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COLLEGE OF LITERATURE, SCIENCE, AND THE ARTS
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STUDIES OF COLOR PREFERENCE

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Final Report on the research project on
"Color Preference and Subjective Color Structure"

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FOREWORD AND ACKNOWLEDGMENTS

The research reported here was partially supported by a grant from the Paint Research Institute to the first author. The Munsell Color Company, the Macbeth Daylighting Corporation, and others have also supported the research in a variety of ways.

Percival Tomlinson is now at the New York Psychiatric Research Institute, Columbia University. Joseph Zinnes is presently at Indiana University, Bloomington, Indiana.

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This report grows out of the research program on "Color Preference and Subjective Color Structure" at The University of Michigan. An earlier paper (Hefner and Zinnes, 1959) discussed three theories of preferential choice and the principles of color measurement that lie behind the research program; the present paper reports in some detail a series of studies on color preference.

The doctoral thesis of Joseph Zinnes, "A Probabilistic Theory of Preferential Choice" (1959)[1], is also a direct outcome of the research program (although Zinnes had done much work in his doctoral program before he became a Paint Research Institute Fellow). In addition, the doctoral thesis of Percival Tomlinson, tentatively titled "A Game Theoretic Approach to the Resolution of Conflicting Preferences," is related to the present program and will utilize some of the research data. Other reports on this research program have been delivered at the Paint Research Institute "Congresses of Professors" (1958, 1959, 1960, 1961) and at the 1959 meetings of the Federation of Societies in Paint Technology (Hefner, 1959).

The purpose of this research program is to provide basic information on the theory and methodology of color preference. It is predicated on the assumption that fundamental progress in understanding color preference will not be made until the nature of the preference judgment is understood. In the terminology of Genetics, information like that contained in customer color preference surveys (Wingate, 1958) and past sales records of colors (Cook, 1958) constitutes the phenotypic data, which will always seem capricious and unpredictable to us unless and until we understand the genotypic variables that underlie and account for the phenotypic preferences.

Therefore, the present study deals with the processes by which color preference judgments are made, and not directly with preferences of consumers. Such a study indeed seeks practical results for the paint industry--but practical results in the rather distant future, not in the markets of 1963. One prominent color expert, in reviewing the proposals for the present study, commented that while it was an excellent and interesting piece of research it looked more like a 20 year program than a three year program. We personally would not be quite that pessimistic, but a reading of the present paper will indicate that many problems remain after three years. Perhaps a more functional view of the timetable of applications of this research should take the following into account:

[1]The first doctoral thesis completed by a Paint Research Institute Fellow,

1. A full understanding of preferences (in the sense that we now understand color-mixture functions, for example, which we do not fully understand for all levels of adaptation etc.) may not come for a number of years, but partial developments and applications can and will be made along the way. A possible example of this application of our partial understanding might be Hefner's suggestion, made in his address to the Federation (Hefner, 1959) that another color-order system representing a metric of color preference be developed. This would make possible the evaluation of color fading in terms of changes in "preferability" rather than in terms of equally perceptible units (N.B.S. units, Godlove, 1951) or in terms of physical units. Then perhaps we could make a quantitative evaluation of such "common sense" notions as the housewife who is concerned that her yellow kitchen not fade to a greenish color, even though she is willing to accept quite perceptible shifts of color in other directions. This need for quantification of preferability may also be what Vesce had in mind when he said, in his detailed study of fading of organic pigments: "Although the overall change on exposure is being reported as a quantitative measured value, it must be emphasized that there is still no substitute for close visual inspection and interpretation by a trained color observer." (Vesce, 1959)

2. The paint industry, by its three-year support of this program has significantly advanced research on preferences, and perhaps more importantly from the industry's point of view—has insured that color may be a significant subject area in present and future research on preferences, along with more traditional topics of economics and psychology. Basic studies of preference will continue in these areas, whether or not they are financed by the Paint Research Institute, but the present project has helped both the pure researchers and the applied workers in the paint industry to recognize the potential application of this basic work to color preferences.

3. As a result of this support, the researchers have participated in scientific and professional meetings and committees which further the objectives of the Paint Research Institute. For example, Professor Hefner is a member of the Optical Society of America Committee on Uniform Color Scales and the Inter-Society Color Council Problem Committee 23 on Historical Color Usage. He has also given a paper on "The Multidimensional Scaling of Color" to the American Psychological Association and a paper on "Color-Order Systems and Color Preference" to the Federation of Societies for Paint Technology. Presumably such activities continue far beyond the financial support of the Paint Research Institute.

Since the present research is the only psychology project financed by the Paint Research Institute (in the midst of many in the area of chemistry) it might help place the present report in perspective to review the considerations that led up to the present research. The paint industry, in recent years, has been plagued by an "explosion" of consumer interest in color. In place of the relatively few "standard" colors of the past, manufacturers were faced with producing an ever-increasing number of colors to satisfy demands. Furthermore, the color choices made seemed fickle, and past sales were an untrustworthy guide to the future. At the same time, existing color-order systems were in a confused state, and they did not seem to provide the hoped-for guide to color marketing decisions. Therefore, when the Paint Research Institute was founded "Color preference and subjective color structure" was on the initial lists of possible research projects.

In the meantime, there were two developments in the Department of Psychology at the University of Michigan related to these interests. Under the direction of Professor H. Richard Blackwell,[1] the Vision Research Laboratories were pursuing several research projects on color vision and color perception. Professor Clyde Coombs was developing a general mathematical model that related preference and choice behavior to the subjective scaling of the stimuli. Dr. Hefner and Dr. Zinnes, both coming to Psychology from Physics, were working in both of these areas, and Dr. Hefner had recently completed his doctoral thesis on the development of a multidimensional scaling model applied to the Munsell Color Space (Hefner, 1958).

