, red, and purple Persian rug yarn. The pile samples were woven on a table loom and the flossa knot technique which is the half ghiordes knot was employed.¹

The knots of all the samples were tied over one of two height flossa bars which determined the pile heights of one-half or one-and-one-half inches. The one-half inch pile height was chosen to conform with the Gross study. The variable of two pile densities was achieved by using either two or three rows of heavy wool filler yarns between each row of knots and by using either sixteen separated yarns in each knot or eighteen separated yarns (constant with the Gross study). The two yarn sizes used were three ply and

¹Osma Couch Gallinger and Josephine Del Reo, Rug Weaving for Everyone (Milwaukee: Bruce Publishing Co., 1957).

one ply. The one ply yarn was a double strand of untwisted three ply yarn. The approximate overall size of the samples, $3\frac{1}{2} \times 3\frac{1}{2}$ ", was achieved by weaving ten rows of fourteen knots each. Because the investigator had a tendency to make tighter knots as she progressed with the making of the pile samples, the overall dimension of the samples varied slightly. A two inch by two inch portion in the center of each sample was marked and this portion was analyzed by both the human observers and the spectrophotometer. Within the two inch demarcation, each sample contained exactly the same number of knots. This procedure assured uniformity in the samples. After the samples were woven and before they were cut apart, they were spray coated on the back surface with a synthetic rubber compound. Later, the top of each sample was sheared to insure uniform pile height for each sample.

Analysis

As in all colorimetry, the fundamental question to be answered requires the study of the stimulus (light wavelength) and the resulting human visual response (perceived color). This explains the objective and subjective approaches to color analysis used in this study. Three judges were used for the subjective analysis portion of this study to coincide with the three judges used in the Gross study. However, a spectrophotometer was used in this study to help determine whether this instrument could measure as affectively

color change due to textural variation as did the instrument used in the Gross study. All the findings were converted into Munsell¹ nomenclature to facilitate easier understanding of the data.

A comparison of results of this research and the preceding Shipley and Gross studies was not made because of the following reasons.

1. The Shipley pilot study was unpublished material that was not readily available.
2. The results of the Gross study were averaged; the data from the present study was not.
3. An instrument other than a spectrophotometer was used in the Gross study to collect objective data.

Objective Color Analysis

The General Electric Recording Photoelectric Spectrophotometer² was used, so that maximum information concerning the wavelengths of the colors in the study could be found. The General Electric Recording Photoelectric Spectrophotometer, specifically designed for the measurement of spectral reflectance and transmission, was used in this study to

¹Albert H. Munsell, A Color Notation (New York: Munsell Color Co., 1919), p. 111.

²Committee on Colorimetry of the Optical Society of America, Science of Color (New York: Thomas Y. Crowell Co., 1953).

analyze objectively the color of the carpet samples. This instrument employs a double monochromator for the elimination of stray energy. The energy supplied by this monochromator passes through a polarizing photometer. An additional polarizing prism is rotated at high speed to produce two flickering beams which alternately attain their maximum intensities. One of these beams is reflected from the sample which was placed before the instrument through a two inch aperture and the other beam is reflected from the standard of magnesium oxide. The reflected light is averaged by further reflection within a hollow sphere lined with magnesium oxide, after which the light finally falls upon the photoelectric cell. The fluctuations in the photocell current resulting from irregularities in the reflected intensities of the flickering beam are amplified and actuates a motor that rotates the balance prism of the photometer. Through a mechanical coupling, the reflectance corresponding to the condition of the optical balance is recorded on a graph sheet, which is rotated continuously under the recording pen as the wavelengths change. Simultaneously, the attached tristimulus integrator automatically ascertains and records on three dials the tristimulus values of the color sample. Each carpet sample was presented four times to the spectrophotometer and an average of the tristimulus values was taken as recommended by Judd and Wyszecki.¹

¹Judd and Wyszecki, p. 100.

The tristimulus values, X Y Z, for each pile sample were then used in a color difference formula that D. Nickerson and Stultz perfected in 1943.¹ Before the values of X Y Z obtained from the spectrophotometer became usable in the formula, each value had to be converted in a Munsell value function $V_x V_y V_z$. This conversion was done through the interpolation of the data found in the appendix of Color in Business, Science, and Industry by Judd and Wyszecki.²

The values $V_x V_y V_z$ for each sample was compared using the following formula in order to determine color differences due to changes in pile height, yarn size, and pile density:

$$\Delta E = 0.23 (V_y - V_y^1)^2 + [(V_x - V_x^1)]^2 + 0.4 [(V_z - V_z^1) - (V_y - V_y^1)]^2 \frac{1}{2}$$

ΔE = the unit of color difference

V_y = the Munsell value function obtained from the tristimulus value Y.

V_x = the Munsell value found from the same function of V_y setting $Y = X_c$.

$$X_c = \frac{X}{X \text{ MgO}} = \frac{X}{98.04}$$

V_z = Munsell value for $Y = Z_c$

$$Z_c = \frac{Z}{Z \text{ MgO}} = \frac{Z}{118.0}$$

¹Ibid., p. 296.

²Ibid., appendix.

V_y^1 V_x^1 V_z^1 indicate the V_y V_x V_z values for the second sample of a pair that was compared to first sample.

The Nickerson and Stultz equation was programmed and the numerical data obtained gave values for ΔE .

Subjective Color Analysis

The three judges who participated in the subjective color analysis were members of the faculty at Michigan State University. All were knowledgeable in the field of color.

