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An application of the method of constant stimuli to the ratio scaling of color saturation.

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AN APPLICATION OF THE METHOD OF CONSTANT STIMULI TO THE RATIO SCALING OF COLOR SATURATION

by

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ABSTRACT

This study was an attempt to investigate the ratio properties of the Munsell chroma notation for color saturation.

The basic technique is that of the bisection of a saturation interval, using standard psychophysical procedures to determine indirectly the mid-point of the internal. The stimulus materials were Munsell chips of four hues, covering a chroma range of 0 to 14.

The results of the present experiment indicate that the Munsell chroma scale does not actually reflect perceived saturation ratios. The precision of the present technique of scaling, bisection of an interval using the method of constant stimuli, is comparable to previous studies and is within the limits of stimulus variability.

PREFACE

This study reports a further step in the investigation of color saturation and is based in part on previous research carried out by J. T. Sempowski at this University.

The author wishes to express his grateful appreciation to Dr. A. A. Smith who initially proposed the study and whose patient guidance was so helpful in its execution. He is also indebted to Rev. R. C. Fehr, whose suggestions were benificial in organizing and clarifying the text of the thesis. Finally, he expresses his thanks to Dorothy Fleming who diligently typed the many drafts and to the subjects who gave generously of their time.

TABLE OF CONTENTS

		Page
PREFACE		iii
LIST OF TABLES		v
LIST OF FIGURES		vi
Chapter		
I	INTRODUCTION	1
II	METHOD	13
	Observers	13
	The Basic Design	13
	Apparatus	14
	Procedure	17
III	RESULTS	19
IV	DISCUSSION OF RESULTS	31
V	SUMMARY	34
BIBLIOGRAPHY		36
VITA AUCTORIS		38

LIST OF TABLES

Table		Page
1	Munsell Notations of Anchor and Intermediate Color Stimuli . . .	16
2	Relative Frequency of Judgments Similar to Chromatic Anchor for Hue 5R 5/	21
3	Relative Frequency of Judgments Similar to Chromatic Anchor for Hue 5R 8/	22
4	Relative Frequency of Judgments Similar to Chromatic Anchor for Hue 2.5G 5/	23
5	Relative Frequency of Judgments Similar to Chromatic Anchor for Hue 5PB 5/	24
6	Mid-point Chromas and j.n.ds. for each O and each Saturation Chroma .	26
7	Mid-point Chromas and j.n.ds. for each O and each Saturation Chroma .	27
8	Mean Mid-point Chromas and j.n.ds. .	28

LIST OF FIGURES

Figure		Page
1	Organization of Color Perception Space	5
2	Observer's view of the apparatus on which the color chips were presented .	15
3	Sample plot of relative frequency of judgments "more like chromatic anchor" as a function of chroma of intermediate stimulus, with visually estimated probit line and estimated one-half point and j.n.d. Data for chromatic anchor 5R 5/14 with subject SG	25
4	Mean Mid-point chroma at the chromatic anchor in studies by Sempowski and Fleming	29

CHAPTER 1

INTRODUCTION

The present day scientist conceives of color in terms of the dual concepts of radiant energy and subjective sensation. The Optical Society of America, (1959, P. 221), defines color in the following way:

> Color consists of the characteristics of light other than spatial and temporal inhomogeneities, light being that aspect of radiant energy of which a human observer is aware through the usual sensations which arise from the stimulation of the retina of the eye.

Thus, color must include both concepts of radiation and sensation; it is not complete as only one of these.

The concept of radiant energy is most useful to the physicist in specifying the nature of color. As in all physical events, the perception of color can be considered in terms of the transfer of energy from a source to the eye of an observer. This transfer can be described by specifying (a) the rate of flow of radiant energy, the so-called radiant flux, and (b) the way in which the flux is distributed throughout the visable spectrum, over all wave lengths to which receptor cells in the eye are sensitive. From the physical point of view, then, color (of an object, or of a light source) can be completely and unequivocally specified by specifying the amount and distribution of the radiant flux passing through a given area in the direction of the observer.

Psychologically, (i.e., from the point of view of the observers), these concepts seem to have little to do with the direct experience. Two quite different distributions of spectral radiant flux (and this is the basic fact on which systems of color painting, color photography and color television are based) can give rise to equivalent color perceptions. Conversely, identical spectral description can appear differently depending on the "appearance mode" (to be discussed later), the presence or absence of the colors in the total field of view, and the state of adaption of the eye psychologically. Then it is both possible and probable to describe color in terms of three primary dimensions, or attributes: hue, saturation and brightness. Hue refers to the distinction we make between a red, a yellow and a blue; saturation to the distinction between a grey, a pink, and a red; and brightness to the perceived difference between black, grey, and white. Certain combination of these attributes have fairly well recognized characteristics; for example, a color appears paler, if it is both lighter and more like a grey, or deeper, if it is both more saturated and darker.

Of the three, hue, saturation, and brightness, saturation seems to be the most difficult to define adequately. It has been defined by several authors in slightly different ways but usually it is considered to be a function of the content of grey in each sample. One definition is that saturation is "that attribute of all colors possessing a hue which determines their degree of difference from a grey of the same brillance". (Jones and Lowry, 1926, p. 23). Another definition is that saturation is "the attribute of any chromatic color which determines the degree of its difference from the achromatic color most closely resembling it". (Judd, 1940, p. 23).

Saturation can be described in terms of high saturation, medium saturation and low saturation. When the chromatic component of a light, which is made up of both chromatic and achromatic light, is increased, the saturation of the color sensation changes with it. (Newhall, Nickerson and Judd, 1943, p. 544).

Evans (1959), in discussing the Munsell system with regard to grey content of each color, says that when hue and luminance are constant, the grey decreases as the saturation increases. That is, the grey is gradually displaced by the chromatic element. Again, when the hue and chroma are constant the grey content or value appears to remain the same in all of the samples. The grey content not only will cause colors to change in saturation but it will also act as a change in brightness.