Therefore the Paint Research Institute approached the University of Michigan and granted research funds to extend these developments in areas of particular interest to the paint industry. There has perhaps been some misunderstanding and some false expectation that the present program was designed to give the "latest word" on the color preferences of consumers, or that paint manufacturers would be told how to solve their inventory problems by reducing color lines, etc. Of course, no such practical results are viewed as the end product of <u>any</u> Paint Research Institute project, but it always seems easier to understand the justification for "basic" research in one's own area of competence than in an alien field. In fact the Paint Research Institute was established by the Federation and financially aided by the National Paint, Varnish and Lacquer Association and the Canadian Paint, Varnish and Lacquer Association in order to encourage and support <u>basic</u> scientific research of potential interest to the paint industry. The interest in basic research and the cooperative nature of the effort require that the Paint Research Institute not support research of direct and immediate commercial interest. To do so would be to compete with and duplicate the efforts of the companies that directly or indirectly support the Paint Research Institute.

Also, the technical nature of the industry requires that most of the research supported be on technical subjects (in chemistry, physics, engineering). However, protective coatings involve not only complex technologies but also sales to consumers. This means that the ultimate evaluation of the product is a subjective one--the decision to purchase or not by a buyer, the satisfaction

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[1] Now director of the Institute for Research in Vision, Ohio State University.

or dissatisfaction of an owner, etc. One definition of the science of psychology is that it is the objective study of subjective phenomena—hence the psychology of color is the application of scientific methodology to the subjective reactions of people to colors. An excellent example of an explicit application of research in psychology is in the area of the specification of small color differences. In the determination of color differences due to fading (Vesce, 1959) it would be possible to express the differences in a variety of ways, physically and chemically, for example. Because it is widely recognized that what is wanted, in many cases, is the change in subjective appearance, these differences are often reported in color-order systems having visually equi-spaced color scales (Nickerson, 1948) and in N.B.S. units (Godlove, 1951) which are designed to quantify the difference in equal subjective units. This application did not result from applied research on color fading, but from more than 20 years of basic research of color measurement, carried out at the National Bureau of Standards, the Department of Agriculture, and in University and Industrial research laboratories. The most recent publication on the topic of color difference (Little, 1963) compared eleven suggested methods of specifying color difference by a single number and concluded that the choice of a method requires comparison of suggested methods with visual evaluations specific to the application being considered. Perhaps our knowledge of color aesthetics is not so far behind our knowledge of color differences!

Since the ultimate evaluation of the products of the industry is largely subjective, then it follows that the industry should also engage in basic research regarding these subjective reactions. Color is obviously one of the subjective attributes that needs to be studied, but there are probably many others. For example, consumer satisfaction with aging automobile surfaces may be more closely related to corrosion factors than to color and color change. The apparent ease of cleaning (another subjective factor) of enamel appliance surfaces might be another good example, and one involving many parameters—surface smoothness, design of panels, color and other visual characteristics (as in spatter finishes inside dishwashers), etc. Therefore, it is hoped that the Paint Research Institute will continue to go beyond a narrow technical conception of its role and carry out more studies relevant to the evaluation of its products.

The following section of the report is comment on previous work on color preference, with particular emphasis on the limitations of the early work and an indication of how the present study attempts to overcome some of these limitations—particularly limitations in the theoretical formulation of the problem, but also including limitations of experimental control. The next section reports a series of small experimental studies designed to test the theoretical propositions put forth regarding color preference, and the last section contains suggestions for further studies and theoretical modifications that will contribute to our fundamental understanding of subjective reactions to the products of the paint industry.

PREVIOUS STUDIES OF COLOR PREFERENCE AND CHOICE

A number of earlier papers (Hefner, 1959; Hefner and Zinnes, 1959; Zinnes, 1959; Norman and Scott, 1952; Eyesenck, 1941; Chandler, 1934; Pressey, 1921) have reviewed the extensive literature on color preferences. Without repeating in detail what is contained in these reviews, we will here discuss the previous work particularly as it has a bearing on the present study. Readers interested in the details of earlier studies may refer to the papers mentioned above. Norman and Scott (1952) present the most complete bibliography. An interesting review of this work from the point of view of the interior designer may be found in the paper by Ball (1965).

It has been said that the "common sense" of today is the science of 50 years ago. If that is true, then our common sense about color preference must be almost totally worthless. Even though the classification of colors as being located throughout a color solid dates back to at least 1810 (Boring, 1942), it was not until the detailed experiments of Guilford and his students in the 1930's (Guilford, 1934, 1939, 1940; Guilford and Smith, 1959) and Eyesenck and his students in the 1940's and 1950's (Eyesenck 1941, Granger, 1955) that any systematic exploration of the color solid was made in studies of color preference. Worse than that—earlier studies were not only unsystematic in their selection of colors, but also typically identified the colors used by a few gross color names. Thus, in view of the undoubted effect on color preference of a number of other factors besides the gross color-name group (Guilford and Smith, 1959) these early results are essentially uninterpretable.

Three other kinds of difficulties beset studies of color preference, including even the more sophisticated Eyesenck and Guilford studies mentioned above. These are:

1. The problem of experimental control, including especially the illumination of the colored samples and the instructions given the subjects. This problem, like the one of adequate sampling and specification of colors throughout color space, is certainly easily solvable, given present technology. However, to say that they are easily solvable is not the same thing as saying that recent, current or planned studies in _fact_ are solving these problems in a satisfactory manner.

2. The problem of appropriate and sufficient statistical analysis of the data. Since the "appropriate" statistical analysis of the data depends on what theory you want to test, this point is closely related to the one below. Recent technical developments in the fields of statistics, factor analysis, game theory, mathematical models of multidimensional analysis, etc., make it quite possible to recover meaningful relations in the data. Again,

however, availability doesn't guarantee use, and these methods are likely to be less easily available to individuals in the color field than the latest technical developments in the specification of color samples and lighting.

3. A more complex problem concerns inadequate theories of color preference, and particularly failure to account for individual differences in preference. There has been for many years, and still is, an unfortunate tendency to equate a "scientific" or systematic study of color preference with the patently ridiculous notion that there are no individual differences in color preference. This equation is often not made explicit, but it is nonetheless implicit in such methods as averaging of preference judgments over a number of people—as in Guilford's computation of "affective value." Since the techniques exemplified by Guilford's work are apparently very widespread, and since he has been kind enough to explicitly publish his technique and the rationale for its use, let us analyze in detail what is wrong with what he says.