The Macbeth Munsell Colorimeter Type Number One was used in this part of the color analysis to help control the environment in which the color assessments were made. The colorimeter is a box-like structure with two hinged doors on the front. The interior of the box, painted a neutral gray (Munsell N8), is illuminated with a light source similar in temperature to that of North Sky daylight. The light source is composed of two R40 300-watt Reflector Flood lamps used with two 7¼" Macbeth daylight filters. The doors of the colorimeter were opened just far enough to expose a mask bar mounted in front of the samples. The mask had two rectangular apertures through which the observers were to view the samples and standard. The doors helped to shield out extraneous light.

A complete book of Munsell color chips provided the standards for comparison. The subjective color judging involved the following steps.

1. The colorimeter was made ready (doors opened, mask in place, lights turned on).
2. The sample texture was placed inside the box on a plastic holder which held the sample so that the nap of the carpet was directly toward the viewer.
3. The observer then selected a Munsell chip, and held it next to the texture sample in the same angle plane as the texture sample.
4. The samples were viewed in a given order: red, purple, and red-purple, in order that the observer's eyes did not become too adapted to one color.
5. Each judge made his selection with only the investigator present, who recorded the judge's estimates of color.

The above stated procedure was established in the Gross study and certain innovations were made to adapt the procedure for this study.

Comparison with the Gross Study

Although this study stemmed directly from the Gross study, changes in the research design and the availability of more sophisticated instrumentation for collecting data invalidated the possibility of directly comparing the Gross study and this study. The factors which contributed

specifically to the dissimilarity between the two studies were the following:

I. Subjective Color Analysis

- A. In the Gross study, the notations of the judges were averaged.
- B. In this study the data was not averaged.
- C. In neither study were sufficient numbers of color matches made to statistically negate the possible chance of error.

II. Objective Color Analysis

- A. The Hunter-Gardner Colorimeter was used in the Gross study to measure color difference.
- B. A General Electric Recording Photoelectric Spectrophotometer was used in this study to measure wavelengths.

CHAPTER III

SUBJECTIVE COLOR ANALYSIS

The color notations of the judges were analyzed in order to ascertain whether variations in pile structure, size of yarn ply, pile density, and pile height affected the color of the samples.

The Effect of Variations of Yarn Ply on Red, Red-Purple and Purple

When the color notations reported by the three judges were analyzed for the effect of variation in yarn ply on the color of the samples, it was found that as the size of the yarn ply decreased, the judges perceived color changes, on various occasions, in all of the three attributes of color: hue, value, and saturation (see Table 2).

Only two instances of hue change due to variations in yarn ply were perceived by Judge A. Both of these hue changes were from 7.5 RP to 10.0 RP. These changes in hue were in a clockwise movement on the Munsell color wheel. This clockwise movement indicated that the judge perceived the sample color as becoming more red and less purple-blue as the yarn ply of the sample decreased.

Table 2. Subjective color analysis showing the effect of variation of yarn ply on red, red-purple, and purple

Judge Color	Constant Pile Structure of the Sample Textures		Munsell Color Notations by the Judges		Unit of Color Change on the Munsell Charts	
			Three Ply	One Ply	Hue	Value Saturation
A	R	HP	2.5R 3/10	2.5R 3/10-3/8		
	R	HP	2.5R 3/10	2.5R 3/10		
	R	LP	2.5R 3/8	2.5R 3/10		+1
	R	LP	2.5R 3/10	2.5R 3/10		
	P	HP	10PB 2/10	10PB 2/10		
	P	HP	10PB 2/10	10PB 3/10-2/10	+1	
	P	LP	10PB 2/10	10PB 2/10		
	P	LP	10PB 2/10	10PB 2/10		
	RP	HP	7.5RP 2/8	10RP 2/8	+1	
	RP	HP	10RP 2/8	10RP 2/8		
	RP	LP	7.5RP 2/8	10RP 2/8	+1	
	RP	LP	10RP 2/8	10RP 2/8		
B	R	HP	2.5R 4/14	2.5R 4/14-4/16		
	R	HP	2.5R 4/14	10 RP 4/14-3/14		
	R	LP	2.5R 3/10-3/12	2.5R 3/10		
	R	LP	2.5R 3/10	2.5R 3/10		
	P	HP	10PB 2/10-2/12	10PB 2/10-2/12		
	P	HP	10PB 2/10-2/14	10PB 2/10-2/12		
	P	LP	10PB 2/10-2/12	10PB 2/10-2/12		
	P	LP	10PB 2/10-2/12	10PB 2/10		
	RP	HP	7.5RP 3/10	7.5RP3/10-3/12		
	RP	HP	7.5RP 3/10-3/12	7.5RP3/10		
	RP	LP	7.5RP 3/10-3/12	7.5RP3/8	-1	
	RP	LP	7.5RP 2/8-2/10	7.5RP3/10	+1	

Table 2--Continued

Judge	Color	Constant Pile Structure		Munsell Color Notations by the Judges	One Ply	Unit of Color Change on the Munsell Charts	
		Sample	Textures	Three Ply		Hue	Value Saturation
C	R	HP	HD	2.5R 3/10	2.5R 3/10+		
	R	HP	LD	2.5R 3/10	2.5R 3/10		
	R	LP	HD	2.5R 3/10	2.5R 3/10		
	R	LP	LD	2.5R 3/10	2.5R 3/10		
	P	HP	HD	10PB 2/10	10PB 2/10		
	P	HP	LD	10PB 2/10 m	10PB m-2/10	+3	
	P	LP	HD	10PB 2/10 m	10PB m-2/10	+3	
	P	LP	LD	10PB 2/10	10PB 2/10-m		
	RP	HP	HD	7.5RP 2/8	7.5RP 3/10	+1	
	RP	HP	LD	7.5RP 2/8+	7.5RP 2/8		+1
	RP	LP	HD	7.5RP 2/8-3/10	7.5RP 2/8		
	RP	LP	LD	7.5RP 2/8-2/10	7.5RP 2/8		

A decrease in yarn ply produced a value change--the color change observed was a one value level increase on the Munsell chart. Judge A perceived a value change between pairs of purple samples with a constant pile structure (HP-LD). Judges B and C each perceived a value change between different pairs of red-purple samples that had a constant pile structure of (LP-LD) and (HP-HD), respectively.

