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ABSTRACT

Since visual discrimination is one of the factors involved in learning from instructional media, the present study was designed (1) to investigate the effects of hue contrast, illuminant intensity, brightness contrast, and viewing distance on the discrimination accuracy of those who see color normally and those who do not, and (2) to investigate the extent to which the discrimination accuracy of color deficients improves, as compared with that of color normals, as a function of brightness contrast. Color deficiencies of two types--deuternopia (green blindness) and protanopia (red blindness)--were represented by six children each in the experiment. With six color normals, they were paid to discriminate the orientation of the gap in chromatic rings presented on chromatic surrounds. The degrees of hue contrast in Part I of the study were 36, 72, 108, 144, and 180 on the Munsell Hue Circle. The illuminant intensities were 25, 50, 75, and 100 footcandles. Viewing distance was 3 meters. Brightness contrast in Part II of the study had four values between 30 and 80 percent. Illuminant intensity was 50 footcandles, and viewing distances were 5, 6, 7, and 8 meters. On the evidence of the study the recommendation is that a brightness contrast of 30 percent or more be provided in colored instructional materials. (MF)

VISUAL DISCRIMINATION OF COLOR NORMALS AND COLOR DEFICIENTS

BY

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Y.W.C.

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CHAPTER I

Problem

Recent years have seen an extensive use of color in instructional media. More and more instructional films have been made in color, various coloring methods have been introduced for making transparencies and color plates have been abundantly used in textbooks.

Further, an emphasis on such factors as aesthetic design and balanced overall illumination in the classroom has resulted in a preferance for the green chalkboard over the traditional blackboard. Also, it has been commonly accepted that colored chalks can be used with good effect to highlight important aspects of the instructional materials displayed on the chalkboard. However, it seems apparent that people in using color in instructional situations often assume, with insufficient empirical evidence, that the use of color in a given case will improve or at least will not impair learning.

VanderMeer (1952) investigated the comparative effectiveness of color and black and white instructional films for nearly 600 ninth and tenth grade high school students. In the five films included in his experiment, the variable of color was either intrinsic to the learning of subject matter, or color was used to increase the aesthetic effect and to highlight important parts of films or both. None of the color films used resulted in significantly more learning than their black and white counterparts.

May and Lumsdaine (1958) studied the contribution of color to the learning of seasonal phenomena by fifth and ninth graders. Two films, a color version and a black and white version printed from this color version, were used for their experiment. None of the differences between the amount of learning, which was assessed by multiple-choice items, resulting from students' viewing the two films reached statistical significance.

Another approach has been taken by a number of investigators. They have investigated the effect of the use of color cues on the legibility of printed matter. Results of some of these studies will be summarized in the Related Research chapter. Unfortunately, this research has left some important questions unanswered. Firstly, in several of these studies the variable of brightness contrast was confounded with the variable of hue contrast. As a result, if, for example, a particular target-surround color combination resulted in high legibility, it might have been due to the contribution of the relatively high brightness contrast that happened to exist between the target and the surround rather than to the contribution of hue contrast.

Secondly, stimulus materials have not always been specified in ways that make replication of the reported studies possible. For instance, a color named "red" by one observer could be named "orange" by another observer. Also, two colors that are easily discriminated may be called by the same name. In experimental research, it seems clear that vernacular color names should be replaced with standardized units such as International Commission on Illumination (ICI) tristimulus coefficients, wavelength, the Ostwald System or the Munsell System of Color Notation.

Thirdly, apparently no serious effort has been made to determine how color should be used so that color deficients may make adequate visual discrimination when colored materials are involved.

Many instances of learning require that the organism first of all make accurate visual discriminations of stimuli. Therefore, finding answers to such questions as to whether color should be used and how it can most effectively be used presumably will occur through investigating the discriminability of color stimuli and exploring methods which can be used to improve their discriminability for all observers including color deficients.

Visual discrimination of a target is a function of quite a number of variables, such as light intensity, spectral composition of illuminating light, brightness contrast, hue contrast, saturation contrast, exposure time, type of target, target size, viewing distance, whether observation is made binocularly or monocularly, whether the target is stationary or moving, visual acuity, age and color vision of the observer. The magnitude of the effect of any one of these variables is dependent very importantly on the values of the other variables. Consequently, strict control of these variables is essential if the functional relations between them and the accuracy of visual discrimination of a target are to be specified precisely.

Introduction of color in an otherwise achromatic situation, with brightness contrast and saturation contrast between the target and the surround held constant, should improve or at least should not impair visual discrimination for the reason that observers with normal color vision are provided with an additional basis for discrimination.

However, in practice the use of color in instructional media is apt to involve low brightness contrast between the target and the surround. In other words, a higher brightness contrast is usually present in the achromatic materials than in chromatic materials simply because it is easier to build a high brightness contrast in black and white than it is in color. For example, the Munsell System of Color Notation provides a brightness contrast range of 1:26 or more in its achromatic value scale, but this brightness contrast range is reduced to about 1:8 in its chromatic value scales for relatively well saturated colors. As will be pointed out in the Related Research chapter, it has been found in several studies that the brightness contrast between the target and the surround is more important than the hue contrast in influencing the accuracy of visual discrimination.

Up to this point the discussion has been focused on observers with normal color vision. The fact that nearly 8.5 percent of school children are color deficients of one kind or another (Burham, Hanes and Bartleson, 1963; Graham, 1966) also demands a critical evaluation of the consequences of introducing color on the chalkboard and in other instructional media.

Rod monochromats, who cannot discriminate hues at all, and dichromats, who can discriminate only two of the three primary hues, depend greatly on the brightness contrast between the target and the surround for visual discrimination. Hence, if color is introduced at the cost of reduced brightness contrast between the target and the surround, then color deficients will not see as well and, other things equal, presumably will not learn as well as color normals.

Although there is not sufficient evidence to specify with any precision the circumstances under which the use of color has a positive effect on learning, the trend seems to be toward more and more extensive use of color in instructional media. It is evident that additional studies on how to use color most effectively for instructional purposes are needed. If color cues can be used effectively to facilitate the visual discrimination of color normals, then it would not seem advisable to be content with abolishing the use of color in instructional media just for the sake of the minority group of color deficients. Rather, a strenuous effort should be made to find ways in which color can be used to facilitate the visual discrimination of color normals and color deficients as well.

The purpose of the present study is to obtain empirical evidence in a laboratory situation, on the basis of which recommendations can be made with respect to using color in instructional media for color normals and particularly for color deficients, such that visual discrimination of color normals can be facilitated without reducing visual discrimination of color deficients and vice versa.

The present study is intended to accomplish the following:

1. To measure the effect of hue contrast between the target and the surround on the discrimination accuracy of color normals and color deficients. The purpose of this is to investigate the contribution of hue contrast to the visual discrimination of color normals and to investigate the extent to which color deficients may be handicapped by the use of chromatic stimuli.

2. To measure the effect of illuminant intensity within the medium photopic range, in which vision is predominantly dependent upon the function of cones, on the discrimination accuracy of color normals and color deficients. Illuminant intensity is the amount of light emitted by a source such as a light bulb. The purpose of this is to find out the minimum

illuminant intensity which is most effective for visual discrimination of chromatic stimuli by color normals and color deficients.

3. To measure the effect of brightness contrast between chromatic targets and chromatic surrounds on the discrimination accuracy of color normals and color deficients. The purpose of this is to investigate how brightness contrast in chromatic stimuli can be used to increase discrimination accuracy of color normals and to investigate the extent to which the discrimination accuracy of color deficients improves as brightness contrast in chromatic stimuli is increased.

4. To measure the effect of viewing distance on the discrimination accuracy of chromatic stimuli of color normals and color deficients. The purpose of this is to determine whether changing the viewing distance affects the discrimination accuracy of color normals and color deficients to the same extent.