> "The practical value of these isohedon charts [which describe the affective value, the average of preference rankings over a large number of people, as a function of hue, value, and chroma.] should be very apparent. Assuming that we can obtain in this manner the intrinsic affective values of colors for the masses of buying customers, it should be relatively simple to set up a series of charts, one for each of the twenty Munsell hues, let us say. Once any particular color sample is evaluated on the Munsell system, a glance at the appropriate chart would tell us how well the average person likes it. Predictions for single individuals cannot be so accurately made as for groups, of course, but in these days commodities are made to please the masses." (Guilford, 1939, page 21)

First of all, he is wrong in saying that the chart "would tell how well the average person likes it." What the chart does tell is the average of how well a number of people like a color. An affective value of 5 (middle of the scale) might occur because everybody made a 5 rating, or because 40% made a 5 rating and the other 60% are symmetrically distributed around it, or because 50% made a rating of zero and 50% a rating of 10.

Secondly, the statement that "commodities are made to please the masses" with the implication that a failure of prediction in a few individual cases is not serious, compounds the error regarding what is averaged. The actual <u>choice</u> of a commodity for purchase is a much more complex subject than preference. I think that two examples can illustrate the point.

If we assume that choice is an individual matter, and not a group decision, then the problem can be handled as follows: We may regard choice as being determined by the relative degree of preference of an individual for a number of colors. (Note: Choice is always relative; preference may be relative or absolute. In Guilford's study, preferences were expressed on an absolute scale.) A color that has an average of 5 because of ratings of 4, 5, and 6 will probably never be first in degree of preference for anybody in any large choice set, and therefore might never be chosen. Another color with an average of 5 because of ratings of zero and 10 might be the first choice of nearly half of the individuals, thus breaking all sales records for paint colors! These are admittedly extreme examples—but they indicate the degree to which "Predictions for single individuals cannot be so accurately made as for groups." Thurstone (1945) has described a general theory of choice among a set of alternatives depending on the mean and standard deviation of preference rankings.

If we assume that choice is a group decision, then even more complexities emerge. Group decisions often take the form of a compromise between a number of competing preference rankings, and it is very important to recognize that the mechanism of the compromise may bear no relationship to the averaging process that Guilford performs to get the affective value for his "standard observer." For example, Guilford describes the isohedon lines for men for Munsell yellows varying in value and chroma as roughly concentric circles centered around 5Y416, smaller circles representing colors of lower affective value. See Figure 1. This indicates that the standard observer is rather

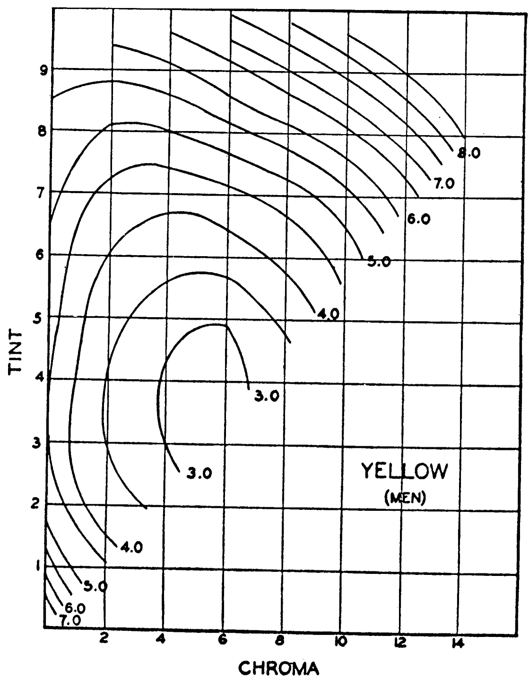

Figure 1. Isohedon lines for Munsell 5Y (Yellow) for men. (Guilford, 1949, p. 207).

definite about the one color he dislikes most, but relatively unconcerned about his first choice. His criterion of preference is merely that a yellow be maximally dissimilar to the most disliked (or non-ideal) color. All colors equally dissimilar to the non-ideal color are equally acceptable. While there are situations in which such behavior may be expected, it does not seem to be a characteristic response of most persons. One is led to suspect that the behavior of the "standard" person is the result of certain artifacts introduced by the analysis technique, and is not typical behavior. Consider a one-dimensional case for simplicity. Let us suppose that there are two types of persons, those preferring bright, highly saturated colors and those preferring shaded, unsaturated colors. If each person were indifferent toward colors at the opposite extreme of his preferred colors, as illustrated in Figure 2, the average

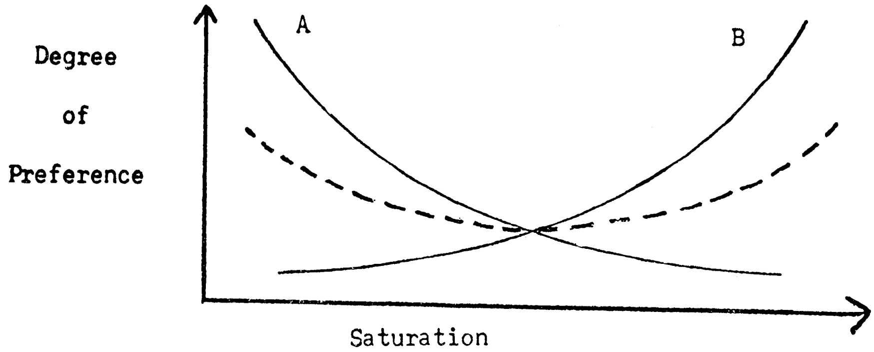

Figure 2. An example of two types of observers. Observer A prefers low-saturated colors while observer B prefers high-saturated colors. The average, or "standard", observer, represented by the dotted line (the average of the other lines), prefers both and dislikes the middle.

of these two types of persons would exhibit the same strange behavior as Guilford's standard observer. However, if this is in fact the nature of the judgments underlying Figure 1, then a particular color lying on the circle of maximum radius would be preferred by one type of observer only, not by the majority. Also, individuals on the opposite side would regard that color as their most disliked. In fact, if compromise is reached by a group decision process that chooses the least disliked (rather than the most liked) as most simple voting schemes do (Coombs, 1963) then the best compromise color for all subjects might very well be the non-ideal color, the color with the lowest affective value. Thus we see that techniques that explicitly or implicity involve averaging indiscriminately over a large group of people may bear almost no relation to the actual color choices of consumers.