Each judge perceived at least one instance of saturation change due to a variation of yarn ply. Judge A perceived the only saturation change that occurred in the red samples. Judge B perceived a one level increase in saturation for a pair of red-purple samples with a constant pile structure (LP-LD), and one level decrease in saturation between another pair of red-purple samples (LP-HD). Judge C perceived a three level increase in saturation between pairs of purple samples with a constant pile structure (HP-LD), and (LP-HD), respectively.

From the foregoing data dealing with the effect of a decrease in size of yarn ply on color, it may be concluded that whenever color changes were observed by the judges, the changes indicate that the hue of the samples increased in warmth, thus, becoming more red as the color moved clockwise on the color wheel; the value of the samples increased, thus, becoming lighter; and the saturation of the samples increased, thus, becoming more intense.

The Effect of Variations of Pile Density
on Red, Red-Purple, and Purple

Contradictory evidence of color change was observed when the notations of the judges were analyzed in order to determine the influence of a decrease in pile density on color (see Table 3).

The only observation of hue change between a pair of samples that differed from one another in pile density was perceived by Judge A. The hue change between a pair of red-purple samples was from 7.5 to 10, representing a clockwise movement on the Munsell color wheel.

Each judge occasionally perceived value changes in the color of the samples which varied only in pile density. One judge perceived a one level value increase between one pair of purple samples. Judges B and C perceived one level decreases in value between pairs of red-purple samples which had constant pile structures of (LP-3PL), and (HP-1PL), respectively.

There was a lack of agreement among the judges concerning the nature of the saturation change of some samples due to a decrease in pile density. Judge A perceived the only saturation change in the red samples; this was a one level increase in saturation. Judge B perceived saturation changes only in the red-purple samples. Two pairs of red-purple samples appeared to decrease in saturation one level

Table 3. Subjective color analysis showing the effect of variations of pile density on red, red-purple, and purple

Judge	Color	Constant Pile Structure		Munsell Color Notations by the Judges		Unit of Color Change on the Munsell Charts	
		of the	Sample Textures	High Density	Low Density	Hue	Value Saturation
A	R	HP	3PL	2.5R 3/10	2.5R 3/10		
	R	HP	1PL	2.5R 3/10-3/8	2.5R 3/10		
	R	LP	3PL	2.5R 3/8	2.5R 3/10		+1
	R	LP	1PL	2.5R 3/10	2.5R 3/10		
	P	HP	3PL	10PB 2/10	10PB 2/10		
	P	HP	1PL	10PB 2/10	10PB 3/10		
	P	LP	3PL	10PB 2/10	10PB 2/10		+1
	P	LP	1PL	10PB 2/10	10PB 2/10		
	RP	HP	3PL	7.5RP 2/8	10RP 2/8		+1
	RP	HP	1PL	10RP 2/8	10RP 2/8		
	RP	LP	3PL	7.5RP 2/8	10RP 2/8		+1
	RP	LP	1PL	10RP 2/8	10RP 2/8		
	R	HP	3PL	2.5R 4/14	2.5R 4/14		
	R	HP	1PL	2.5R 4/14-4/16	2.5RP 4/14		
	R	LP	3PL	2.5R 3/10-3/12	2.5R 3/10		
	R	LP	1PL	2.5R 3/10	2.5R 3/10		
B	P	HP	3PL	10PB 2/10-2/12	10PB 2/10-2/14		
	P	HP	1PL	10PB 2/10-2/12	10PB 2/10-2/12		
	P	LP	3PL	10PB 2/10-2/12	10PB 2/10-2/12		
	P	LP	1PL	10PB 2/10-2/12	10PB 2/10		
	RP	HP	3PL	7.5RP 3/10	7.5RP 3/10-3/12		
	RP	HP	1PL	7.5RP 3/10-3/12	7.5RP 3/10		
	RP	LP	3PL	7.5RP 3/10-3/12	7.5RP 2/8-2/10		-1
	RP	LP	1PL	7.5RP 3/8	7.5RP 3/10		-1
	R	HP	3PL	2.5R 4/14	2.5R 4/14		
	R	HP	1PL	2.5R 4/14-4/16	2.5RP 4/14		
	R	LP	3PL	2.5R 3/10-3/12	2.5R 3/10		
	R	LP	1PL	2.5R 3/10	2.5R 3/10		
	P	HP	3PL	10PB 2/10-2/12	10PB 2/10-2/14		
	P	HP	1PL	10PB 2/10-2/12	10PB 2/10-2/12		
	P	LP	3PL	10PB 2/10-2/12	10PB 2/10-2/12		
	P	LP	1PL	10PB 2/10-2/12	10PB 2/10		

Table 3--Continued

Judge	Color	Constant Pile Structure of the		Munsell Color Notations by the Judges		Unit of Color Change on the Munsell Charts	
		Sample	Textures	High Density	Low Density	Hue	Value Saturation
C	R	HP	3PL	2.5R 3/10	2.5R 3/10		
	R	HP	1PL	2.5R 3/10+	2.5R 3/10		
	R	LP	3PL	2.5R 3/10	2.5R 3/10		
	R	LP	1PL	2.5R 3/10	2.5R 3/10		
	P	HP	3PL	10PB 2/10	10PB 2/10-m		
	P	HP	1PL	10PB 2/10	10PB m-2/10		+3
	P	LP	3PL	10PB 2/10-m	10PB 2/10		
	P	LP	1PL	10PB m-2/10	10PB 2/10-m		-3
	RP	HP	3PL	7.5RP 2/8	7.5RP 2/8+		
	RP	HP	1PL	7.5RP 3/10	7.5RP 2/10		-1
	RP	LP	3PL	7.5RP 2/8-3/10	7.5RP 2/8-2/10		
	RP	LP	1PL	7.5RP 2/8	7.5RP 2/8		

as the pile density decreased. Judge C perceived an increase of three levels of saturation between a pair of purple samples with a constant pile structure of (HP-1PL), and between another pair of purple samples with constant factors (LP-1PL) saw a decrease of three levels.