CHAPTER II

Related Research and Experimental Hypotheses

Related Research

Hue Contrast

The three properties of color, namely, hue, brightness and saturation are so closely interrelated that a change in one property usually causes a simultaneous change in the other two properties. For instance, when a particular green of 520 nanometers (nm., synonymous with millimicrons) is shifted to a green of 500 nm., the apparent brightness and saturation also change unless they are deliberately controlled.

As Walls (1943) pointed out, discriminating an object is a function of contrasts of hue, brightness and saturation. It will be seen from some of the descriptions below of prior studies that a difficulty in interpreting them may arise because of lack of control of one or more of these variables.

Bishop (1966) investigated resolution visual acuity using colored bars against an equiluminous white surround and also against a dimmer black surround. The subject adjusted, with alternating ascending and descending orders, for the minimum separation of the bars which was just noticeable. The colored bars seen against a dimmer black surround resulted in a higher visual acuity. However, a relatively fine visual acuity was obtained with the colored bars seen against an equiluminous white surround. This indicates that hue contrast alone is sufficient for a rather fine visual discrimination.

Cavonius and Schumaker (1966) investigated grating visual acuity as a function of hue contrast. The subject was required to line up the upper halves with the lower halves of alternating bars which had equal brightness but different wavelengths. A high grating visual acuity was obtained when the wavelengths of the alternating bars were very different from each other. In other words, hue contrast between the alternating bars resulted in a fine visual discrimination that was, in fact, as good as that resulting from a considerably high brightness contrast between the adjacent bars. Furthermore, once a relatively high grating visual acuity was obtained by means of a high hue contrast between the equiluminous bars, increasing the brightness contrast did not improve visual acuity even though there was still room for improvement. The writers therefore concluded that a fine visual acuity can occur via hue contrast alone and that brightness contrast is not the sole factor and probably not even a predominant factor for visual discrimination.

MacAdam (1949) investigated recognition visual acuity as a function of hue contrast between the target and the surround. He reported that in order to be equally effective for visual discrimination, the amount of brightness contrast between a neutral target and a neutral surround must be equal to the square root of the sum of the squares of brightness contrast and hue contrast when chromatic stimuli are used. MacAdam's finding indicated a positive summation effect of brightness contrast and hue contrast when a chromatic target is presented on a neutral surround. Therefore, with the brightness contrast between the target and the surround held constant, the addition of hue should improve visual discrimination. In other words, a chromatic target on a neutral surround should contribute more to visual discrimination than should an equiluminous gray target on the same surround. To obtain the same discrimination accuracy, the brightness contrast between a neutral target and a neutral surround presumably would have to be somewhat greater than the brightness contrast between a chromatic target and a neutral surround. MacAdam's data are highly accurate measures of the comparative effectiveness of hue contrast on visual discrimination.

Intensity and Wavelength of Illuminant

Accuracy of visual discrimination can be measured by visual acuity tests which require the observer to discriminate certain aspects of the target.

Within the range from mesopic level, at which cone function gradually takes over rod function, to low photopic level, at which vision is primarily cone function, visual acuity is a linear function of the illumination. Beyond an illumination of 10 millilamberts (mL.), however, the rate of increase of visual acuity diminishes as the illumination is further increased. Finally, at the high photopic level of about 1,000 mL., visual acuity no longer increases as illumination increases (Hecht, 1934, in Graham, 1966).

The ideal level of luminance for comfortable reading is 10 mL. (Graham, 1966). The National Council on School House Construction (1964) reports that illumination of 50 foot-candles (fc.) is commonly available in classrooms today. If colored media such as green chalkboards and blue tackboards have an average of approximately 30 percent reflectance from their surfaces, then the overall luminance in classrooms under the illumination of 50 fc. is approximately 50 mL. Konig's (Graham, 1966) data show that the visual acuity of average observers increases only slightly when luminance of achromatic stimuli is increased from 10 to 100 mL.

The effect of illuminant intensities of 25, 50, 75 and 100 fc. on visual discrimination was investigated in Part I of the present study in order to find whether Konig's data apply for all observers including color deficients when chromatic stimuli are used. An illumination of 50 fc. was chosen for Part II of the study for two reasons. Firstly, according to Konig, discrimination accuracy is increased very little as a function of illumination above this level. Secondly, this level of illumination is said to be commonly available in classrooms. Thus, the data obtained under this condition may provide useful information for real classroom situations.

It might be argued that it is not the external stimulus intensity but the retinal illumination on which visual discrimination is really dependent. However, the data obtained by Shlaer (Berger, 1941) on the dependency of visual acuity on retinal illumination coincide very well with Konig's data on the dependency of visual acuity on external illumination. The agreement between the data of these two authors indicates that external light intensity can be used in a valid way as an index of retinal illumination.

The spectral composition (wavelengths) of the illuminant, as well as its intensity, affects discrimination accuracy. Brown, Phares and Fletcher (1960) determined discrimination threshold as a function of spectral composition of the illuminant for a given level of resolution visual acuity. In order for average observers to show a resolution visual acuity of 100 lines per inch, the intensity of the illuminant at both ends of the spectrum had to be considerably higher than the illuminant at the central region of the spectrum. For instance, illuminants of 400 nm. and 680 nm. must have approximately 100 times as much energy as an illuminant of 500 nm. in order for average observers to see 100 lines per inch.

The illuminant used in the present study was an approximation of Source "C" which is standardized by the ICI. This illuminant was chosen for the present study for two reasons. Firstly, the stimulus materials were to be constructed with Munsell color paper, which is supposed to be used with Source "C". Secondly, the color temperature (°K) of this illuminant approximates closely that of fluorescent lights commonly used in classrooms today.

Brightness Contrast

It has been found in numerous studies that the brightness contrast between the target and the surround is an important variable for visual discrimination. For example, Ludvigh (1941) reported that recognition visual acuity of achromatic stimuli increased markedly when the brightness contrast between the target and the surround was increased from 5 percent to about 34 percent. Further increase in brightness contrast contributed little to visual acuity. Presumably, Ludvigh used subjects with normal color vision. In view of his finding, it seemed likely that if in the present study a brightness contrast of approximately 34 percent between the target and the surround were provided, then color deficients would be able to recognize the target almost as well as color normals even if chromatic stimuli were used.

Miyake (1930), Tinker and Patterson (1931), Preston and Schwanke (1932) and Sumner (1932) investigated the effect of color on the legibility of printed matter. The results of these studies indicated that brightness contrast between printed matter and the background had more effect than hue contrast on legibility.

MacNeil (1965) compared the legibility of white letters on an international-orange background, white letters on a red background, red letters on a black background, black letters on a red background and white letters on a black background under low-red, low-white and high-white illumination conditions. Black letters on a yellow background and white letters on a black background resulted in a significantly better legibility than other letter-background color combinations under the three illuminations. However, MacNeil pointed out that the above-mentioned two particular letter-background color combinations had the highest brightness contrast, which fact may very well account for their being most legible. Indeed, MacNeil concluded that reading speed is proportional to the brightness contrast between the letters and the background.

McLean (1965) investigated the effect of color contrast on the legibility of a circular dial. Legibility increased whenever the brightness contrast was increased. Chromatic numerals resulted in significantly better legibility than equiluminous achromatic numerals when the numerals were lighter than the background. However, this advantage of chromatic stimuli was not observed when the numerals were darker than the background.

The results of the above-mentioned studies confirm that brightness contrast is a major variable affecting legibility. However, they also indicate the contribution of hue contrast to visual discrimination. Their weakness is either that brightness contrast was confounded with hue contrast, or that not enough target-surround hue combinations were used or both.