Since it is possible to pass in (fine) gradations from any one surface color to any other, these colors may be represented by points in a space diagram in which the dimensions in cylindrical co-ordinates are brightness, saturation and hue. Figure 1 shows these dimensions in oblique projection. Brightness is plotted along the central axis with black at the bottom and proceeding through the greys to white at the top. Saturation is represented by perpendicular distance from the vertical brightness axis and the hues by the angle around the axis. Surface colors perceived to be equally bright will form a flat disc on one horizontal plane in the color solid. Colors perceived to be of the same hue will be represented by a vertical plane intersecting the black-white axis. Those perceived to be of the same saturation will form a circular cylinder coaxial with the line of greys on the black-white axis, which are of zero saturation or no hue at all.

Another factor which effects the perception of color is the mode in which the color is perceived. There are several of these different modes. The illuminant mode is one in which the color is perceived as belonging to a source of light. The illumination mode is color which is reflected from an object or surface. Color belonging to a surface is said to be in the surface mode. Color perceived from light passing through a transparent substance is known as the volume mode. The film mode is obtained when a colored reflecting surface is seen through an aperature in a screen which reveals only a limited area of the surface. (OSA 1943, p. 146).

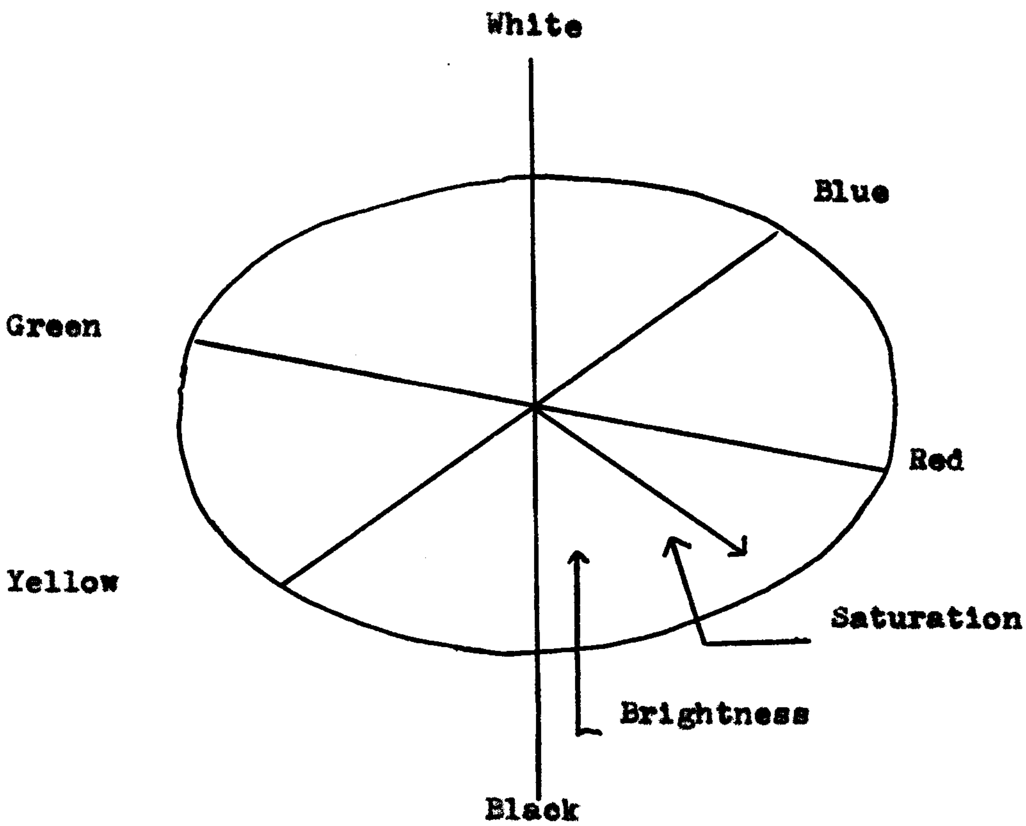

Fig. 1. Organization of color perception space

The film mode is obtained by the use of aperature because the observer experiences a loss of focus. The observer naturally focuses on the plane of the surface containing the aperature, but the stimulus color is farther away. (OSA 1943, p. 147). This mode, although somewhat artificial, is extremely useful since color perception depends solely on variations in the primary color dimensions, hue, saturation and brightness, and not on other factors peculiar to the particular surface.

A complete theory of color (not yet advanced) should include at least (a) the physical aspect, and (b) the psychological aspect; and since there is no one-to-one correspondence between these two concepts (c) a comprehensive account of the psycholophysical function or functions relating them. The requirements of (a) are met in principle by giving the spectral distribution of radiant flux; those of (c) are partially satisfied by stating the properties of three elementary or primary colors which, when mixed, will yield an equivalent perception.

The quantification of primary psychological dimensions has been approached by a variety of color notation systems, that developed by A.H. Munsell in 1909 being the most widely used and useful. The Munsell system is in essence a large collection of standard color chips, carefully painted and reliably reproduceable, varying along the three primary dimensions of hue, brightness (value, in Munsell terminology) and saturation (or chroma). Successive samples along any one of these dimensions are designed to represent equal "sense distances". That is to say, the perceived difference in brightness between chips of value one and two should equal the perceived difference between value two and three and so on over the whole value scale from zero (black) to ten (white). Similar statements hold for the differences along the other dimensions. The original Munsell notation was defective in a number of aspects. The renotation by Newhall, Nickerson and Judd in 1943 appears to have yielded samples which are satisfactorily spaced at equal intervals along the three primary dimensions, and thus permits a practical and reliable technique for the measurement of color.

Before the Munsell renotation can be accepted as the final answer to the problem of the psychological specificant of color, what is meant by "measurement" must be considered. The question has been discussed in a number of places and by a number of authors and most comprehensively by Stevens (1951). Briefly, at least three kinds of measurement can be distinquished. There is, first, the assignment of numbers to phenomena or to attributes of phenomena in such away that the order of the numbers represents the order of the phenomena, yielding ordinal scales of which the Beaufort scale of wind force and many intelligence scales are representitive. At a higher level of quantification, numbers can be assigned to phenomena so that equal differences between the numbers imply equal differences between the attributes measured. The standard Centigrate and Fahrenheit scales of temperature are examples from physics. The Munsell scales appear to be equal-interval scales in psychology. Finally, as the goal to which the other forms of measurement are often thought of as approximations, is the assignment of numbers so that the ratios of the numbers represent adequately ratios of the attributes.. The fundamental physical measurements of length, mass, and time are of this kind; psychological examples are unfortunately rare but are possibly represented by the sone scale for loudness, and a few others. In the present instance, the concern is with the psychological measurement of saturation, and, in particular, with the question as to whether the equal interval Munsell Chroma scale represents saturation ratios.