Color changes that may be attributed to change in pile density are not as clearly defined as were those color changes attributed to change in yarn ply. Evidence was not conclusive as to the dominant direction of change of the three attributes of color for all the samples as pile density decreased. Generally, the hue of the samples remained constant or changed in a clockwise direction on the Munsell color wheel; the values of some samples were reported as lighter and others were reported darker; the saturation of most samples decreased and, thus, appeared less intense.

The fact that the judges in many instances gave contradictory color judgments as to whether there were increases or decreases in value and saturation when they noted any changes at all indicates that color changes due to variation of pile density were difficult to discern. The difficulty may be attributed to the fact that the samples did not differ enough in pile density to make discernment of color easy. It is also possible that pile density does not appreciably influence color.

The Effect of Variations of Pile Height on
Red, Red-Purple, and Purple

Analysis of the subjective findings revealed that the judges perceived more color changes when pile height was altered than they had perceived when yarn ply or pile density was altered (see Table 4).

A hue change of one Munsell unit was perceived between pairs of red samples with a constant pile structure of (LD-1PL) by Judge B. As the pile of this pair of samples decreased, the color was perceived to move in a clockwise direction from 10 RP to 2.5 R on the Munsell color wheel. Because Judge B chose 10 RP only once to describe the color of a red sample, this investigator felt that this judgment may have been an error.

All three judges observed that all the paired samples appeared darker in value as the pile height of the samples decreased. Each value change that was indicated by the judges was a decrease of one level on the Munsell value scale. Judge B saw a value change between every pair of red samples. The other two judges saw no change between these paired samples. Only one judge, A, saw a value change between a pair of purple samples. Judge B and C perceived a value change between two pairs of red-purple samples.

In all but one instance the saturation changes that were observed by the judges were decreases in saturation.

Table 4. Subjective color analysis showing the effect of variation of pile height on red, red-purple, and purple

Judge	Color	Constant Pile Structure of the		Munsell Color Notations by the Judges		Unit of Color Change on the Munsell Charts	
		Sample	Textures	High Pile	Low Pile	Hue Value	Saturation
A	R	HD	3PL	2.5R 3/10	2.5R 3/8		-1
	R	LD	3PL	2.5R 3/10	2.5R 3/10		
	R	HD	1PL	2.5R 3/10-3/8	2.5R 3/10		
	R	LD	1PL	2.5R 3/10	2.5R 3/10		
	P	HD	3PL	10PB 2/10	10PB 2/10		
	P	LD	3PL	10PB 2/10	10PB 2/10		
	P	HD	1PL	10PB 2/10	10PB 2/10		
	P	LD	1PL	10PB 3/10-2/10	10PB 2/10	-1	
	RP	HD	3PL	7.5RP 2/8	7.5RP 2/8		
	RP	LD	3PL	10RP 2/8	10RP 2/8		
	RP	HD	1PL	10RP 2/8	10RP 2/8		
	RP	LD	1PL	10RP 2/8	10RP 2/8		
B	R	HD	3PL	2.5R 4/14	2.5R 3/10-3/12	-1	-2
	R	LD	3PL	2.5R 4/14	2.5R 3/10	-1	-2
	R	HD	1PL	2.5R 4/14	2.5R 3/10	-1	-2
	R	LD	1PL	10RP 4/14	2.5R 3/10	+1	-2
	P	HD	3PL	10PB 2/10	10PB 2/10		
	P	LD	3PL	10PB 2/10	10PB 2/10		
	P	HD	1PL	10PB 2/10	10PB 2/10		
	P	LD	1PL	10PB 2/10	10PB 2/10		
	RP	HD	3PL	7.5RP 3/10	7.5RP 3/10		
	RP	LD	3PL	7.5RP 3/10	7.5RP 2/8	-1	-1
	RP	HD	1PL	7.5RP 3/10	7.5RP 3/8		-1
	RP	LD	1PL	7.5RP 3/10	7.5RP 3/10		

Table 4--Continued

Judge	Color	Constant Pile Structure of the		Munsell Color Notations by the Judges		Unit of Color Change on the Munsell Charts		
		Sample	Textures	High Pile	Low Pile	Hue	Value	Saturation
C	R	HD	3PL	2.5R 3/10	2.5R 3/10			
	R	LD	3PL	2.5R 3/10	2.5R 3/10			
	R	HD	1PL	2.5R 3/10+	2.5R 3/10			
	R	LD	1PL	2.5R 3/10	2.5R 3/10			
	P	HD	3PL	10PB 2/10	10PB 2/10-m			
	P	LD	3PL	10PB 2/10-m	10PB 2/10			+3
	P	HD	1PL	10PB 2/10	10PB m-2/10			-3
	P	LD	1PL	10PB m-2/10	10PB 2/10-m			
	RP	HD	3PL	7.5RP 2/8	7.5RP 2/8-3/10			
	RP	LD	3PL	7.5RP 2/8+	7.5RP 2/8-2/10			
	RP	HD	1PL	7.5RP 3/10	7.5RP 2/8	-1		-1
	RP	LD	1PL	7.5RP 2/10	7.5RP 2/8			-1

Judge C saw the only increase in saturation. This was an increase of three levels of saturation and occurred between a pair of purple samples. Judge B perceived that all of the red samples decreased two saturation levels as the pile height of those samples decreased. The color difference between two samples with a constant structure of (HD-3PL) appeared to Judge A as a decrease one level in saturation. Judge C, the only judge who perceived any saturation change in the purple samples, indicated a decrease of three levels of saturation between a pair of samples that had a constant pile structure (LD-1PL).