In the present study the intent was to equalize the apparent brightness of the target and the surround in measuring the effect of hue contrast (Part I) by using hues of equal brightness and saturation as standardized by the Munsell System of Color Notation.

Saturation Contrast

Of course, saturation of a color can be changed by such means as adding various amounts of gray to a given hue. However, there are factors that result in changes in apparent saturation. For example, the apparent saturation of a color changes as a function of brightness contrast and hue contrast between the target and the surround.

Liebman (in Koffka, *et al.*, 1931) pointed out that a chromatic target and a surround having equal brightness and saturation but differing in hue when viewed independently, do not look equally saturated when they are paired together. In order to make them look equally saturated the brightness of one of them must be adjusted. The results of a study by Koffka and Harrower (1931) supported the Liebman effect.

MacAdam (1949) also reported the effect of saturation contrast on visual discrimination. For example, for an illuminant of about 575 nm., where the target and the surround are of the same hue, a saturation contrast of approximately 35 percent is as effective as a 5 percent brightness contrast between the target and the surround for visual discrimination.

Color Deficients

Hecht and Shlaer (1936a) reported that protanopes and deuteranopes could discriminate a wavelength difference of 1 nm. in the region of 500 nm. on the spectrum. However, their ability to discriminate wavelength, relative to color normals, is low at both ends of the spectrum (Graham, 1965, p. 402).

Protanopes and deuteranopes discriminate wavelength by the relative saturation of lights (Hecht and Shlaer, 1936b). In other words, protanopes and deuteranopes discriminate hues but not in the way color normals do. This conclusion is supported by the fact that these two types of color deficients can match any spectral light either by desaturating a 440 nm. light or a 650 nm. light with white light (Hecht, et al., 1939b).

Hecht and Shlaer (1948) reported that rod monochromats had maximum sensitivity at 520 nm. on the spectrum and that their brightness discrimination was as good as color normals'.

According to Hecht and Shlaer's findings, it is plausible to assume that if there is sufficient contrast of either saturation, brightness or both between the target and the surround, then color deficients will be able to make a visual discrimination which is as fine as color normals'.

Experimental Hypotheses

The present study was designed to investigate the effect of hue contrast, illuminant intensity, brightness contrast and viewing distance on the discrimination accuracy of color normals and color deficients when chromatic stimuli are used. It was of special interest to determine the conditions under which color deficients discriminate as accurately as color normals on the basis of brightness contrast in chromatic stimuli. The experimental hypotheses for the present study were as follows:

1. Discrimination accuracy of color normals, deuteranopes and protanopes increases as the amount of hue contrast between targets and surrounds is increased.
2. Discrimination accuracy of color normals, deuteranopes and protanopes does not increase by raising illuminant intensity from 25 fc. to 100 fc.
3. Discrimination accuracy of color deficients is lower than that of color normals if there is hue contrast between chromatic targets and chromatic surrounds but neither brightness contrast nor saturation contrast.
4. Discrimination accuracy of color deficients is as good as that of color normals if the brightness contrast between chromatic targets and chromatic surrounds is approximately 30 percent or more.
5. As the viewing distance is increased, discrimination accuracy of color deficients decreases more than that of color normals.

CHAPTER III

Method

Subjects

Six subjects (Ss) with normal color vision, six deuteranopes and six protanopes participated in this experiment. All of them were male except one in the color normal group. One deuteranope was a fifteen-year-old junior high boy. The rest of the Ss were Indiana University students with an age range of 19 to 28. The Ss are identified by two initials such as "W.D."

Apparatus

Instrumentation. A black box 36" high, 82" wide and 26" deep with a circular hole of 4 3/4" diameter in its front side was used to exclude extraneous light from the stimuli, namely, targets and their surrounds. The stimuli were supported in a frame, behind a black mask, located 20" from the front of the box. There was a circular hole of 2 2/5" diameter at the center of the black mask. The center of this circular hole where each target was placed was aligned with the center of the circular hole of the black box. The stimuli were illuminated by four GE Type PH/211 bulbs placed approximately 90° from each other in a plane parallel with that of the target. A cone-shaped reflector of 5" diameter was used for each bulb. The light from each bulb passed through a Macbeth Roundel Filter No. 55590000 to give an approximation of the ICI Source "C" illumination. The illuminant intensity was controlled both by the voltage supplied by a variac to the bulbs and by the number of lamps used. Either the horizontal pair of lamps, the vertical pair of lamps or all four lamps were used at any one time. The relationship between the applied voltage, illuminant intensity, luminance from a surface with 30 percent reflectance and color temperature is shown in Table 1.

TABLE 1

Applied Voltage and Number of Lamps Used to Obtain Required Illuminant Intensities, Color Temperature of the Illuminants and the Luminance of a Surface Having 30 Percent Reflectance

Required illuminant intensity (fc.)	Applied voltage (v.)	Number of lamps used	Color temperature (°K)	Luminance (mL.)
100	117.5	4	6500	101.46
75	110.0	4	6000	76.10
50	112.0	2*	5750	50.73
25	102.5	2**	4900	25.37

*The horizontal pair of lamps.

**The vertical pair of lamps.

A chinrest with a headrest was used to obtain central fixation. A photographic timer ("Time-O-Lite") was used to give an approximately eight-second exposure for each stimulus.

Stimulus materials. Each stimulus consisted of a target and a surround, both made of Munsell color paper. The target was a Landolt-type broken circle with an outside diameter of six millimeters (mm.), a thickness of two mm. and a gap of two mm. Each target was placed at the center of a 3" x 5" surround. The visual angles subtended by the surround, the target and the gap in the target at each viewing distance are shown in Table 2. The viewing distance is that between the target and S's eye.

TABLE 2

Visual Angles Subtended by the Surround, the Target and the Gap in the Target at Each Viewing Distance

Viewing distance in meters	Visual angles in degrees(°), minutes(') and seconds(")		
	Surround	Target	Gap in target
3	1°8'37"	6'53"	2'18"
5	41'23"	4' 8"	1'23"
6	34'29"	3'27"	1' 9"
7	29'33"	2'57"	1' 0"
8	25'50"	2'35"	52"

The complete specification of a chromatic color according to the Munsell System of Color Notation is written symbolically in the order of hue, brightness and saturation. A hue is specified by a numeral and an alphabetic letter following this numeral. A brightness and a saturation are specified, respectively, by two numerals with a slash in between them. For example, in the notation 5R 4/6, the R stands for red hue and the 5 specifies the position of this specific red in the entire region of red hue on the Munsell Hue Circle (Fig. 1). The expression 4/6 specifies that the brightness and saturation of this specific color are ranked, respectively, at the 4th and 6th position in the Munsell scales