A complete concept of color consequently must include the physical, psychological and psychophysical aspects. However, for study or practical use in industry, one of the concepts alone can be helpful and useful in solving particular problems. This was the approach used by A. H. Munsell in 1909 when he developed a color appearance system of color notation. The system is based on three co-ordinates, hue, chroma and value, corresponding to hue, saturation and brightness, respectively. This system was renotated in 1943 by the Optical Society of America (OSA), Committee on Colorimetry (Newhall, Nickerson and Judd, 1943).

It was the original aim of Munsell that the brightness, hue, and saturation of these colors would be equal sense distances. This was the purpose of the OSA subcommittee when the renotation was done by a particular method of ratio scaling.

Although scales have been created in other areas, little has been done in the past with color saturation. Munsell (1909), as we have seen, was the first to try to create a scale which would give psychologically equidistant spacing to the saturation of a number of hues. Later in 1925, Lowry and Jones, created a scale which gave the j.n.d. steps in saturation for several hues.

Purdy (1931, p. 313), did not develop a scale but did measure intensities at the lower threshold of saturation and at the visual limit. He found that at the threshold of visibility there is no sensation of saturation and at low intensities the saturation is only partial.

The last major scale was completed in 1943 by the OSA subcommittee on the spacing of the Munsell Colors (Newhall, Nickerson and Judd, 1943). This work is considered to be closer to the original purpose of A. H. Munsell, which was to create a scale of psychological equidistance and practical usefulness (OSA, p. 225).

Complex procedures of observation and computation, known for many years as the psycho-physical methods, are necessary in the construction of scales. Various methods have been used depending upon the size of the steps in the scales. The method of paired comparisons provides numerical frequencies of judgments which are used as a basis for laying out the relative visual spacing of the samples. The method of single stimuli is useful in creating scales with larger steps. The observer can distinquish different hues and whether the color is "saturated" or " desaturated".

The ratio method has the greatest number of variations. The relationships of the judged interval to the unit interval are matched in the physical and psychophysical measurements. These samples provides a basis for adding units until the scale gives equal visual spacing. Maxwell (1929) used this method in measuring the saturation of one red hue. His observers, a group of boys, put a mark corresponding to their impressions of the stimulus, a mixture of red and white on a color wheel, on a line 10 cm. long, labeled red at one end and white at the other. The results were more appropriate for the scale ~~near~~ each end that in the centre.

Newhall (1950) originated another variation of the ratio method. His observers adjusted and re-adjusted the locations of small space markers in a simple rectangular co-ordinate system. The ratios in the space set up by the markers represented the sense-ratios perceived in the stimulus. His results were consistent and he suggests that the apparatus can be checked by using the Munsell scales as a criterion.

The method of bisection is another variation used in developing scales. The observer's task is to estimate a color, for example, which divides the interval equally between two terminal colors. A comparison of these observed visual relations is made with their psychophysical specifications and an equispaced scale results.

Harper (1948) in using this method with the estimation of weights found a consistent ratio scale. The subject chose one of three weights as being one-half as heavy as the standard. Reese (1943) was successful in constructing a ratio scale for the rate of flickering light. He found small variability between subjects in the one-half judgments, and in the shape of the curves.

It is evident that ratio scales developed by one-half judgments are successful. The method of obtaining the one-half point varies from one experimenter to another, however. There is a possibility that this factor would influence the shape of the resulting curve for the scale. Various methods of obtaining the one-half point can be used. The observer can adjust the apparatus himself until he obtains a judged half point. The experimenter can take the more active part by presenting the stimuli by a method of limits. Or, the method of constant stimuli can be used as an alternate method. The results of using these diverse methods are not known and no studies have been designed for this purpose.

Sempowski, working from a definition of saturation proposed by Smith, (Sempowski 1963, p. 15), i.e., that "saturation is a function of the amount of neutral grey which must be added to a color so that the mixture is perceived as one-half as saturated as the original", used a method of limits to obtain the mid-point for a saturation scale of three Munsell hues, each of chroma 10. The stimuli were three color wheels, one neutral grey, one of the hue of chroma 10 and the third a combination of the hue and the neutral grey. The third stimulus was placed between the other and the mixture of grey on it, and the hue could be varied. The percentage of grey was increased until the observer reported that it appeared more like the grey than the hue. Then, the grey percent was decreased until the observer reported that it appeared more like the hue. The mid-point was later calculated from these measurements.

Sempowski was able to show that the judged one-half points he obtained did not correspond to the numerical one-half points of the renotated Munsell chroma scale. Only one of the three hues of chroma ten used was judged to have a one-half point of chroma five.

This present study will have the dual purpose of further investigation of the one-half points of the Munsell scale of chroma and an attempt to demonstrate the feasibility and usefulness of the method of constant stimuli in creating a scale. It may be possible to develope a ratio scale of the Munsell chroma which will have different characteristics than the present one developed by the OSA in 1943. The method of constant stimuli will possibly be a contribution to the already proven methods of scaling.

CHAPTER II

METHOD

Observers

The O's were volunteers, chosen at random from students enroled in an introductory course in psychology at the University of Windsor. There were nine female and three male students between the ages of 18 and 21 years. No observer showed any deficiency in color vision as assessed by a test on the Bausch and Lomb Orthorater.

The Basic Design

The experiment was arranged so that the bisection points of a number saturation intervals could be found indirectly by the method of constant stimuli. Each saturation interval was defined by two terminal or anchor stimuli: one was always a grey (of zero saturation, by definition); the other was of relatively high saturation, as measured by its Munsell chroma. Between these anchors was presented a third stimulus of intermediate saturation, again as measured by its Munsell chroma. All three stimuli were equated for hue and brightness in terms of their Munsell hue and value notations.