Therefore, the present studies were designed with these criticisms of past work directly in mind. The principle effort has been directed toward a more adequate theory of color preference—one which would take individual differences into account, but still in such a way as to provide general laws and principles which will allow the extension of the results beyond the specific details of a single study.

THE PRESENT RESEARCH

The approach taken in the present research is to explore the application of Coombs theory of preference (Coombs, 1963; Hefner and Zinnes, 1959) to color preference. Since the theory is clearly wrong when applied to colors, this may require some explanation. What we are saying is that the theory grossly oversimplifies color preferences and presents an idealized conception of how preference judgments are made. However, the major virtues of the theory make it worth exploring and worth modifying to bring it closer to reality. The two particular advantages we have in mind are:

1. The Coombs theory specifically accounts for individual differences in a logical and general context.

2. The Coombs theory relates color preference to perceived color space, and therefore makes it possible to integrate the two topics and to refer color preference judgments to a metric color space.

The Coombs theory will be described only briefly here. See Coombs (1963) or Hefner and Zinnes (1959) for a more complete discussion. A metric space is postulated in which the subjective impressions of the colors under consideration can be located. This space is probably something like the 3-dimensional psychological space represented in the Munsell system of color, but it is not critical that the Munsell system be correct in detail, and it is conceivable that the metric space that accounts for color preference is substantially different.

The individual's preferential choice behavior is assumed to be related to a point in the space which the individual prefers most of all. Since color is continuously variable, this means that there is one particular color which the individual would prefer to all others, whether real or imagined—an ideal point in the space. All other colors are ranked in preference in terms of their distance from this ideal point: the farther away they are the less preferred they are. The ideal color need not be in the set of colors within which preference is being expressed. In that case, the first preference will be given to the color nearest the ideal, the second preference to the next closest color, etc. The theory states that the basis of ranking is always distance from the ideal in subjective color space. Thus the theory is wrong, in the strictest sense, if there are two or more regions of high preference in color space, not adjacent to each other. If blue is your first choice for an automobile, and red is your second choice, and if there are a number of alternatives which you perceive as being between blue and red, then you have expressed a preference which violates the theory. Of course, in a choice from a very small number of colors scattered around the space, it is perfectly congruent with the theory to have numerically adjacent preferences that are widely separated in the subjective color space.

Individual differences in color preference, according to the theory, can arise in two different ways. First, there may be differences in the subjective metric space to which people refer their preference judgments. For the present study, this possibility was not explored, except to eliminate people who test as "color blind" on the Farnsworth-Munsell 100 Hue Test of Anomalous Color Vision (Farnsworth, 1957). Second, people will certainly differ with respect to their ideal color. The most desirable situation in terms of the description and prediction of color preference would be to have all people with normal color vision alike in their subjective color space, with all of the individual differences in color preferences systematically accounted for in terms of the differing locations of individuals' ideal colors.

What we have done in the present series of studies is to test the Coombs theory in two small experiments; to modify the theory in the direction of a probabilistic conception of preferential choice and test this modified version against two alternative theories; and to explore other modifications and independent developments that might lead to further experiments. This is the organization followed below.

EXPERIMENTAL METHOD

Surround: All experiments were conducted in a windowless room lighted only by three Macbeth Examolite Fixtures, which provide light approximating north skylight (7300° K). The colors were exposed through holes in the 4' x 4' flat screen mounted on a wooden frame sloping away from the subject at an angle of 30°; see Figure 3, but note that some "artistic license" has been used in the preparation of this photograph, particularly with the position of the observer. The total illuminance on the board was approximately 69 ft. candles. The light grey surface of the apparatus had a reflectance of .48 (Munsell value = 7.33). Observers were seated in a position to avoid reflected glare on the surface of the color, 6 to 10 feet away from the stimuli.

Observers: All observers were University of Michigan students, either participating as part of a course requirement for elementary psychology or as paid subjects recruited from the Student Employment Office. Data are reported here only for observers with normal color vision, as measured by the F-M 100 Hue Test. In addition, a number of the observers were tested on the ISCC Color Aptitude Test, published by the Federation.

Stimuli: All colored papers used were cut from sheets of ISCC-NBS Centroid Colors (glossy, manufactured by Davidson and Hemminginger to NBS specifications to represent the geometrical centers of the color name-blocks defined by the ISCC-NBS Dictionary of Color Names (Kelly and Judd, 1955)) or from sheets of Munsell Standard Papers (matte finish, manufactured by the Munsell Color Co.), and in both cases are specified both by Munsell Renotation and by ICI chromaticity coordinates. The papers were pasted on cardboard to facilitate handling. The openings on the display board are 3 x 5 inches; the papers were cut slightly larger so that there was sufficient margin to permit easy handling on the non-viewed portion of the stimuli. To minimize the possibility of identifying a stimulus due to irrelevant distinguishing marks which might appear on the stimulus cards, each stimulus color was represented by at least two cards.

EXPERIMENT 1

Three sets of five stimuli each were chosen, each set varying in only one of the three dimensions of hue, value, and chroma. The stimuli are described in Table 1. Within each of the three sets each stimulus was paired with each of the other four and presented to each of 30 observers for a pair comparison judgment of preference as a color to be painted on all walls of their living-room or dormitory room. There were no replications; thus there were ten pairs from each set presented to each of 30 observers. The pairs were presented

(Either of the photographs supplied to Dr. Long for the November, 1962 meeting of the Paint Research Institute will be suitable. The photographs have not been returned to me and are presumably in Dr. Long's file. For identification purposes, they are photographs of a young woman in a blue suit standing in front of a grey display board. Two or four colored papers are displayed on the board.)

Figure 3. Photograph of the experimental room.