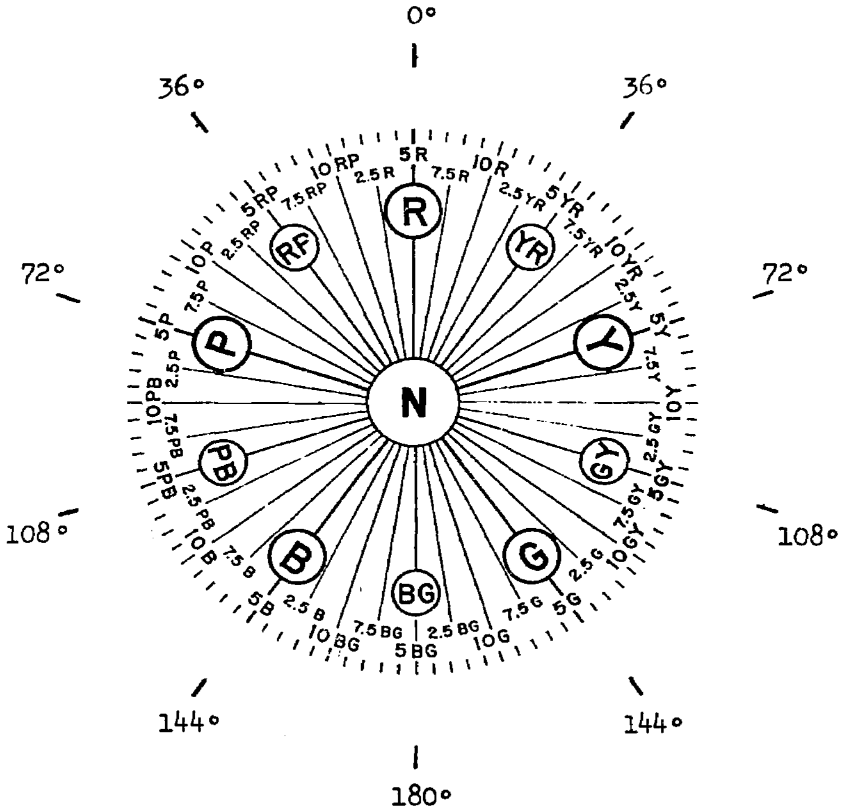

Fig. 1. Munsell Hue Circle (Courtesy of Munsell Color Company)

for brightness and saturation. It will be seen below that saturation was held constant at the 6th position throughout the entire study.

R stands for red, G green, B blue, RP red-purple, P purple, PB purple-blue, BG blue-green, GY green-yellow, Y yellow, and YR yellow-red. An achromatic color is denoted by N followed by a numeral which specifies its brightness. Achromatic colors having no hue at all are not in the Munsell Hue Circle, and there is no saturation scale for achromatic colors. Thus, N 6/ denotes a neutral gray with a brightness ranked at the 6th position in the Munsell brightness scale.

For Part I of the study the target colors were 5R 6/6, 5G 6/6, and 5B 6/6 in the Munsell System of Color Notation. The surround colors were

5R 6/6, 5RP 6/6, 5P 6/6, 5PB 6/6, 5B 6/6, 5BG 6/6, 5G 6/6, 5GY 6/6, 5Y 6/6, 5YR 6/6 and N 6/. There were 30 stimuli, each composed of a particular target-surround pair.

For Part II of the study the target colors were 5R 7/6, 5G 7/6 and 5B 7/6. The surround hues were 5R, 5RP, 5P, 5PB, 5B, 5BG, 5G, 5GY, 5Y, 5YR and N. The brightnesses and saturations of the surrounds were 6/6 for Group A of the stimuli, 5/6 for Group B, 4/6 for Group C and 3/6 for Group D. According to the Munsell System of Color Notation, brightness contrast between the target and the surround was approximately 30.23 percent in Group A of the stimuli, 53.49 percent in Group B, 72.09 percent in Group C and 83.72 percent in Group D. Each group consisted of 33 stimuli. Each stimulus consisted of a particular target-surround pair. Thus, there were 33 different target-surround pairs making up each of the four groups of stimuli.

The orientations of the targets were such that the gap was either upward, up-right, right, down-right, downward, down-left, left and up-left. The loci of the gap in terms of degrees were, respectively, 0, 45, 90, 135, 180, 225, 270 and 315. One of these eight orientations was randomly assigned to each stimulus.

<u>Specification of the amount of hue contrast between the target and the surround</u>. The amount of hue contrast between the target and the surround was specified by the angular displacement between the target hue and the surround hue on the Munsell Hue Circle.

The angular displacement between a pair of adjacent major hues on the circle is 36°. Likewise, the angular displacement between a pair of major hues two steps apart on the circle is 72°. The magnitudes of hue contrast between the target and the surround included in the experiment were 36°, 72°, 108°, 144°, and 180°, the latter being the largest amount of hue contrast obtainable on the Munsell Hue Circle. The Munsell Hue Circle is constructed according to the principles of equal visual space. That is, based on an equal-appearing-intervals method each of 100 separate hues is perceptually equally different from each of its two adjacent hues on the circle. For example, the perceived difference in hue between 5R and 5YR is equal to that between 5YR and 5Y. Thus, 5YR is perceptually at the middle point between 5R and 5Y. The simplicity of the Munsell Hue Circle makes it a very convenient way of specifying hues for preparing instructional materials.

Procedure

Tests on color vision and visual acuity. Each *S*'s color vision was tested with AO H-R-R Pseudoisochromatic Color Plates under the illumination from a Macbeth Lamp ADE-10. A Paraboline Slide Model 11179 and a projector Model 11082 manufactured by the American Optical Company were used to project Snellen-type letters on a silver surface for testing *S*'s recognition visual acuity. The results of these tests are shown in Table 3.

TABLE 3

Visual Acuity, Side of Dominant Eye
and Color Defectiveness of Ss

Color vision	Visual acuity of the dominant eye	Side of the dominant eye	Extent of defective color vision*
Color Normals			
W.D.	20/15+2	Left	
C.D.	20/15-1	Left	
T.S.	20/15-1	Right	
D.S.	20/15-2	Right	
T.D.	20/15-2	Right	
G.W.	20/20+2	Left	
Deuteranopes			
P.J.	20/15+2	Right	Medium
M.Y.	20/15	Right	Medium
K.L.	20/15	Right	Medium
D.L.	20/15-1	Right	Medium
J.J.	20/15-2	Right	Mild
T.N.	20/20+3	Left	Strong
Protanopes			
D.G.	20/15	Right	Medium
T.W.	20/15-1	Right	Medium
E.S.	20/15-2	Right	Mild
J.H.	20/15-2	Left	Mild
S.D.	20/15-3	Right	Medium
J.D.	20/20-2	Right	Strong

*According to the AO H-R-R Pseudiosochromatic Plates Record Sheet; 2nd Edition, 1957.

Each S used his dominant eye for monocular observation throughout the entire experiment. The dominant eye of each S was determined as follows:

a. The experimenter (E) stood in front of S at a distance of approximately 2 m.

b. S stretched his hands straight in front, forming a small hole with his palms and looked at E's forehead with binocular vision.

c. The eye of S which E saw through the hole formed by S's palms was said to be S's dominant eye.

Instructions. Before test trials E showed S eight samples of targets, each with a separate orientation with respect to the position of the gap in the broken circle. Of course, conditions were such that S could easily see the gap. E gave S brief verbal instructions concerning the task to be performed. No verbatim instructions were given for the reason that the task was so simple that the wording of the instructions was judged not to be a critical variable in this experiment.

Test trials. The response required of Ss was to attempt to state aloud the orientation of the gap in each target. Since this was a fairly straightforward task, no practice was given before the experiment. Ss were encouraged to make guesses when they were uncertain of the orientations of the targets. The failure by S to make a response was counted as an incorrect response. If more than one response was made to the same target, the last response was the one recorded.

For each S there were two experimental sessions on separate days. S participated in Part I first. S proceeded to the first half of Part II on the same day. The second half of Part II occurred on another day. The first half of Part II covered observations from two randomly chosen and randomly ordered viewing distances and the second half observations from the remaining two viewing distances which were also randomly ordered. A short rest period was given after the completion of each 30 observations in Part I and 33 observations in Part II. The experiment was conducted in a darkened room, but a certain level of light adaptation was maintained by the successive presentations of the targets and by the light of approximately 8 fc. on the wall behind the box whose source was the lamp inside the box. Room lights of approximately 125 footcandles were turned on during rest periods.