O was asked to indicate which of the two anchor points the intermediate stimulus more nearly resembled. For each saturation interval, four intermediate stimuli were used, each differing from one another and from the anchor stimuli only in saturation. O made ten judgements to each of the intermediate stimuli.

The obtained frequency data were then used to calculate the required Munsell chroma of a stimulus which, if presented, would be judged half the time more like the chromatic anchor and half the time more like the grey anchor. This calculated half-chroma was taken as the chroma notation of the stimulus which would appear half as saturated as the stimulus which furnished the chromatic anchor of the saturation interval being bisected. The proceedure was repeated for a number of saturation intervals, differing with respect to the hue and saturation of the chromatic anchor.

Apparatus

The color stimuli used were Munsell color chips chosen from the Munsell Color file. Table 1 gives the Munsell notations for all of the chips employed, arranged to show the anchor stimuli and the intermediate stimuli. The chips were viewed on an apparatus illustrated in Figure 2 made up of a vertical screen 20 inches by 20 inches and a horizontal base 20 inches by 8 inches. Both the base and the screen were painted with a flat black paint. Each color chip was held in a separate metal frame with a handle which dis-

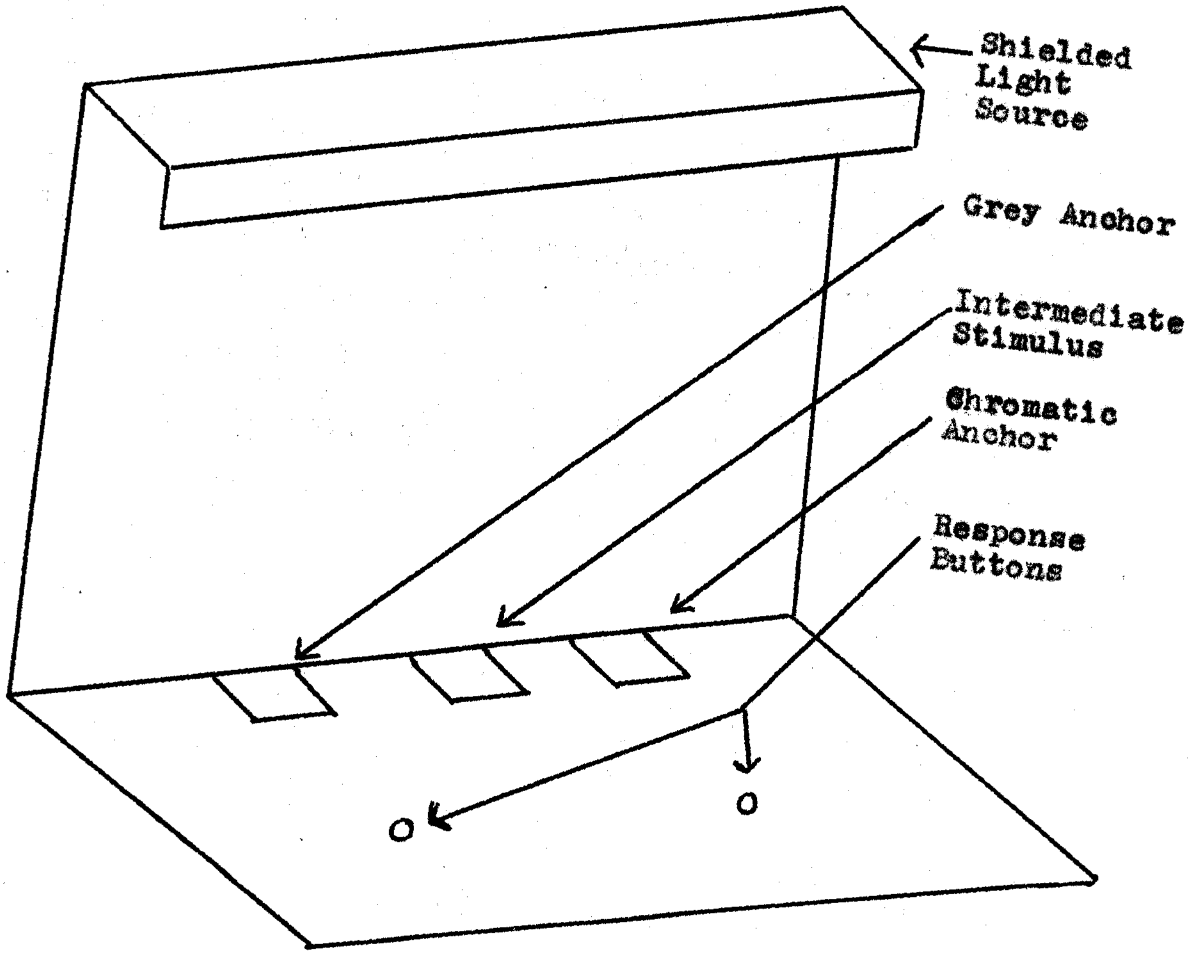

Fig. 2. Observer's view of the apparatus on which the color chips were presented.

Table 1

Munsell Notations of Anchor and Intermediate Color Stimuli

Left (Grey) Anchor	Intermediate Stimuli				Right (Chromatic) Anchor
N 5/	5R 5/2	5R 5/4	5R 5/6	5R 5/8	5R 5/14
N 5/	5R 5/2	5R 5/4	5R 5/6	5R 5/8	5R 5/12
N 5/	5R 5/2	5R 5/4	5R 5/6	5R 5/8	5R 5/10
N 5/	5Y 8/2	5Y 8/4	5Y 8/6	5Y 8/8	5Y 8/14
N 5/	5Y 8/2	5Y 8/4	5Y 8/6	5Y 8/8	5Y 8/12
N 5/	5Y 8/2	5Y 8/4	5Y 8/6	5Y 8/8	5Y 8/10
N 5/	2.5G 5/2	2.5G 5/4	2.5G 5/6	2.5G 5/8	2.5G 5/12
N 5/	2.5G 5/2	2.5G 5/4	2.5G 5/6	2.5G 5/8	2.5G 5/10
N 5/	5PB 5/2	5PB 5/4	5PB 5/6	5PB 5/8	5PB 5/12
N 5/	5PB 5/2	5PB 5/4	5PB 5/6	5PB 5/8	5PB 5/10

played one and one-half inch square of the color, and was presented from behind the screen on the base of the viewing apparatus through a slot in the bottom of the screen.