Table 1

Stimuli used in Experiment 1. The Munsell notation (Munsell, 1954) is given: Hue Value/Chroma

Hue Series	Value Series	Chroma Series
5R 4/4	5R 3/4	5R 4/1
5Y 4/4	5R 4/4	5R 4/2
5G 4/4	5R 5/4	5R 4/4
5BG 4/4	5R 6/4	5R 4/6
5P 4/4	5R 8/4	5R 4/8

randomly within sets, and sets were presented randomly over observers.

For five stimuli there are 5! = 120 rank-orders of preference possible. If there is no systematic basis for preferences (i.e., if choices are made at random) then all 120 possible orderings must be equally likely. If, on the other hand, these stimuli lie on a single dimension of the subjective space, and if the order on that dimension is the same as the order specified by the Munsell space, and if the Coombs theory is correct, then there are a number of restrictions on the possible preference orderings. For example, only the two end stimuli on the dimension can ever be in last place in the preference ordering, since one of these two must be furthest away from any ideal point, no matter where it is located. Similarly, the first two choices in a rank order must be adjacent. The total effect of these restrictions is to reduce the rank orders which satisfy the theory to 16. Therefore, from the 120 possible there is only one chance in 7-1/2 that an order of preference would accidentally turn out to be one of the 16 satisfying the theory. The actual results are given in Table 2. The first column gives the number of consistent

Table 2

Results of Experiment 1

Stimulus series	Number of consistent rank orders	Number of RO satisfying the Coombs Theory	Number of RO satisfied with one reversal
Hue	20/30	1/20*	3/20
Value	22/30	11/22	15/22
Chroma	23/30	4/23	17/23

* Even if the much more liberal requirements for satisfying the theory in a circular array in two dimensions are used, only 8/20 fit.

rank orders. An inconsistent rank order would include sets of pairs like: prefer A to B, prefer B to C, prefer C to A.

The results in column 2 clearly indicate that many more of the orders on the brightness dimension satisfy the theory than on the hue dimension. Since the model represented by the theory is deterministic and permits no error, it does not allow for a direct determination of the "degree of closeness" of those that do not.fit. Therefore, an approximate indication of this was gained by calculating how many of the scales could satisfy the theory if just one pair could be reversed. These results are given in Column 3 of Table 2.

From these results it is clear that the brightness dimension significantly follows the Coombs theory, that the hue dimension does not, and that the saturation dimension probably does follow the theory.

EXPERIMENT 2

Five sets of five stimuli each were chosen to check further on the results of the previous experiment. Each set of five varied only in hue, with value and chroma held constant at different levels in the five cases. Also, some of these series varied over a limited hue range (e.g., series III and IV), while others spanned the entire hue circle (Series I). The 22 observers used in this experiment were divided into five groups, and each group received the ten pair-comparisons for four of the sets of stimuli without replication, but for the fifth set each of the ten comparisons was replicated six times.

Table 3 identifies the stimuli used by Munsell renotation and also by the block number of the ISCC-NBS method of designating centroid colors. Table 4 gives the results of Experiment 2.

It is apparent that Series I, which covers the entire hue circle (as did the hue series in Experiment 1) does not fit the model. However, when a more limited hue arc is involved, there seems to be a fairly large proportion of responses accounted for by the model. When one "reversal" is permitted, to see how many rank orders "come close" to fitting the model, there is not much differentiation among the series. However, none of the hue series come as close to fitting as the value and chroma series of Experiment 1.

Therefore, the conclusion still seems to be that the Coombs model accounts for the brightness (value) choices, and to successively lesser degrees, accounts for the chroma and hue choices. In the hue series, the model clearly works better with short hue series than with the entire hue circle.

Table 3

Stimuli used in Experiment 2. The stimuli are ISCC-NBS Centroid colors, identified by block number (Kelly and Judd, 1955) and Munsell notation

Stimulus	Block	Hue	Value	Chroma
Series I				
A	22	7.6R	5.5	1.2
B	63	6.8YR	5.5	1.2
C	155	7.0G	5.5	0.9
D	191B	9.4B	5.5	0.9
E	233	9.6P	5.5	0.9
Series II				
F	120	4.4GY	6.0	5.2
G	136	0.3G	5.5	5.0
H	145	6.4G	4.5	4.8
I	164	4.7BG	4.5	5.1
J	173	4.6B	4.5	5.2
Series III				
K	107	7.7Y	3.74	6.74
L	125B	5.4GY	3.56	5.24
M	137	0.3G	3.5	5.1
N	146	6.0G	2.7	5.3
O	165	4.9BG	2.76	5.1
Series IV				
P	2	2.4R	7.06	8.67
Q	26	8.5R	7.05	9.36
R	53	4.5YR	6.5	8.3
S	71	8.7YR	7.2	8.3
T	84	3.0Y	7.13	9.73
Series V				
U	4	3.2R	8.46	4.27
V	73	8.8YR	8.52	4.4
W	104	9.1Y	8.89	4.31
X	143	5.0G	8.0	4.0
Y	162	5.6BG	8.1	4.6

Table 4

Results of Experiment 2

Stimulus Series	Number of consistent rank orders	Number of RO satisfying the Coombs theory	Number of RO satisfied with one reversal
I	13/22	1/13	7/13
II	13/22	4/13	9/13
III	16/22	9/16	12/16
IV	15/22	4/15	8/15
V	13/22	6/13	8/13

EXPERIMENT 3

Since it is clear that the Coombs theory does not fit the facts of color preference in detail, and yet there is some indication that a theory of this kind does systematically account for individual differences within a general framework, it was felt that modification and extension of the Coombs theory was justified. Experiment 3 is based upon a development of a probabilistic extension of the Coombs theory for the one-dimensional case, a detailed development of the computational techniques required for the approximate solution of the integral equations involved in the model, and a consideration of the theoretical and computational questions involved in testing the goodness-of-fit of the theory to the data and comparing it with competing theories. This experiment is described only briefly here, but in great detail in Zinnes' 200 page doctoral thesis.[1] The entire thesis is outlined here, and then the major results are summarized.