Sequence of stimulus presentation and randomization of experimental variables. For Part I of the study the viewing distance was fixed at 3 meters (m.) from the target. Four different illuminant intensities, namely, approximately 25, 50, 75 and 100 fc. (see Table 1) were used. Sequences of these four illuminant conditions were randomized for each S, with the restriction that each stimulus was presented once under each of the four different illuminant conditions. Thus, the total number of observations for each S in Part I was 30 stimuli under each illuminant condition x 4 illuminant conditions = 120. The 30 stimuli were randomly arranged in 25 different sequences, and four of these 25 sequences were randomly selected for each S to cover the 120 observations in Part I.

For Part II of the study the illuminant intensity was fixed at 50 fc. Four different viewing distances, namely, 5, 6, 7 and 8 m. and four different brightness contrast groups of stimuli as described earlier in this chapter were used. There were 33 stimuli in each brightness contrast group. Thus, the number of observations for each S in Part II at each of the four viewing distances was 33 stimuli in each brightness contrast group x 4 brightness contrast groups = 132. All 132 observations at each viewing distance were made successively without changing the viewing distance. The order of the four viewing distances was randomized for each S. Also, sequences of presenting the four brightness contrast groups of stimuli were randomized for each S. The 33 stimuli in each brightness contrast group were randomly arranged in 25 different sequences. Sixteen out of these 25 sequences were randomly selected for each S to cover the 528 observations in Part II.

CHAPTER IV

Results

Overall Results of Part I

An analysis of variance for a three-factor experiment having repeated measures on two of the factors (Winer, 1962, p. 319) was applied to the data of Part I of the experiment. There were independent measures with respect to type of color vision and repeated measures on the same Ss with respect to hue contrast and illuminant intensity. The results of the analysis are shown in Table 4.

TABLE 4

Analysis of Variance for the Main Effects of Type of Color Vision, Hue Contrast and Illuminant Intensity

Source	df	MS	F
Between Subjects			
Type of Color Vision (A)	2	217.67	11.48*
Ss within groups	15	18.97	
Within Subjects			
Hue Contrast (B)	4	92.11	36.52*
AB	8	3.26	1.29
B x Ss within groups	60	2.52	
Illuminant Intensity (C)	3	8.80	9.89*
AC	6	.92	1.04
C x Ss within groups	45	.89	
BC	12	.42	.67
ABC	24	.66	1.04
BC x Ss within groups	180	.63	

*$p < .01$

The .01 critical region was adopted for testing the significance of experimental effects and components of trends in this and in later analyses.

The main effects of type of color vision were significant. Color normals' discrimination accuracy was the highest followed by deuteranopes' and then by protanopes'. The mean percentage correct responses was 74.84 for color normals, 66.95 for deuteranopes and 32.26 for protanopes. Results of the Newman-Keuls test revealed that color normals' discrimination accuracy was significantly higher than that of deuteranopes which in turn was significantly higher than that of protanopes. Thus, color normals' discrimination accuracy was also significantly higher than that of protanopes in Part I.

The main effects of hue contrast were also significant. Discrimination accuracy increased as hue contrast was increased from 36° to 180°. The mean percentage correct responses was 31.02 at 36°, 45.60 at 72°, 64.58 at 108°, 72.22 at 144° and 75.00 at 180°.

The main effects of illuminant intensity were also significant. Discrimination accuracy increased as illuminant intensity was raised from 25 to 100 fc. The mean percentage correct responses was 50.74 at 25 fc., 56.48 at 50 fc., 61.48 at 75 fc. and 61.85 at 100 fc. None of the interactions was significant.

The Simple Main Effects of Hue Contrast

The mean percentage correct responses at each amount of hue contrast by Ss having each type of color vision in Part I is shown in Table 5.

TABLE 5

Mean Percentage Correct Responses at Each Amount
of Hue Contrast by *Ss* Having Each Type
of Color Vision

Type of color vision	Hue contrast in degrees (°)				
	36	72	108	144	180
Color Normals	44.44	56.94	84.03	92.36	93.06
Deuteranopes	39.58	50.00	72.22	84.72	87.50
Protanopes	9.03	29.86	37.50	39.58	44.44

Profiles corresponding to the simple main effects of hue contrast for each type of color vision in Part I are shown in Fig. 2. At each value of hue contrast mean percentage correct responses varied significantly from one type of color vision to another.

Since pairs of adjacent values of hue contrast used in the present study are said to be perceptually equally different from each other, we might expect that discrimination accuracy would increase as a linear function of hue contrast in the case of *Ss* with normal color vision. Analyses of trends for the three types of color vision were made. The results of these analyses are shown in Table 6. The linear components of the profiles of the simple main effects of hue contrast for color normals and deuteranopes were significant. None of the components of the profiles for the protanopes was significant. A profile corresponding to the main effects of hue contrast was not plotted in Fig. 2 for the reason that its intercept may not adequately represent either one of the three intercepts for the separate color vision types. This is true because

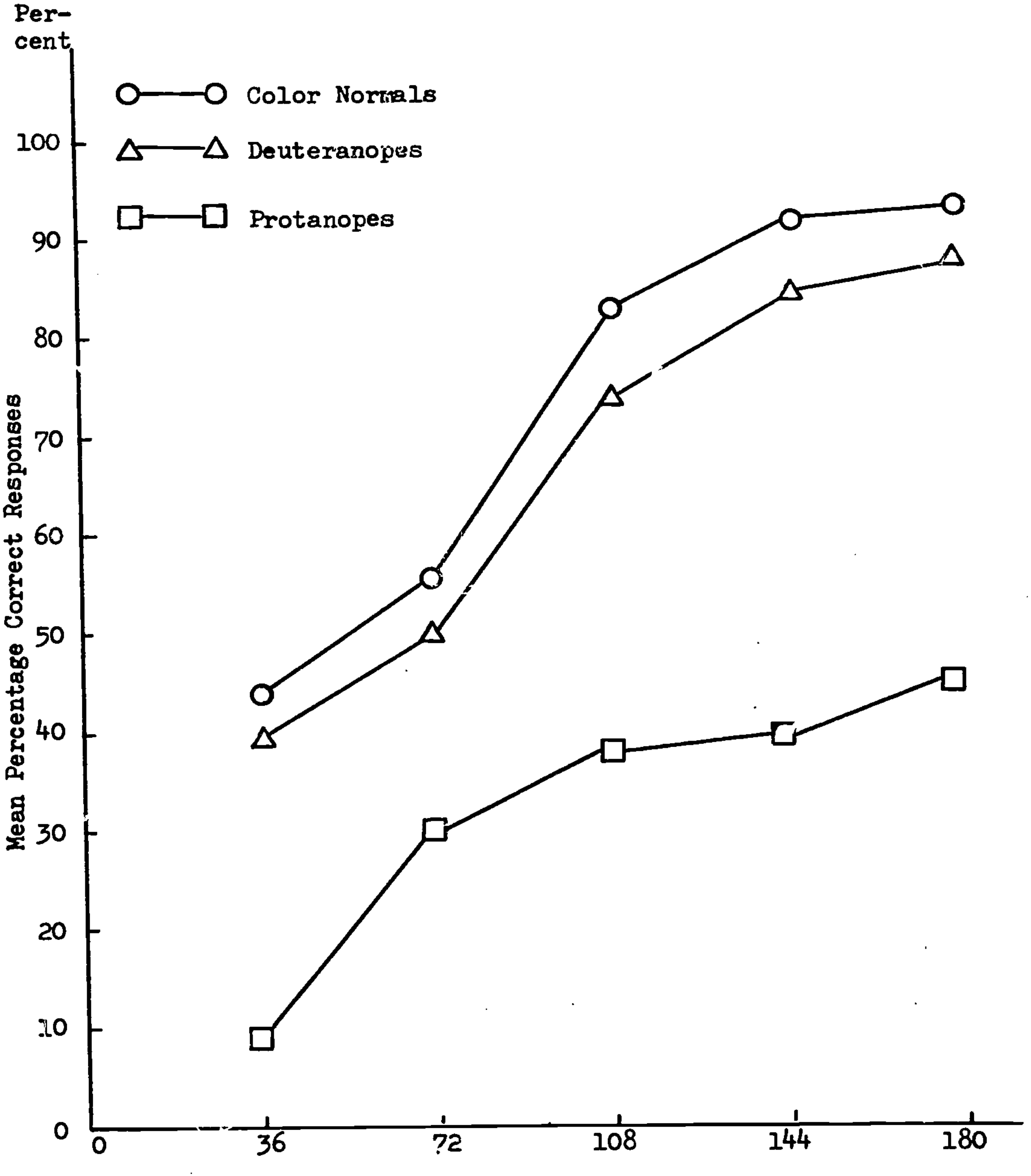

Fig. 2. Profiles of the Simple Main Effects of Hue Contrast in Part I

TABLE 6

Analyses of Trends of the Simple Main Effects of Hue Contrast for Each Type of Color Vision