Illumination was by six 12 volt General Electric number 57 lamps, mounted 12 inches above the viewing surface and shielded from the observer's eyes by a metal hood. The electrical source was an Eico direct current supply regulated to a constant voltage of 12 volts. The testing room was not entirely dark and dark adaption would not take place. The viewing distance for each subject was about 18 inches.

The subject registered his choices by depressing one of two buttons on either the left or right side of the base of the screen.

Procedure

The observer was presented with the neutral grey color chip on his left and the saturated color on his right. The centre color was the desaturated chip upon which he made a judgment. The observer was seated in front of the apparatus with these sample color chips on the apparatus. The observer was told:

> You will be presented with three chips of color. The one on the left is a grey which you may consider to be of zero color. The one on the right is the deepest or richest color. The one in the centre will be a mixture of the two. You are to indicate which of the two the centre one most resembles. It is a mixture of the other two.

> Indicate it by pushing the proper button.

There were a total of ten anchor points of the saturated chip, three each for the red and yellow and two each for the blue and green. There were four intermediate stimuli for each of the above, with ten judgments to each intermediate stimulus, for a total of four hundred judgments by each O.

CHAPTER III

RESULTS

The primary data from this study are the percentages of times each intermediate color chip was chosen as appearing more like the right anchor point. These data are presented for each subject in Tables 2,3,4 and 5. The data were then plotted on probability paper, the best fitting straight line drawn in by eye, and the one-half point chroma read from the graph. An example of one plot for one O is presented in Fig. 3. It gives the data and the fitted line obtained with 5R 5/14 as the right anchor point. The half-saturated chroma for this interval and this O is 6.6. These half points are given in Tables 6 and 7. Estimates of the j.n.d. at the half-point were obtained by reading off the semi-interquartile range from the probability plots. These are also presented in Tables 6 and 7.

Table 8 shows the group averages of the data presented in Tables 2 to 5. It contains the averaged one-half points for each of the right hand anchors and the averaged j.n.ds for each one-half point. The standard deviations between the subjects for each one-half point are also presented.

The averaged one-half chroma points from Table 8 presented in graphical form in Fig. 4. In order to compare these graphs with the previous work done by Sempowski (1963), the data from that study are also shown.

Table 2

Relative Frequency of Judgments Similar to Chromatic Anchor for Hue 5R 5/

	Chromatic Anchor 5R 5/14					5R 5/12				5R 5/10			
	Intermediate Stimulus												
Os R5	5/2	/4	/6	/8	/10	/2	/4	/6	/8	/2	/4	/6	/8
LM	0	0	20	100	100	0	0	10	100	0	0	60	100
MP	0	10	0	90	100	0	0	20	70	0	0	70	100
MK	0	0	60	100	100	0	0	90	100	0	10	70	100
GB	0	0	10	90	100	0	0	90	100	0	0	100	100
MV	0	20	60	100	100	0	40	70	100	0	10	60	100
GC	0	10	20	100	100	0	10	60	100	0	0	70	100
SG	0	10	50	80	100	0	10	20	100	0	10	100	100
FS	0	0	50	100	100	0	10	80	100	0	90	100	100
CF	0	0	40	90	100	0	0	50	100	0	0	80	100
BG	0	0	30	100	100	0	0	90	100	0	0	100	100
RD	0	90	100	100	100	0	100	100	100	0	100	100	100
CM	0	0	10	100	100	0	0	10	90	0	0	100	100

Table 3

Relative Frequency of Judgments Similar to Chromatic Anchor for Hue 5Y 8/

	Chromatic Anchor 5Y 8/14					5Y 8/12				5Y 8/10			
	Intermediate Stimulus												
Os	5Y 8/2	/4	/6	/8	/10	/2	/4	/6	/8	/2	/4	/6	/8
LM	0	30	70	100	100	0	20	100	100	0	20	90	100
MP	0	0	20	100	100	0	0	30	100	0	20	30	100
MK	0	30	100	100	100	0	0	100	100	0	10	100	100
GB	0	30	100	100	100	0	40	100	100	0	60	100	100
MV	0	0	100	100	100	0	0	100	100	0	10	100	100
GC	0	10	70	100	100	0	80	100	100	0	0	70	100
SG	0	0	80	100	100	0	0	100	100	0	0	100	100
FS	0	0	90	100	100	0	0	80	100	0	20	100	100
CF	0	0	20	100	100	0	0	30	100	0	0	90	100
BG	0	0	90	100	100	0	0	100	100	0	0	100	100
RD	0	20	90	100	100	0	20	100	100	0	10	100	100
CM	0	0	70	100	100	0	0	90	100	0	0	100	100

Table 4

Relative Frequency of Judgments Similar to Chromatic Anchor for Hue 2.5G 5/

	Chromatic Anchor 2.5G 5/12					Chromatic Anchor 2.5G 5/10			
	Intermediate Stimulus								
Observers	2.5G 5/2	/4	/6	/8	/10	/2	/4	/6	/8
LM	0	0	20	100	100	0	10	100	100
MP	0	0	50	80	100	0	0	80	100
MK	0	30	100	100	100	0	40	100	100
GB	0	80	90	100	100	0	90	100	100
MV	0	10	100	100	100	0	50	100	100
GC	0	0	80	100	100	0	0	90	100
SG	0	60	100	100	100	0	60	100	100
FS	0	10	80	100	100	0	40	90	100
CF	0	0	100	100	100	0	20	100	100
BG	0	20	100	100	100	0	20	100	100
RD	10	80	100	100	100	0	100	100	100
CM	0	0	100	100	100	0	20	100	100

9 11

Table 5

Relative Frequency of Judgments Similar to Chromatic Anchor for Hue 5PB 5/

	Chromatic Anchor 5PB 5/12					5PB 5/10			
	Intermediate Stimulus								
Observers	5PB 5/2	/4	/6	/8	/10	/2	/4	/6	/8
LM	0	0	30	100	100	0	0	100	100
MP	0	0	50	100	100	0	20	50	100
MK	0	0	60	100	100	0	0	80	100
GB	0	0	40	100	100	0	10	30	100
MV	0	0	60	100	100	0	10	50	100
GC	0	10	20	100	100	0	0	30	100
SG	0	0	50	100	100	0	0	60	100
FS	0	0	30	100	100	0	0	90	100
CF	0	0	0	100	100	0	0	40	100
BG	0	0	20	100	100	0	0	100	100
RD	0	0	80	100	100	0	0	50	100
CM	0	10	50	90	100	0	0	60	100