The purpose of this study was to extend the Coombs theory of preferential choice so that it could be used when there is inconsistency or error in the data and so that it can provide an interval scale of measurement, instead of merely an ordered-metric. The probabilistic extension of the Coombs theory developed here is called the Q theory. In the first part of the study the equations for the Q theory were developed and an approximate method of solution was indicated. This approximate method estimates the parameters of the theory from the empirical preference probabilities based upon judgments satisfying certain conditions. In general, not all of the judgments in a given set of data would satisfy these conditions, so that only part of the data would be

[1]The thesis is available on microfilm or in positive prints from University Microfilms, Ann Arbor, Michigan (Zinnes, 1959).

used in arriving at a solution. To test the adequacy of the theory in predicting the preference probabilities based on all judgments present in a given set of data, numerical methods for evaluating the integrals appearing in the equations of the theory were described.

The implications of the Q theory for the transitivity of preference judgments were also discussed. It was shown that this theory does not necessarily imply strong stochastic transitivity (SST), which is in direct contrast with the Thurstone (1927) and Bradley (1953)-Luce (1959) theories, both of which account for total preferability without treating individual differences and both of which imply SST.

In the experimental portion of this study observers were required to indicate their preferences for Munsell colored chips, presented in pairs. The ten stimuli used formed a single linear dimension in Munsell space, from 5R 4/8.3 to 5BG 4/6.0, including a grey, N 4. The data were analyzed by all three theories.

The results and theoretical considerations indicated that for the stimuli employed in the experiment the Bradley-Luce and Thurstone theories were essentially equivalent—it is not possible to differentiate between them with any reasonable amount of data. When the parameters of the Bradley-Luce and Thurstone theories were calculated from the entire set of data, they do a better job of describing the data considering both blue-green and red hues, and they are equal to the Q theory when only the red hues are considered. However, in all cases when the parameters of the Bradley-Luce and the Thurstone theories were evaluated from only part of the data (in more strict comparability with the Q theory) the Q theory better accounted for the data. There was some evidence that the failure of the Q theory when both hues were involved was due to a partial folding of the "one-dimensional" Munsell scale.

The results also had implications for the Munsell scale. When a single hue was involved the Munsell scale represented, to a first approximation, a scale valid for both discriminative and preferential judgments. This, however, was not the case when more than one hue was involved.

One of the major factors limiting the degree to which the Q theory can reproduce the data is the relatively small amount of data which can be incorporated into the solution. In particular, it was shown that the reproducibility of the Q theory was directly related to the amount of data used in the analysis.

Table 5 gives the Munsell Renotation specification of the colored papers used in this experiment. The 64 observers in this portion of the study were all female. The viewing conditions previously described were used with some modification. In order to insure the necessary inconsistency required for the Q theory, the colors were exposed for a brief time interval and with no

Table 5

Stimuli used in Experiment 3. The stimuli are Munsell papers, identified by Munsell renotation designations of Hue Value/Chroma (Newhall, Nickerson, and Judd, 1943) and by CIE tristimulus coordinates

Munsell renotations	Abbreviated designation	CIE tristimulus coordinates x	y	z
5R 4/8.3	R8	.1591	.1060	.0660
5R 4/6.2	R6	.1752	.1280	.0969
5R 4/4.2	R4	.1420	.1139	.0989
5R 4/2.0	R2	.1328	.1217	.1250
5R 4/1.0	R1	.1268	.1218	.1364
N 4/	N	.1201	.1232	.1437
5BG 4/1.0	G1	.1099	.1180	.1430
5BG 4/2.0	G2	.1122	.1293	.1633
5BG 4/4.4	G4	.0979	.1263	.1731
5BG 4/6.0	G6	.0775	.1140	.1645

overlap—that is, it was not possible to see both members of the pair of colors at the same time. Each color was exposed in turn for approximately 3/10 second by this method. Each pair was replicated 3 times. In addition, certain pairs were replicated slowly, to be sure that the rapid presentation did not introduce an undesired artifact.

One of the more interesting results of the Q theory analysis is the fact of the merging of the Red and Blue-green stimuli to form a single scale. Figure 4 compares one Q analysis with the Munsell spacing of the same stimuli.

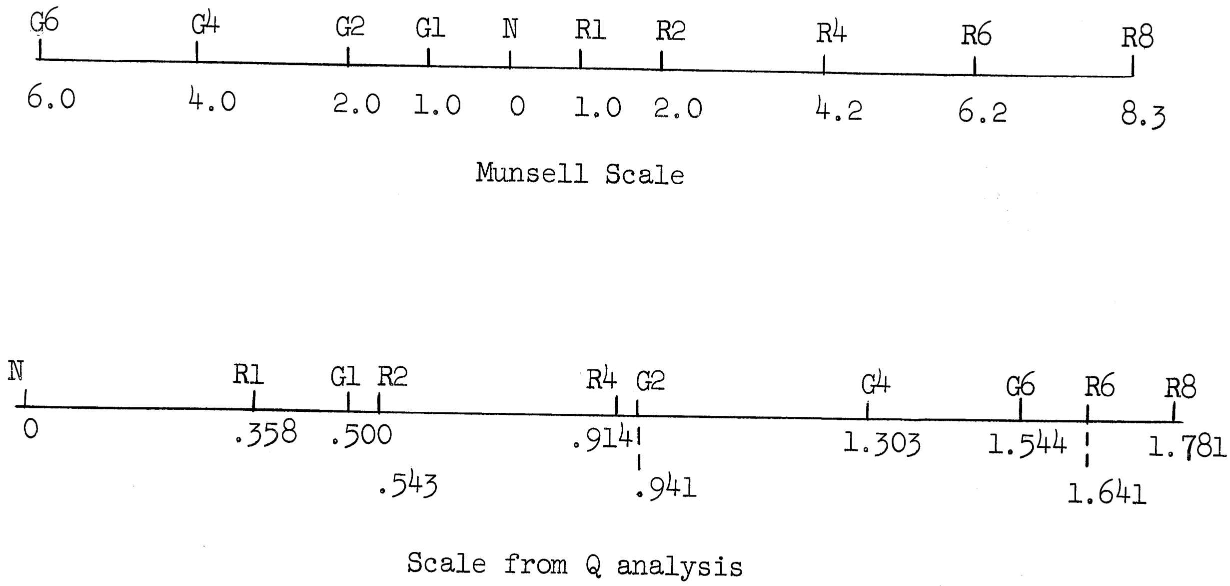

Figure 4. Munsell spacing and spacing derived from the Q analysis. (Zinnes, 1959, p. 169).