Source	df	MS	F	Percentage of the sum of squares for overall trend
COLOR NORMALS				
Overall trend	4	169.78	18.74*	
Linear	1	608.02	29.97*	89.53
Quadratic	1	44.30	6.48	6.52
Cubic	1	17.07	8.26	2.51
Between individual trends	20	9.04		
Linear	5	23.42		
Quadratic	5	6.84		
Cubic	5	2.07		
DEUTERANOPES				
Overall trend	4	155.70	22.24*	
Linear	1	589.07	62.76*	94.58
Quadratic	1	15.43	1.58	2.48
Cubic	1	16.02	9.44	2.57
Between individual trends	20	7.00		
Linear	5	9.39		
Quadratic	5	9.77		
Cubic	5	1.70		
PROTANOPES				
Overall trend	4	66.95	4.77*	
Linear	1	224.27	5.81	83.74
Quadratic	1	34.71	3.52	12.90
Cubic	1	8.82	1.32	3.29
Between individual trends	20	14.05		
Linear	5	38.59		
Quadratic	5	9.86		
Cubic	5	6.70		

*$p < .01$

NOTE: The total percentage of linear, quadratic and cubic components is less than 100 for each type of color vision because the quartic component was not included in this table.

color normals' mean percentage correct responses was significantly higher than that of deuteranopes, which in turn was significantly higher than that of protanopes. The linear regression coefficient and intercept of the profile for color normals were .369 and 34.37, respectively, while they were .363 and 27.64 for deuteranopes.

The Newman-Keuls test was applied to determine the significant ranges in the simple main effects of hue contrast (Table 7). The amounts of hue contrast were arranged in Table 7 from left to right in the order of increasing discrimination accuracy.

TABLE 7

Significant Ranges in the Simple Main Effects of Hue Contrast for Each Type of Color Vision

Type of color vision	Hue contrast in degrees (°)				
	36	72	108	144	180
Color normals			—	—	—
Deuteranopes	—	—		—	—
Protanopes		—	— —	— —	—

NOTE: The simple main effects of hue contrast underlined by a common line do not differ significantly from each other.

Color normals' discrimination accuracy increased significantly when the amount of hue contrast was increased each step from 36° to 108°. There was no evidence that further increase in the amount of hue contrast beyond 108° contributed to color normals' discrimination accuracy. Deuteranopes' discrimination accuracy increased significantly when the amount of hue contrast was increased each step from 72° to 144°. Their discrimination accuracy did not differ significantly within the hue contrast ranges of 36° to 72° and 144° to 180°. Protanopes' discrimination accuracy increased significantly when the amount of hue contrast was increased from 36° to 72° and from 72° to 180°. Their discrimination did not differ significantly within the hue contrast ranges of 72° to 144° and 108° to 180°.

The Simple Main Effects of Illuminant Intensity

The mean percentage correct responses at each illuminant intensity by Ss having each type of color vision is shown in Table 8.

TABLE 8

Mean Percentage Correct Responses at Each Illuminant Intensity by Ss Having Each Type of Color Vision

Type of color vision	Illuminant intensity in footcandles (fc.)			
	25	50	75	100
Color normals	66.11	72.78	78.89	78.89
Deuteranopes	56.67	68.33	69.44	72.22
Protanopes	29.44	28.33	35.00	34.44

Profiles corresponding to the simple main effects of illuminant intensity for each type of color vision are shown in Fig. 3. At each value of illuminant intensity mean percentage correct responses varied significantly from one type of color vision to another.

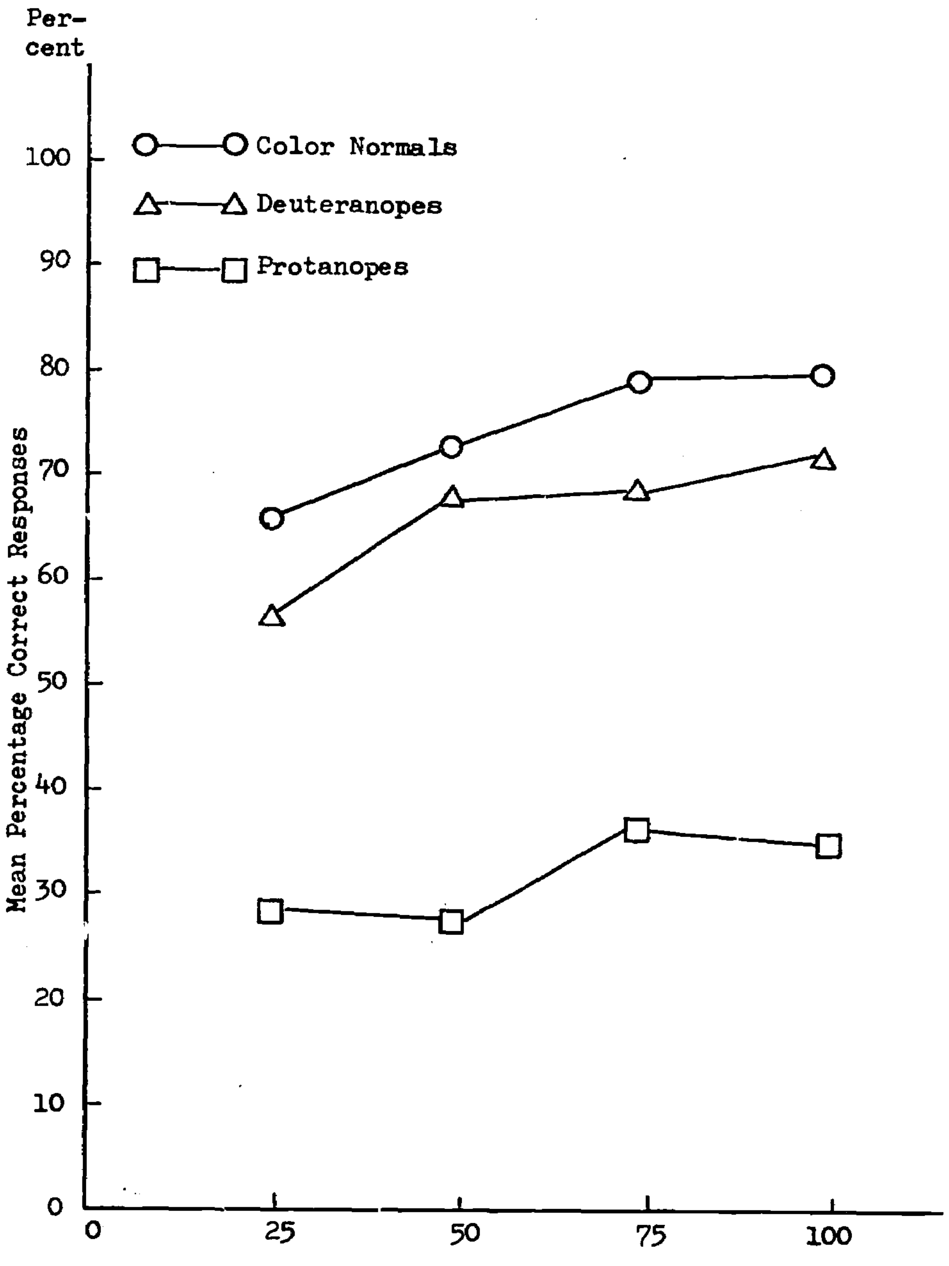

Fig. 3. **Profiles of the Simple Main Effects of Illuminant Intensity**

Since pairs of adjacent values of illuminant intensity used in the present study are physically equally different from each other, we might expect discrimination accuracy to increase as a linear function of illuminant intensity. Analyses of trends were made for the three types of color vision. The results of these analyses are shown in Table 9.