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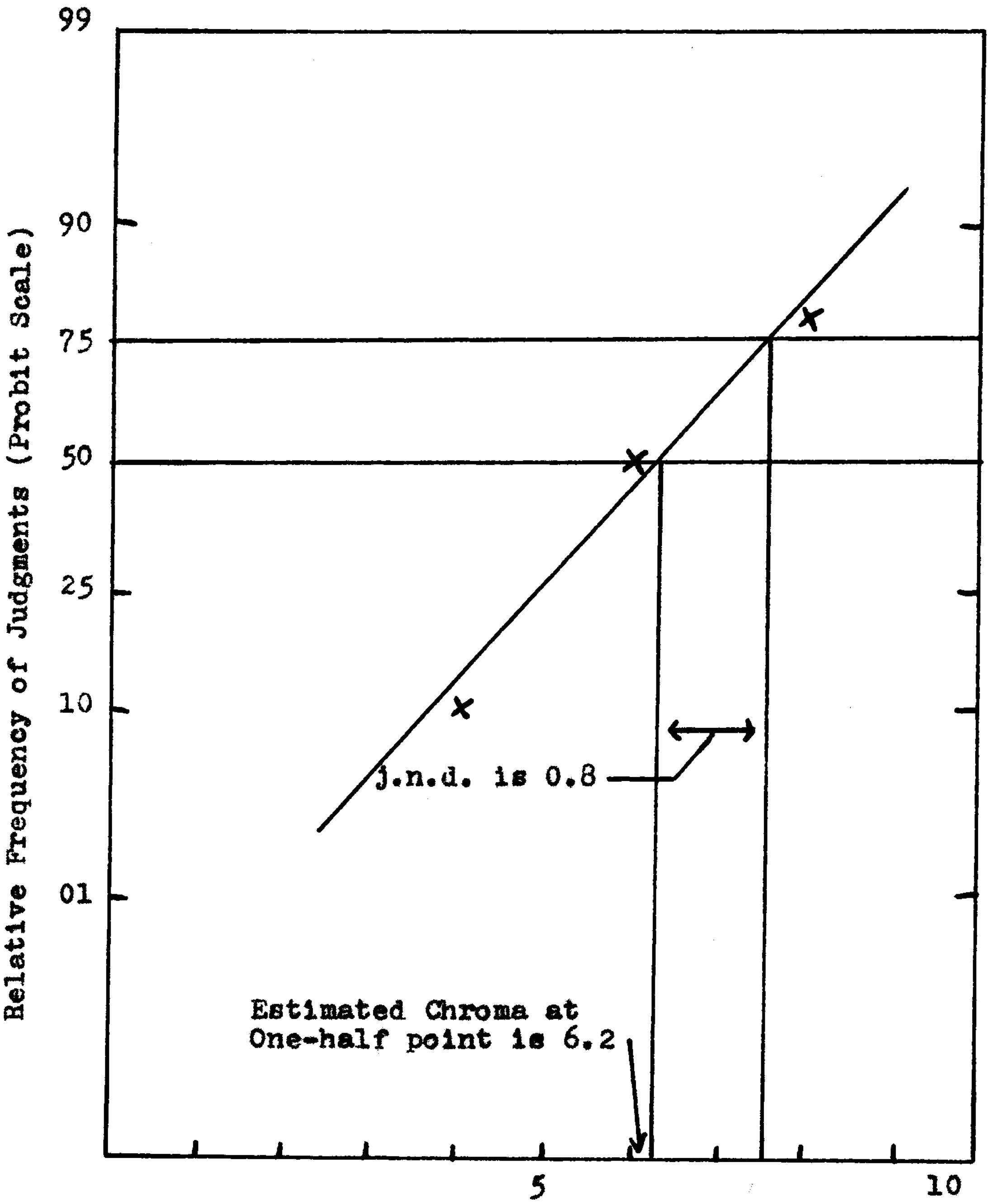

Fig. 3. Sample plot of relative frequency of judgments "more like the chromatic anchor" as a function of the intermediate stimulus, with visually estimated probit line and estimated one-half point and j.n.d. data for chromatic anchor 5R 5/14 with subject SG.

Table 6

Mid-point Chromas and j.n.ds.* for each O and each Saturation Interval

	Chromatic Anchor of Interval				
	5R 5/			5PB 5/	
Observers	/14	/12	/10	/12	/10
LM	6.6 (0.4)	6.7 (0.4)	5.8 (0.3)	6.3 (0.5)	6.0 (0.4)
MP	7.0 (0.5)	7.0 (0.7)	5.7 (0.4)	6.0 (0.4)	5.7 (0.4)
MK	5.9 (0.3)	5.5 (0.3)	5.6 (0.3)	5.9 (0.5)	5.6 (0.5)
GB	5.5 (0.5)	5.5 (0.5)	5.0 (0.4)	6.2 (0.7)	5.6 (0.6)
MV	5.3 (0.5)	5.3 (0.6)	5.3 (0.5)	5.9 (0.4)	5.4 (0.5)
GC	6.9 (0.6)	6.0 (0.6)	5.7 (0.4)	6.2 (0.4)	6.1 (0.4)
SG	6.7 0.7)	6.1 (0.4)	4.3 (0.5)	6.0 (0.5)	5.8 (0.3)
FS	6.0 (0.3)	5.8 (0.4)	3.5 (0.3)	6.3 (0.6)	5.6 (0.9)
CF	6.4 (0.8)	6.0 (0.3)	5.6 (0.4)	7.0 (0.3)	6.1 (0.4)
BG	6.5 (0.4)	5.3 (0.5)	5.0 (0.3)	6.3 (0.3)	5.0 (0.3)
RD	3.2 (0.3)	3.0 (0.3)	3.0 (0.3)	5.7 (0.6)	6.0 (0.6)
CM	6.3 (0.4)	5.0 (0.6)	5.0 (0.3)	6.0 (0.3)	5.4 (0.4)