Notice that the Reds and Blue-greens separately are in correct order, going away from the neutral grey with increasing saturation, but that the Reds and Blue-greens are completely interwined..

When the Red stimuli are analyzed separately one of the most striking findings is the distortion of the Munsell spacing. Figure 5 shows one such

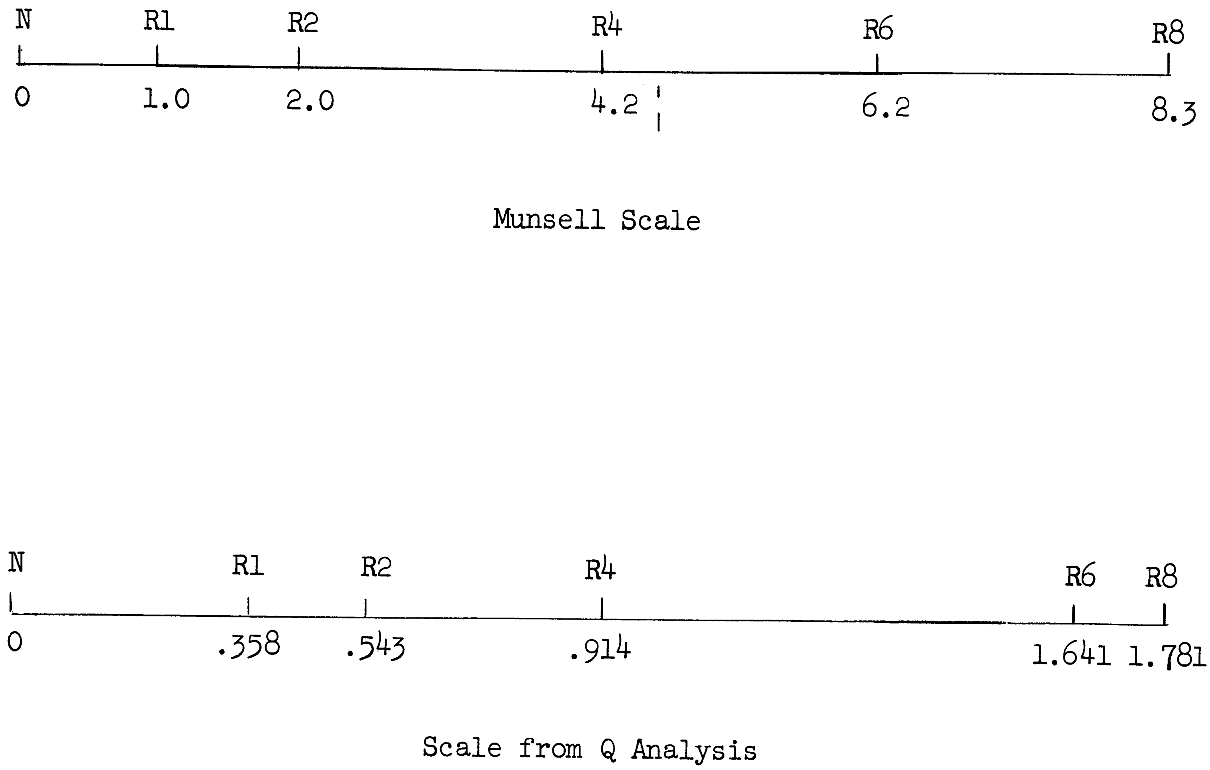

Figure 5. Munsell spacing and spacing derived from the Q analysis, Red stimuli only. (Zinnes, 1959, p. 169).

result . The largest change is that a Red with saturation 1 is seen as very different from N4, while a Red 6 and Red 8 are seen fairly close together—both described by our observers as "bright red."

In general it would appear that the usefulness of the one-dimensional probabilistic Q theory as it is applied to the present study is greatest in situations for which 1). the ideal stimuli of the subjects are known, 2) the order of the stimuli on the underlying scale is known, and 3) a minimal number of preferential judgments is desired to quantify the underlying scale. It is clear that under these special conditions the Q theory parameters could be determined from a relatively small number of preferential choices. The predictability of the Q scale based on the small number of judgments should be considerably better than the Bradley-Luce or the Thurstone theories (which ignore individual differences) for the same number of judgments.

DISCUSSION

Clearly the probabilistic extension of the Coombs theory for the one-dimensional case does not solve all of the problems! First, it is already clear that multidimensional preference spaces are required for some regions that are one-dimensional in the Munsell space. Second, it is clear that the notion of one ideal point does not describe preferences for colors differing only in hue. And third, even if the one-dimensional theory did fit the situation for hue, value and chroma taken separately, there would still be severe problems in predicting the amalgamation of these orderly preferences over a number of dimensions into a single rule for the choice in the entire domain.

It is this latter problem that Tomlinson has chosen for his thesis topic, and he is now exploring the application of n-person game-theory to this situation. Each dimension takes the role of a "player" in the game-theory analysis, and the preference ranking on that dimension forms the ordinal utilities of that player for the game outcomes. The resolution of the conflicting utilities is expressed in a choice, described as an intersection of the dimensions. Present work consists of theoretical determination of whether a solution exists for a given set of utilities, and empirical comparison of predicted outcomes with actual data on color preference.

Another idea for possible extension of the work to multidimensional situations is the observation by Coombs and Kao (1960) that a Q-technique factor analysis (based on the intercorrelation of the rankings of color preference by all pairs of individuals) would recover the underlying multidimensional space in which the colors are perceived, as well as an additional dimension corresponding to a "social preference function" over the colors for the entire group. The location of the individuals ideal points would not be recovered directly by the factor analysis, but could presumably be reconstructed easily from the known perceptual space and the observed rankings. The principle remaining problem is that of specifying the rotation of the factor solution to differentiate the "social preference function" from the underlying perceptual dimensions of the space. The major drawback of this technique is that it involves the same unrealistic assumption that there is a single ideal point for a person, and that all colors are preferred in terms of their rank order of distance from that point.