The dominant patterns of color change due to variations in pile height were established by Judge B. This judge perceived all of the red samples decreasing one value level and two saturation levels as the pile height decreased. The color judgments of the other two judges generally reinforced the patterns of color change established by Judge B, although the color judgments of the other judges were made on colors other than red. The judges reported more color changes in the samples that varied in pile height than in those that varied either in yarn ply or pile density.

The Effect of Variations of Pile
Structure Upon Red-Purple

When the red-purple color notations of judges were analyzed, certain specific characteristics of that color were noticed. As the pile structures of the samples were varied, judges more frequently reported color changes between pairs of red-purple samples than were reported for the other two colors. Also, the red-purple samples were the only ones perceived by the judges to change in all three attributes of color--hue, value and saturation. Further, each of the judges perceived as the color he saw most frequently, for the red-purple samples, a Munsell color different from the other judges. Judge A saw 10 RP 2/8 most frequently regardless of the textural variations of the red-purple samples. Judge B saw 7.5 RP 3/10 most frequently and Judge C saw 7.5 RP 2/8 most frequently. With the other two colors, red and purple, all three observers generally agreed that the color they saw most frequently regardless of the textural variation of the samples was 2.5 R 3/10 or 10 PB 2/10 for the red and purple samples, respectively.

Summary

The subjective color analysis was done by a panel of three judges. The judges matched the color of each

sample with a Munsell color chip within the controlled environment of the Macbeth-Munsell Colorimeter.

The notations of the judges showed that variations of yarn ply, pile density, and pile height did affect the color of some samples. Of the three variables, pile height appeared to have the greatest influence on the color of the sample. No regular pattern of color change was found.

CHAPTER IV

OBJECTIVE COLOR ANALYSIS

The following is a discussion, first, of the numerical expressions of color difference, ΔE , found between samples by the Nickerson and Stultz color difference formula and, second, of an evaluation and comparison of reflectance curves of the sample colors (see Table 5).

Color Difference Formula

The Effect of Variations of Size of Yarn Ply on Red, Red-Purple, and Purple

For all three colors, the expression of color difference between pairs of samples was 0.0008 to 0.001, as the yarn ply decreased. According to the National Bureau of Standards' guide established in 1940,¹ color difference as small as those found would not be seen by the human eye. Therefore, color difference resulting from a decrease in yarn ply was negligible.

¹F. L. Rizzo, "Quartermaster Research and Engineering Command," American Dye Report, Vol. V, No. 6 (March 20, 1961), pp. 211-220.

Table 5. Color difference between samples that differ from one another in either size of yarn ply, pile density, or pile height

Variable	Constant Pile Structure of the Sample Textures		Color Difference Quantitatively Measured by the Nickerson + Stultz Formula (ΔE)		
			Red	Red-Purple	Purple
Yarn ply	HP	HD	0.00787	0.00787	0.00715
	HP	LD	0.00523	0.00581	0.00048*
	LP	HD	0.00581	0.00111	0.00079*
	LP	LD	0.00976	0.00375	0.00535
Pile density	HP	3PL	0.00361	0.00222	0.00377
	HP	1PL	0.00569	0.00063*	0.00362
	LP	3PL	0.00128	0.00048*	0.00126
	LP	1PL	0.00471	0.00437	0.00345
Pile height	HD	3PL	0.01390	0.00602*	0.01360
	LD	3PL	0.01700	0.00798*	0.01830
	HD	1PL	0.01620	0.01270	0.01990
	LD	1PL	0.00580*	0.01500	0.01290

* Indicates color difference between pairs of samples that deviated from the other two expressions of ΔE .

The Effect of Variations of Pile Density
on Red, Red-Purple, and Purple

The numerical expressions of color differences tabulated by the computer for pairs of samples that varied from one another in pile density ranged from 0.0006 to 0.001. The ΔE for many of the samples clustered from 0.004 through 0.002.

Pile density produced greater color differences than changes in yarn ply. The reader should be reminded that these expressions of color difference are quantitative in nature, not qualitative. From the data, it is known that color differences between samples do exist but it remains unknown whether these color differences are in hue, value, or saturation.

The Effect of Variations of Pile Height
on Red, Red-Purple, and Purple

Color differences recorded for samples that varied in pile height were far greater than differences recorded for samples that varied in either size of yarn ply or pile density. The range of color difference between high and low pile samples was 0.008 and 0.01. Most of the color differences were recorded at 0.02.

The data, as a result, indicate that of these three variables (pile height, yarn ply, and pile density) pile height had the greatest relative effect upon the color of

the samples. The color difference between most of the pairs of texture samples was 0.02. This is not a perceptible color difference for the human eye since the National Bureau of Standard guide defines a color difference of 0.0 through 0.5 as a "trace" of color difference.

Even though the color differences that were found to exist between samples as pile height, yarn ply, or pile density was altered were too small to be called a "trace" by NBS standards, these color changes were measureable by the spectrophotometer. This indicates to this researcher that perhaps greater textural changes would have created greater color differences.