*The numbers in parentheses are the j.n.ds. as determined by the semi-interquartile range

Table 7

Mid-point Chromas and j.n.ds. * for each O and each saturation Interval

	Chromatic Anchor of Interval				
	5Y 5/			2.5G 5/	
Observers	/14	/12	/10	/12	/10
LM	5.6 (0.6)	4.7 (0.4)	5.2 (0.6)	5.7 (0.4)	4.8 (0.3)
MP	6.4 (0.3)	6.1 (0.4)	5.5 (0.3)	6.0 (0.4)	5.7 (0.5)
MK	4.5 (0.6)	5.0 (0.5)	4.8 (0.3)	4.7 (0.3)	4.2 (0.3)
GB	4.7 (0.5)	4.5 (0.5)	3.9 (0.5)	3.7 (0.5)	3.5 (0.4)
MV	5.0 (0.4)	5.0 (0.4)	4.8 (0.4)	5.0 (0,5)	4.0 (0.7)
GC	5.6 (0.5)	5.7 (0.4)	5.7 (0.4)	5.7 (0.6)	5.4 (0.6)
SG	5.7 (0.5)	5.0 (0.4)	5.0 (0.4)	3.9 (0,4)	4.0 (0.5)
FS	5.5 (0.4)	5.6 (0.4)	4.7 (0.4)	5.5 (0.4)	4.4 (0.4)
CF	6.7 (0.4)	6.6 (0.4)	5.5 (0.5)	5.0 (0.4)	4.7 (0.4)
BG	5.5 (0.4)	5.0 (0.4)	5.0 (0.4)	4.3 (0.4)	4.3 (0.3)
RD	5.3 (0.6)	4.7 (0.3)	4.8 (0.3)	3.5 (0.4)	3.0 (0.3)
CM	5.8 (0.4)	5.5 (0.6)	5.0 (0.6)	5.0 (0.9)	4.8 (0.5)

*The numbers in parenthesis are the j.n.ds. as determined by the semi-interquartile range.

Table 8

Mean Mid-point Chromas and j.n.ds

	Chromatic Anchor of Saturation Interval									
	5R 5/			5Y 8/			2.5G 5/		5PB 5/	
	/14	/12	/10	/14	/12	/10	/12	/10	/12	/10
Mean Mid-point	6.0	5.6	5.0	5.5	5.3	5.0	4.8	4.4	6.1	5.7
Mean j.n.d	0.49	0.48	0.38	0.46	0.40	0.44	0.46	0.48	0.48	0.45
S.D. of Mid-points	1.79	1.90	1.70	1.70	1.65	1.51	1.62	1.47	1.92	1.90

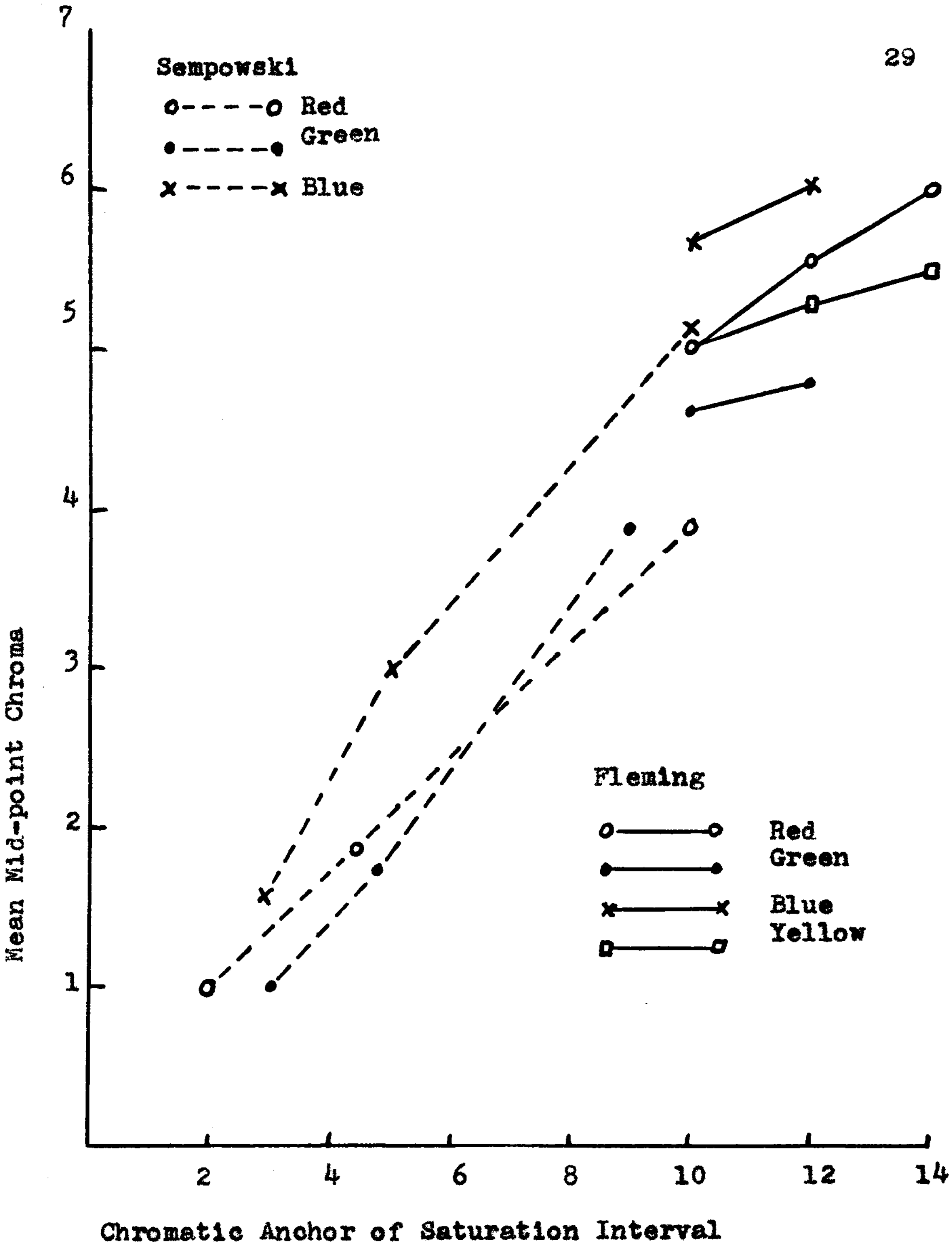

Fig. 4. Mean mid-point chroma at each saturation interval in studies by Sempowski and Fleming