The linear component of the profile obtained for color normals was significant. None of the components of the profiles obtained for deuteranopes and protanopes was significant. A profile corresponding to the main effects of illuminant intensity was not plotted in Fig. 4 for the reason that its intercept may not adequately represent either one of the three intercepts for the separate color vision types. This is true because color normals' mean percentage correct responses was significantly higher than that of deuteranopes which in turn was significantly higher than that of protanopes. The linear regression coefficient of the trend for color normals was .178 and the intercept was 63.06.

TABLE 9

Analyses of Trends of the Simple Main Effects of Illuminant Intensity for Each Type of Color Vision

Source	df	MS	F	Percentage of the sum of squares for overall trend
COLOR NORMALS				
Overall trend	3	20.06	16.41	
Linear	1	53.33	135.59*	88.64
Quadratic	1	6.00	4.00	9.97
Cubic	1	.83	.47	1.39
Between individual trends	15	1.22		
Linear	5	.39		
Quadratic	5	1.50		
Cubic	5	1.77		
DEUTERANOPES				
Overall trend	3		2.71	
Linear	1	61.63	3.19	80.74
Quadratic	1	10.67	4.00	13.98
Cubic	1	4.03	.66	5.28
Between individual trends	15	9.38		
Linear	5	19.31		
Quadratic	5	2.67		
Cubic	5	6.15		
PROTANOPES				
Overall trend	3	7.71	2.81	
Linear	1	14.01	3.14	60.58
Quadratic	1	.04	.03	.18
Cubic	1	9.08	3.76	39.24
Between individual trends	15	2.74		
Linear	5	4.47		
Quadratic	5	1.34		
Cubic	5	2.42		

*$p < .01$

The Newman-Keuls test was applied to determine the significant ranges in the simple main effects of illuminant intensity (Table 10). The amounts of illuminant intensity were arranged in Table 10 from left to right in the order of increasing discrimination accuracy.

TABLE 10

Significant Ranges in the Simple Main Effects of Illuminant Intensity for Each Type of Color Vision

Type of color vision	Illuminant intensity in footcandles (fc.)			
	25	50	75	100
Color normals			———	———
Deuteranopes		———	———	———
Protanopes	———	———	———	———

NOTE: The simple main effects of illuminant intensity underlined by a common line do not differ significantly from each other.

Color normals' discrimination accuracy increased significantly when illuminant intensity was raised each step from 25 to 75 fc. There was no evidence that further increase in illuminant intensity beyond 75 fc. contributed to their discrimination accuracy. Deuteranopes' discrimination accuracy increased significantly when illuminant intensity was raised from 25 to 50 fc. There was no evidence that further increase in illuminant intensity beyond 50 fc. contributed to their discrimination accuracy. Protanopes' discrimination accuracy increased when illuminant intensity was raised from 50 to 75 fc. Their discrimination accuracy did not differ significantly within the illuminant intensity ranges of 25 to 50 fc. and 75 to 100 fc.

Overall Results of Part II

As in Part I of the experiment, an analysis of variance for a three-factor experiment having repeated measures on two of the factors was applied to the data obtained in Part II of the experiment. There were independent measures with respect to type of color vision and repeated measures on the same Ss with respect to brightness contrast and viewing distance. The results of the analysis are shown in Table 11.

TABLE 11

Analysis of Variance for the Main Effects of Type of Color Vision, Brightness Contrast and Viewing Distance

Source	df	MS	F
Between Subjects			
Type of color vision (A)	2	231.50	.39
Ss within groups	15	592.12	
Within Subjects			
Brightness contrast (B)	3	3658.62	309.95*
AB	6	6.27	.53
B x Ss within groups	45	11.80	
Viewing distance (C)	3	3333.41	109.68*
AC	6	14.13	.47
C x Ss within groups	45	30.39	
BC	9	45.99	2.79*
ABC	18	7.78	.47
BC x Ss within groups	135	16.54	

$^{*}p < .01$

The main effects of type of color vision were not significant. Thus, there was no evidence that color normals, deuteranopes and protanopes differed in their discrimination accuracy in Part II of the experiment. The mean percentage correct responses in Part II was 61.34 for color normals, 57.83 for deuteranopes and 53.25 for protanopes.

The main effects of brightness contrast were significant. Discrimination accuracy increased as the amount of brightness contrast between the target and the surround was increased from 30.23 to 83.72 percent. The mean percentage correct responses was 28.75 at the brightness contrast of 30.23 percent, 57.20 at the brightness contrast of 53.49 percent, 72.39 at the brightness contrast of 72.09 percent and 76.39 at the brightness contrast of 83.72 percent.

The main effects of viewing distance were also significant. Discrimination accuracy decreased significantly as viewing distance was increased from 5 to 8 m. The mean percentag orrect responses was 81.78 at 5 m., 67.59 at 6 m., 51.34 at 7 m. and 34.01 at 8 m.

The interaction between brightness contrast and viewing distance was significant. The nature of this interaction will be described later in this chapter and its implications will be discussed in Chapter V.

The Simple Main Effects of Brightness Contrast

The mean percentage correct responses at each brightness contrast by Ss having each type of color vision is shown in Table 12.

TABLE 12

Mean Percentage Correct Responses at Each Brightness Contrast by Ss Having Each Type of Color Vision

Type of color vision	Brightness contrast in percent			
	30.23	53.49	72.09	33.75
Color normals	30.43	61.36	75.88	78.66
Deuteranopes	31.44	60.73	74.62	78.03
Protanopes	24.37	49.50	66.67	72.48

NOTE: An average hue contrast of approximately 108° was available in each brightness contrast.

Profiles corresponding to the main effects and the simple main effects of brightness contrast for each type of color vision are shown in Fig. 4. Since pairs of adjacent values of brightness contrast used in the present study are said to be perceptually equally different from each other, we might expect that discrimination accuracy increases as a linear function of brightness contrast. Analyses of trends were made for the three types of color vision. The results of these analyses are shown in Table 13. The linear and quadratic components of the profiles of the main effects of brightness contrast as well as those of the simple main effects of brightness contrast for each type of color vision were significant. Since neither the main effects of type of color vision nor the interaction between type of color vision and brightness contrast was significant, the profile corresponding to the main effects of brightness contrast may adequately represent the effect of brightness contrast on discrimination accuracy for all three types of color vision.