The Effect of Variations of Pile Structure Upon the Color Red-Purple

Further examination of the data indicated in Table 5 showed that on seven occasions (starred on the charts) large discrepancies existed between the color differences obtained for matched pairs of one color samples as compared with pairs of matched samples of the other two colors.

Earlier the Nickerson and Stultz formula was used to discover how much color difference existed between sample textures which varied from one another in only one characteristic. All factors of color and pile structure were kept constant except for one characteristic of pile structure, such as yarn ply, pile density, or pile height. Therefore,

this researcher believes that each given variable of pile structure should affect the same amount of color difference between pairs of samples even though these pairs of samples are different--red, red-purple, or purple. For example, it may be seen that a variation in the size of yarn ply was responsible for a color difference of 0.00787, 0.00787 and 0.00715 between pairs of red, red-purple and purple samples with constant pile structures of (HP-HD). The closeness of these numerical expressions of color differences should be expected if no factor other than yarn ply was affecting the color of the samples.

The data, however, indicate that upon seven occasions the numerical expression of color difference between matched samples of one color were unlike the expressions of color difference between pairs of samples of the other two colors. Four out of seven times it was the color difference between red-purple samples that was dissimilar. On all four occasions the color difference between the red-purple samples was far less than the color difference between pairs of red or purple samples. The dissimilarity indicates to this researcher that perhaps it was some innate quality of the colors themselves that influenced the amount of color change exhibited by the samples as pile structure was varied.

The Effect of Variations of Pile Structure on Red, Red-Purple, and Purple

Reflectance Curves

The spectrophotometric data were also used to evaluate the influence of variations of pile structure on the reflectance curves for each individual sample texture. The color difference formula provided a quantitative measure of color difference between two compared samples which varied from one another in one factor of pile structure only. Examination of the reflectance curves of those same pairs of samples provided the qualitative measure of color difference between two samples. Such an examination of the color reflectance curves of matched samples indicated that as the texture of each sample changed, certain definite changes took place in the color of each sample (see Table 6).

The size of yarn ply variable had little or no effect on the amount and kind of color reflected from the red-purple and purple samples. The pairs of reflectance curves of the red samples, however, demonstrated that decreasing the size of yarn ply resulted in loss of reflectance in the 600 to 700 millimicron portion of the spectrum. This meant that as the yarn ply size decreased the sample became less red (a loss in saturation) and became perhaps a little darker, because a loss in percentage reflectance indicates a darker color.

Table 6. Objective color analysis showing comparison of reflectance curves of the effect of variations of pile structure on red, red-purple, and purple

Variable	Constant Pile Structure of the Sample Textures		Drop in Percentage of Difference Between Pairs of Reflectance Curves for Each Color at Certain Wavelengths			
			Red	Red-Purple	Purple	
		% Change	Portion of Wavelength	%	%	
Yarn ply	HP	HD	400-460 mu	...	1	400-500 mu
			700 mu	3½	...	...
	HP	LD	400-420 mu	...	1	438 mu
			680-700 mu	1	...	...
	LP	HD	400-460 mu	...	1	438 mu
			640-700 mu	½	1	650 mu
	LP	LD	480-570 mu	...	1½	438 mu
Pile density		7	660-700 mu	1½	½	640 mu
	HP	3PL	400-460 mu	...	1	440 mu
		3	700 mu	1½	4	700 mu
	HP	1PL	400-440 mu	...	3½	440 mu
		3	700 mu	3	2½	650 mu
	3PL	½	400-480 mu	...	...	...
		1½	700 mu	1	...	...
	LP	*1	400-440 mu	...	...	...
		*2	700 mu	...	2	700 mu
	HD	2	400-470 mu	1	5½	430-440 mu
Pile height		12	700 mu	8	10	700 mu
	LD	2	400-470 mu	1½	4½	458 mu
		9	700 mu	8½	8	700 mu
	HD	3	400-440 mu	2	6	440 mu
		12	700 mu	11	6½	700 mu
	LD	...		2	2	430-450 mu
		7½	700 mu	8½	10	700 mu

* Indicates a percentage rise of low density samples.

As the samples' pile density decreased, the resulting color change between pairs of samples apparently was extremely slight at both ends of the spectrum. The red samples lost reflectance at both the blue and red ends of the spectrum. As the pile density was decreased, the red-purple samples' color changed the least.

Variation in pile height resulted in relatively large color change in samples of all three colors. Great losses in reflectance were common among samples of all three colors at about 600-700 millimicrons. Two pairs of red samples demonstrated the greatest individual reflected percentage loss in the red region of the spectrum. The purple samples lost considerably more reflectance at 430-450 millimicrons than did the other two colors.

The reflectance curves indicated that decreasing pile height produced a decrease in the amount of red reflected. Because the reflectance curves of the low pile samples dropped at both ends of the spectrum 400, and 700 millimicrons, a darkening of the sample was indicated.

The reflectance curves for the red-purple samples showed that as size of yarn ply was decreased and pile density was decreased, the percentage reflectance loss of various wavelengths for that color was more similar to percentage reflectance loss for purple than for red. The percentage reflectance loss for each color was more significant, however, when pile height was reduced. The loss in

reflectance of the red-purple samples was far more similar to the loss suffered by the red samples than to the loss among the purple samples.

When comparing actual reflectance curves, those of the red-purple were also similar to the red. Consequently, both colors reflect nearly the same type and quality of light and have a similar spectral nature.

Summary

The objective color analysis was done by the General Electric Recording Spectrophotometer. The data were analyzed in two ways: (1) the Nickerson and Stultz color difference formula, and (2) comparison of the reflectance curves.