CHAPTER IV

DISCUSSION OF RESULTS

The Munsell scale of chroma was designed to be an equal interval scale. The renotation by the Optical Society of America in 1943 was carried out to further refine the scale. Since the scale has a meaningful zero point (neutral grey) it follows from the definition that the Munsell chroma scale should be a ratio scale. However, Sempowski (1963), has presented evidence that Munsell chroma numbers represent saturation ratios only for the low chromas up to chroma 4 or 5. Sempowski used a bisection procedure, in which the mid-point was found indirectly by a method of limits. The resulting scale was developed only up to chroma 10 for three hues of intermediate brightness. The present experiment attempts to carry Sempowski's work further, that is, to extend the ratio scale to the highest chromas available; and to determine the feasibility of an alternate method of indirect scaling, using a method of constant stimuli. In addition to this, since Sempowski used a method which yielded colors in the film mode, and the Munsell chips are commonly used in the surface mode, the present experiment was designed in such a way that the colors were viewed in the surface mode.

The results of the present experiment indicate that the Munsell chroma scale is not a true ratio scale. For the hues 5R 5/, 5Y 5/, 2.5G 5/, the judged one-half points are below the expected numerical one-half point of a true ratio scale. For the 5PB 5/, however, the judged one-half point is not significantly different from the numerical one-half point. Green shows the greatest discrepancy. It would not be possible to create a ratio scale from the available data, but it is evident that a scale derived in this manner would vary, with the different colors, from the present Munsell scale. The one-half points obtained in this study compare with those obtained by Sempowski (1963). In both studies the one-half points for the red and yellow hues were lower than the numerical one-half points; those of the blue were slightly higher. The resulting data, when plotted, show curves which are similar except for a break where the two sets of curves join (Fig. 4).

The precision of the present data is comparable to studies done in the past. The just noticeable differences of saturation obtained from these data compare favourably with the tolerances set by the Munsell Color Company for the reproduction of the color chips (Judd and Wyszecki 1963, p. 306). The average j.n.d. of 0.4 chroma obtained in this study is as accurate as the tolerances of 0.4 to 0.6

chroma set for the reproduction of the color chips. The inter-observer variability of the present study (S.D.of 2) is small and compares with the results obtained by Sempowski (1963), (S.D. of 2.5). This also meets Garner's (1959, p. 1007), chief objection to the usual ratio methods, when he writes "the inter-observer differences provide the largest single source of variability in the data".

One possible source of error in the present study can be attributed to the fact that the Munsell color chips could only obtained in 2-chroma steps. These steps were large, compared with the j.n.d., and hence, only three intermediate stimuli gave frequency data suitable for fitting the probit lines (zero and 100 percent frequency are, of course, unusable). This data loss undoubtably introduced some error in estimating the one-half points. In addition to this the Munsell color chips were developed under conditions of illuminant "C" and using a white or grey surround which were not used in this experiment.

Some suggestions for further study are evident from the present findings. This study and that of Sempowski (1963) incorporate two psychophysical methods and two modes of color presentations; i.e., Sempowski used the method of limits with the film mode, and the present study used the method of constant stimuli with the surface mode.

Further studies could be done using the remaining combinations, that is, the method of limits with the surface mode and the method of constant stimuli with the film mode. This would yield four sets of data for comparison.

Although Jones and Lowry (1926) did a study to determine the j.n.d. steps of saturation, which were achieved by varying the colorimetric purity, this could be done again in terms of the Munsell color chips. The writer has not been able to discover work done to compare the Munsell scale with a j.n.d. scale in saturation.

The Munsell color chips, as used in this study, have a small error in hue, value and chroma. This error could be partially eliminated by using only two color discs, on a color mixing wheel, in which each color represented each anchor point, that is, one neutral grey and the other, the saturated hue. These anchors could be viewed, along with the mixture, by means of a stroboscopic light source.

A further suggestion would be to repeat the present study, presenting the stimuli for a controlled time, using a tachistoscope. This control of exposure time could be expected to reduce the variability of the judgments, both from trial to trial and between O s.

CHAPTER V

SUMMARY

The purpose of this study was to investigate the ratio properties of the Munsell chroma notation for color saturation. Sempowski (1963), using a newly developed indirect bisection technique, has presented evidence that the Munsell numbers do not generally represent perceived saturation ratios. Sempowski employed a version of the classical method of limits in his scaling procedure and worked with Munsell chroma only as high as 10. The present study employs, the method of constant stimuli and uses chromas up to 14.

The basic technique is that of the bisection of a saturation interval, using standard psychological procedures to determine indirectly the mid-point of the interval. The mid-point of the intervals from grey to chromas 14, 12, and 10 were obtained for the Munsell hues, red, yellow, green and purple-blue.

The results showed a difference in judged one-half points as compared with the expected numerical one-half points for the red, yellow and green. Those of the purple-blue were very close to the expected numerical one-half point. The method of constant stimuli proved to be a satisfactory method for obtaining the one-half point.

The results were found to be in keeping with related work done in the past. The resulting scale of saturation was similar to that of Sempowski (1963). The j.n.d. of saturation is comparable to that used by the Munsell Color Company for control of the reproduction of the color chips.

Certain further experimentation seems to be indicated from these results. Differences in resulting scales could be investigated by a methodological study in which the bisection of the interval was done by the method of limits and by the method of constant stimuli with various modes of presentation of the colors. A j.n.d. scale could be constructed using the Munsell color chips. Error could be eliminated by using the grey and red, for example, on a color wheel with a stroboscopic light source for mixing the colors. Some of the variability between subjects could be eliminated by controlled time of presentation of the stimuli using a tachistoscope.

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