Perhaps what will eventually be required is something like what Hefner suggested in his address to the Federation in Atlantic City (Hefner, 1959). In view of the proliferation of color-order systems he suggested that we try to achieve agreement on a single method for specifying colors—perhaps the CIE chromaticity coordinates, with variables like preference being described as a metricized 4th dimension attached to the 3-dimensional CIE space. In other words, we could describe a profile or contour of preference (perhaps for homogeneous subgroups of people) over the CIE coordinates.

A number of other new techniques for preference scaling have appeared recently. Two that deserve special mention are the Tucker Vector Preference Model (1961) and the Lingoes Multiple-Scalogram Technique (1960). Because both of these involve a dichotomizing of the space between preferred and not-preferred stimuli, they may turn out to construct rather strange models of preference space.

An important question in a large number of these studies concerns the accuracy of our present representations of color space. This area is developing rapidly, and methods are likely to be quite different in just a few years. The paper by Guttman (1967) discusses the theoretical work on models of nonmetric multidimensional scaling.

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If we had the temerity to make specific recommendations for a program of color preference research for the future, we would probably include at least these elements:

Further research on small, narrowly defined regions of color space to get more basic information on the nature of the judgments;

A large-scale study, perhaps using the Q-technique factor analysis mentioned above, to determine the preferences of a large sample of observers for a large and representative group of colors, perhaps the ISCC-NBS centroid colors;

Detailed laboratory studies to determine the influence of the instructions and the choice set and the content of the choice (i.e., paint, fabrics, etc.) on judgments; and

Finally, when the above problems are solved, a series of nationwide interviews of consumers on color preference, closely coordinated with good information on paint sales, in order to make the ultimate linkage of prime importance to the paint industry.

REFERENCES

Ball, Victoria K. The aesthetics of color: a review of fifty years of experimentation. The Journal of Aesthetics and Art Criticism, 23, 1965, pp. 441-452.

Boring, E. G. Sens. & Perc. in Exp. Psych. N. Y.: App. Cent. 1942.

Bradley, R. A. Some statistical methods in taste testing and quality evaluation. Biometrics, 1953, 9, 22-35.

Chandler, A. R. Beauty and human nature. New York: Appleton-Century-Crofts, 1934.

Coombs, C. H. A theory of Data. New York: Wiley, 1963.

Coombs, C. H. and R. C. Kao. On a connection between factor analysis and multidimensional unfolding, Psychometrika, 1960, 25, 219-31.

Eyesenck, H. J. A critical and experimental study of color preferences. Amer. J. Psychol. 1941, 54, 385-394.

Farnsworth, D. Manual: The Farnsworth Munsell 100 Hue Test. Baltimore: The Munsell Color Co., 1957.

Godlove, I. H. Improved color difference formula, J. Opt. Soc. Amer., 1951, 41, 760-772.

Granger, G. W. An experimental study of color preferences, J. Gen. Psychol. 1955, 52, 3-20.

Guilford, J. P. The affective value of color as a function of Hue, Tint, and Chroma, J. Exp. Psychol. 1934, 17, 342-370.

Guilford, J. P. A study in psychodynamics, Psychometrika, 1939, 4, 1-21.

Guilford, J. P. There is system in color preference, J. Opt. Soc. Amer., 1940, 30, 455-459.

Guilford, J. P. System in color preferences, Journal of the Society of Motion Picture Engineers, 1949, 52, 197-210.

Guilford, J. P. and P. C. Smith. A system of color preferences, Amer. J. Psychol., 1959, 72, 487-502.

Guttman, L. A general nonmetric technique for finding the smallest euclidean space for a configuration of points, Psychometrika, 1967, in press.

Hefner, R. A. Extensions of the Law of Comparative Judgment to discriminable and multidimensional stimuli. PhD dissertation, University of Michigan 1958.

Hefner, R. A. Color-order systems and color preference, Address to the Federation of Societies on Paint Technology, 1959, Atlantic City.

Hefner, R. A. and J. F. Zinnes, Color preference and subjective color structure, Official Digest of the Federation of Paint and Varnish Production Clubs, 1959, 31, 1030-48.

Kelly, K. L. and D. B. Judd, The ISCC-NBS method of designating colors and a dictionary of color names, Washington, National Bur. of Standards, 1955.

Lingoes, J. C. Multiple scalogram analysis, PhD dissertation, Michigan State University, 1960.

Little, Angela C. Evaluation of single-number expressions of color difference, J. Opt. Soc. Amer., 1963, 53, 293-296.

Luce, R. D. Individual Choice Behavior. New York: John Wiley, 1959.

Munsell, A. H. A color notation (10th Ed.) Baltimore: Munsell Color Co., 1954.

Newhall, S. M., Nickerson, Dorothy, and D. B. Judd, Final report of the O.S.A. subcommittee on the spacing of the Munsell colors. J. Opt. Soc. Amer., 1943, 33, 385-418.

Nickerson, Dorothy. Color Tolerance specification, J. Opt. Soc. Amer., 1944 34, 550-570.

Norman, R. D. and A. Scott, Color and affect: a review and semantic evaluation. J. Gen. Psychol. 1952, 46, 185-225.

Pressey, S. L. The influence of color upon mental and motor efficiency. Amer. J. Psycho. 1921, 32, 326-356.

Thurstone, L. L. A law of comparative judgment. Psychol. Rev. 1927, 34, 273- 286.

Thurstone, L. L. The prediction of choice. Psychometrika, 1945, 10, 237-253.

Tucker, L. R. Intra-individual and inter-individual multidimensionality in Psychological Scaling Ed. by H. Gulliksen and S. Messick, New York: Wiley, 1960.

Vesce, V. C. Exposure studies of organic pigments in paint systems, Official Digest, 1959, 31, No. 419.

Wingate, J. W. Customer preference clinics. New York Retailer, 1958, 11.

Zinnes, J. F. A probabilistic theory of preferential choice. PhD dissertation, University of Michigan, 1959.