The Nickerson and Stultz formula showed the color difference between samples to be extremely small. Pile height was the one variable that influenced the greatest amount of color change between samples.

Comparison of the reflectance curves revealed that, generally, as pile structure varied there was a decrease in the percentage of reflectance in the red region of the spectrum. Red and red-purple lost the greatest single amounts of red reflectance. Red-purple reflectance curves were similar to the red reflectance curves.

CHAPTER V

COMPARISON OF THE SUBJECTIVE AND OBJECTIVE METHODS OF COLOR ANALYSIS

In comparing the spectrophotometric tristimulus data, translated into Munsell nomenclature, with the responses given by the three judges (see Table 7), a great deal of agreement between both methods of color analysis was discerned. Generally, the spectrophotometric color analysis and the judge's color perceptions for a given sample indicated the same Munsell color, 2.5 R 3/8 through 2.5 R 3/10, 7.5 RP 3/8 through 7.5 RP 3/10, and 10 PB 2/8 through 10 PB 2/10.

There were occasions when the spectrophotometric results did not agree with the color notations of the judges. This investigator feels that the reason for the lack of spectrophotometric reinforcement of the subjective notations was primarily because the color differences between pairs of samples varying only in one structural detail (size of yarn ply, pile density, and pile height), was very small indeed. The spectrophotometer was able to analyze the smallest trace of color change between samples of varying structure as is evident by the extremely small values of color difference calculated with the Nickerson and Stultz formula.

Table 8. Comparison of the responses of the three judges with the spectrophotometer translated into Munsell nomenclature

Color	Sample	Spectro- photometer		Judges	
		A		B	
					C
R	HP	3PL	2.5R 3/8-3/10	2.5R 3/10	2.5R 3/10
R	HP	3PL	2.5R 3/8-3/10	2.5R 3/10	2.5R 3/10
R	HP	1PL	2.5R 3/8-3/10	2.5R 3/10-	2.5R 3/10+
R	HP	1PL	2.5R 3/8-3/10	2.5R 3/10	2.5R 3/10
R	LP	3PL	2.5R 3/8-3/10	2.5R 3/8	2.5R 3/10
R	LP	3PL	2.5R 3/8-3/10	2.5R 3/10	2.5R 3/10
R	LP	1PL	2.5R 3/8-3/10	2.5R 3/10	2.5R 3/10
R	LP	1PL	2.5R 3/8-3/10	2.5R 3/10	2.5R 3/10
P	HP	3PL	10PB 2/8-2/10	10PB 2/10	10PB 2/10
P	HP	3PL	10PB 2/8-2/10	10PB 2/10	10PB 2/10
P	HP	1PL	10PB 2/8-2/10	10PB 2/10	10PB 2/10
P	HP	1PL	10PB 2/8-2/10	10PB 2/10	10PB max.
P	LP	3PL	10PB 2/8-2/10	10PB 2/10	10PB 2/10
P	LP	3PL	10PB 2/8	10PB 2/10	10PB 2/10
P	LP	1PL	10PB 2/8	10PB 2/10	10PB max.
P	LP	1PL	10PB 2/8-2/10	10PB 2/10	10PB 2/10
RP	HP	3PL	7.5RP 3/8-3/10	7.5RP 3/10	7.5RP 2/8
RP	HP	3PL	7.5RP 3/8-3/10	7.5RP 3/10	7.5RP 2/8+
RP	HP	1PL	7.5RP 3/8-2/10	7.5RP 3/10	7.5RP 3/10
RP	HP	1PL	7.5RP 3/8-3/10	7.5RP 3/10	7.5RP 2/10
RP	LP	3PL	7.5RP 3/8-3/10	7.5RP 3/10	7.5RP 2/8
RP	LP	3PL	7.5RP 3/8-3/10	7.5RP 2/8	7.5RP 2/8
RP	LP	1PL	7.5RP 3/8-3/10	7.5RP 3/8	7.5RP 3/8
RP	LP	1PL	7.5RP 3/8-3/10	7.5RP 3/10	7.5RP 2/8

The three judges undoubtedly sensed the same small color differences. They could not quantitatively report these differences; the spectrophotometer, however, could report exactly how close the match of the color of the sample texture was to the color of the Munsell chip. However, when the judges thought that the color of a sample was somewhat brighter than the closest matched Munsell chip, they would be forced to use the next closest Munsell chip which was actually far brighter than the color of the sample texture. There were two reasons for such action by the judges. First, all the judges were aware of the purpose of this research and were therefore mentally set to perceive a difference in color due to a difference in texture. Second, the judges were hampered by the non-linear relationship¹ of the Munsell chip. Because of this, they were unable to indicate where the color of the samples fit on the differing lengths of the color continuum between one Munsell chip and another. The tristimulus values provided by the spectrophotometer indicated quickly how close the color of the samples matched the tristimulus specification for each Munsell chip. In this way, it became apparent to this investigator that in nearly all cases, the tristimulus specifications for both the samples and the Munsell chips did not match exactly,

¹The Munsell Color System is a visual system and therefore the spacing between color chips varies in length.

but the specifications were not off enough to justify giving the color of the sample another Munsell notation. Therefore the spectrophotometer did not indicate any color change between samples of varying structure because the small color differences that were manifested in the color difference formula were too minute to be indicated in a change in Munsell notation as the three judges apparently tried to do.

Not only was there no spectrophotometric reinforcement of the color differences perceived by the judges, but also, at no time did any of the judges reinforce each other's indication of color change. Therefore, the conclusions concerning trends in color change caused by variations in pile structure were sometimes established on the basis of one indication of color change made by one judge. Also the number of color matches made by the judges were not numerous enough to negate statistically the possibility of chance selection and error. For the reasons stated above, this investigator feels that in this study, the data received from the spectrophotometer concerning the colors of the samples are more valuable than the subjective color analyses because these data indicate far more accurately the quantitative and qualitative change in color resulting from alteration of pile structure of the samples.

In the previous discussion, the primary concern was to compare the quantitative color change recorded by both subjective and objective methods of color analysis. Further

analysis of the data indicated that the results of both the subjective and objective methods of color analysis agreed more with one another with respect to the qualitative color change than quantitative color change that took place as the pile structures were varied.

The subjective color analysis showed that as pile density and pile height were decreased in the samples, the value levels of the colors of the samples decreased as did their saturation levels. Analysis of the reflectance curves by the spectrophotometer of each sample reinforced the judges' findings.

The objective analysis of the color of the samples showed that the greatest change in color always occurred in the red region of the spectrum. The judges reported most of the color changes in the red-purple paired samples with the second greatest number of color changes in the red samples. This, plus the fact that the reflectance curves of all the red-purple samples were more similar to the reflectance curves of the red samples than were the purple samples has all contributed to the hypothesis that perhaps it was the influence of red in the color red-purple that was responsible for the difficulty with which the color red-purple was discerned in this study and in the previous study.

CHAPTER VI

SUMMARY AND SUGGESTIONS FOR
FURTHER RESEARCH

Summary

In 1961, Gross completed a study on "The Effect of the Height and Yarn Size of a Pile Texture on Color." In this study, the author reported that texture affects color in a manner measurable by both objective and subjective techniques.

The results of the Gross research showed that while the majority of the colors studied changed in a consistent direction as the texture of the samples was altered, a few samples, particularly, the blue-green, yellow-green, and red-purple, exhibited change that deviated from the rest. Gross hypothesized that the hand dying of the blue-green and yellow-green yarns was the cause of irregular changes. The author suggested further research in order to understand better the unique behavior of the color red-purple when modified by texture.

This present study was designed to study the effect of variations of pile structure upon the color red-purple. For this purpose, three sets of samples were woven that

varied from one another in pile structure. One set of samples was woven with red yarns, one set with purple, and with red-purple yarn. The pile structures of the samples in each set varied in size of yarn ply, pile density, and pile height. The combination of variables resulted in a total of 24 samples.

A subjective color analysis was made by a panel of three judges. The judges matched the color of the sample with a Munsell chip within the controlled environment of the Macbeth-Munsell Colorimeter. In addition, color analysis of each sample was also made on a General Electric Recording Spectrophotometer.

The color notation for each sample was compared with the notation of every other sample so that the compared pairs of samples differed one from the other in only one factor, size of yarn ply, pile density, or pile height.

Summary

I. As the yarn ply of the samples decreased the results were as follows:

A. Subjective Analysis

1. The hues of the samples became warmer.
2. The value of the colors increased.
3. The saturation of the colors increased.

B. Objective Analysis

1. Color difference between samples was from 0.008 to 0.001 NBS unit of color difference.

2. Reflectance curves showed that the pairs of red samples especially differed from one another in the percentage of reflectance in the 600-700 millimicron section of the spectrum.

II. As pile density of the samples decreased the results were as follows:

A. Subjective Analysis

1. The hues of the samples became warmer.
2. The values of the samples decreased.
3. The saturation of the samples decreased.

B. Objective Analysis

1. Color differences between pairs of samples were found to be from 0.006 to 0.001 NBS unit of color difference.
2. Reflectance curves showed that between pairs of samples there was a loss in percentage reflected, mostly in the red region but also in the blue region of the spectrum for all three colors.

III. As the pile height of the samples decreased the results were as follows:

A. Subjective Analysis

1. The hues of the samples remained unchanged.
2. The values of the colors of the samples decreased.
3. The saturation of the colors of the samples decreased.

B. Objective Analysis

1. Color difference between samples was found to be from 0.008 to 0.01 NBS unit of color difference.
2. Reflectance curves showed that between pairs of samples there was a large loss in percentage of reflectance in the 600-700 millimicron region of the spectrum for all three colors. Purple samples also lost reflectance in the 400-480 millimicron region of the spectrum.

IV. The data revealed the following specific characteristic of red-purple.

A. Subjective Analysis

1. The judges perceived more frequent numbers of color change between pairs of red-purple samples.
2. As pile variations were made, red-purple was the only color to change in all three attributes of color.

B. Objective Analysis

1. On four occasions, the ΔE for pairs of red-purple samples deviated from the ΔE for red and purple.
2. As variations in pile structure were made, the percentage of reflectance lost in the red region of the spectrum for red-purple was similar to red.

3. Red-purple reflected the same type and quality of light as the red.

From the above findings certain general conclusions were made:

1. Changes in the pile structure of the sample textures were not great enough to permit easy discernment of color change.
2. The spectrophotometer was able to analyze and record the slightest color difference between samples.
3. Pile height was the variable in pile structure that affected the greatest color change.
4. The difficulty with which the color red-purple was discerned was due to the fluctuating red portion of that color.
5. Red-purple showed a greater pattern of irregular color change than did either red or purple.

Recommendations

This study has presented many interesting challenges to this researcher. The task of measuring the effect of texture on color requires an understanding of many fields of knowledge. To explore this topic further, the scientific implications of the physical aspects of light as they pertain to the effect of texture on color phenomena should be

more thoroughly investigated. Moreover greater variations in pile texture, especially in pile density, might result in more definitive answers. If subjective color analysis is used, a larger group of judges should make repeated color matches at different times, so that the possibility of experimental error can be reduced.

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