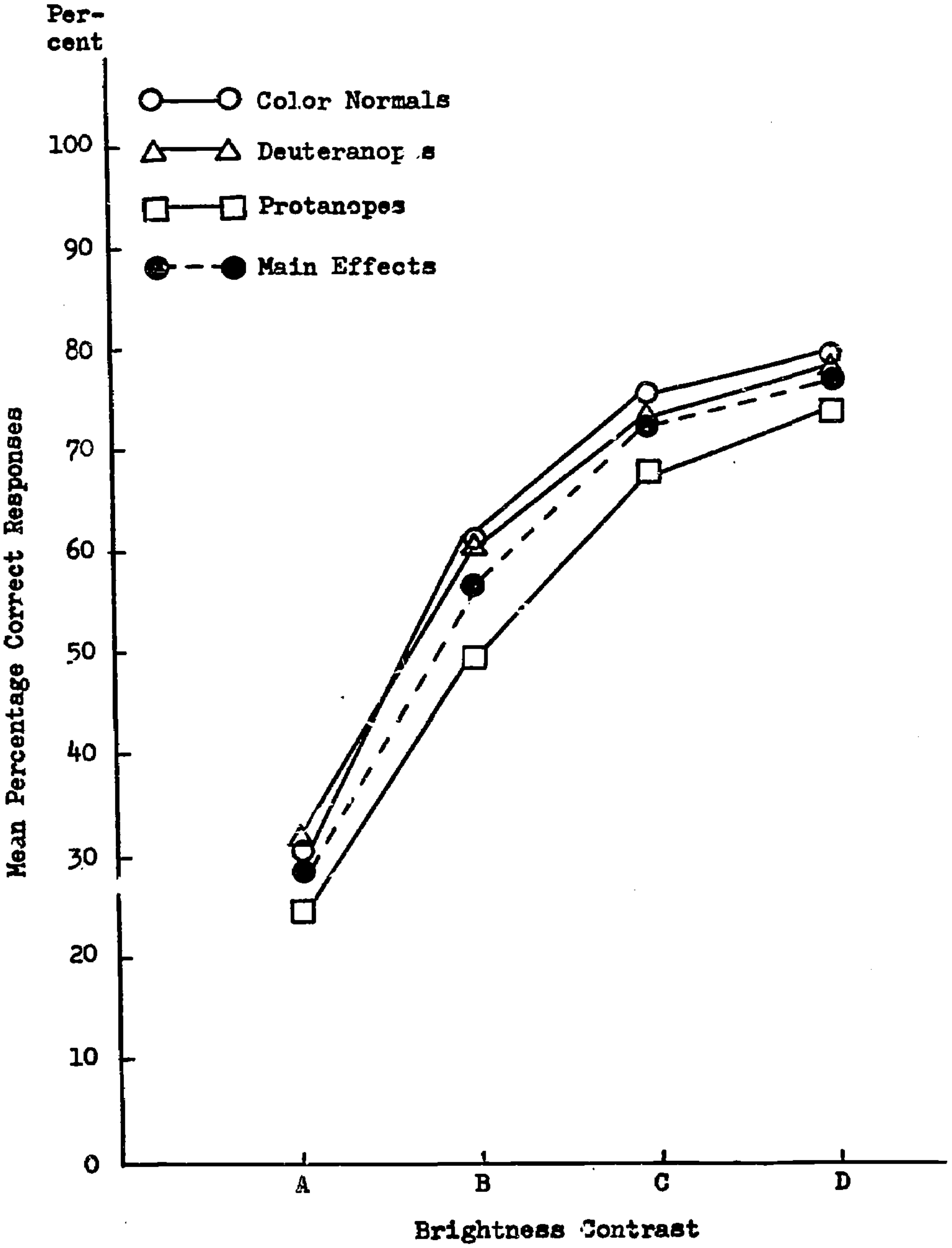

Fig. 4. Profiles of the Main Effects and Simple Main Effects of Brightness Contrast

NOTE: A represents a brightness contrast of 30.23 percent, B represents 53.49 percent, C represents 72.09 percent and D represents 8?.75 percent.

TABLE 13

Analyses of Trends of the Main Effects and the Simple Main Effects of Brightness Contrast for Each Type of Color Vision

Source	df	MS	F	Percentage of the sum of squares for overall trend
MAIN EFFECTS				
Overall trend	3	14634.50	309.95*	
Linear	1	39208.47	728.76*	89.31
Quadratic	1	4688.35	70.41*	10.68
Cubic	1	6.67	.31	.02
Between individual trends	45	47.22		
Linear	15	53.80		
Quadratic	15	66.59		
Cubic	15	21.26		
COLOR NORMALS				
Overall trend	3	5111.49	105.71*	
Linear	1	13251.01	344.65*	86.41
Quadratic	1	2072.04	29.42*	13.51
Cubic	1	11.41	.32	.07
Between individual trends	15	48.35		
Linear	5	38.45		
Quadratic	5	70.44		
Cubic	5	36.17		
DEUTERANOPES				
Overall trend	3	4702.04	68.50*	
Linear	1	12342.41	145.12*	87.50
Quadratic	1	1751.04	16.58*	12.41
Cubic	1	12.68	.83	.09
Between individual trends	15	68.64		
Linear	5	85.05		
Quadratic	5	105.64		
Cubic	5	15.24		

*p < .01

TABLE 13 (Continued)

Source	df	MS	F	Percentage of the sum of squares for overall trend
PROTANOPES				
Overall trend	3	4871.15	197.59*	
Linear	1	13632.01	359.61*	93.23
Quadratic	1	975.38	41.20*	6.67
Cubic	1	6.08	.49	.04
Between individual trends	15	24.65		
Linear	5	37.91		
Quadratic	5	23.68		
Cubic	5	12.38		

The linear regression coefficient and intercept for the profile of the main effects of brightness contrast were, respectively, 15.865 and 18.98. The quadratic regression coefficients for the same profile were 46.653 and -6.158. The intercept for the quadratic regression was -11.81.

The Newman-Keuls test was applied to determine the significant ranges in the simple main effects of brightness contrast (Table 13). The amounts of brightness contrast were arranged in Table 14 from left to right in order of increasing discrimination accuracy.

TABLE 14

Significant Ranges in the Simple Main Effects of Brightness Contrast for Each Type of Color Vision

Type of color vision	Brightness contrast in percent			
	30.23	53.49	72.09	83.75
Color normals			———	———
Deuteranopes			———	———
Protanopes				

NOTE: The simple main effects of brightness contrast underlined by a common line do not differ significantly from each other.

Color normals' and deuteranopes' discrimination accuracy increased significantly when the amount of brightness contrast was raised each step from 30.23 to 72.09 percent. Further increase in the amount of brightness contrast beyond 72.09 percent did not contribute to their discrimination accuracy. Protanopes' discrimination accuracy increased significantly each step as the amount of brightness contrast was raised from 30.23 to 83.75 percent.

The Simple Main Effects of Viewing Distance

The mean percentage correct responses at each viewing distance by Ss having each type of color vision is shown in Table 15.

TABLE 15

Mean Percentage Correct Responses at Each Viewing Distance by Ss Having Each Type of Color Vision

Type of color vision	Viewing distance in meters (m.)			
	5	6	7	8
Color normals	84.09	69.44	52.27	40.53
Deuteranopes	83.84	70.20	54.80	35.98
Protanopes	77.40	63. [illegible]	46.97	25.51

Profiles corresponding to the main effects and the simple main effects of viewing distance for each type of color vision are shown in Fig. 5. Since neither the main effects of type of color vision nor the interaction between type of color vision and viewing distance was significant, a profile corresponding to the overall main effects of viewing distance may adequately represent the effect of viewing distance on discrimination accuracy for all three types of color vision.

Since pairs of adjacent values of viewing distance included in the present study are physically equally different from each other, we might expect that discrimination accuracy decreases as a linear function of viewing distance. Analyses of trends for the three types of color vision were made. The results of these analyses are shown in Table 16. The linear components of the profiles of the main effects and the simple main effects of viewing distance for each type of color vision were significant. The linear regression coefficient for the profile of the main effects of viewing distance was -15.952 and the intercept was 162.38.

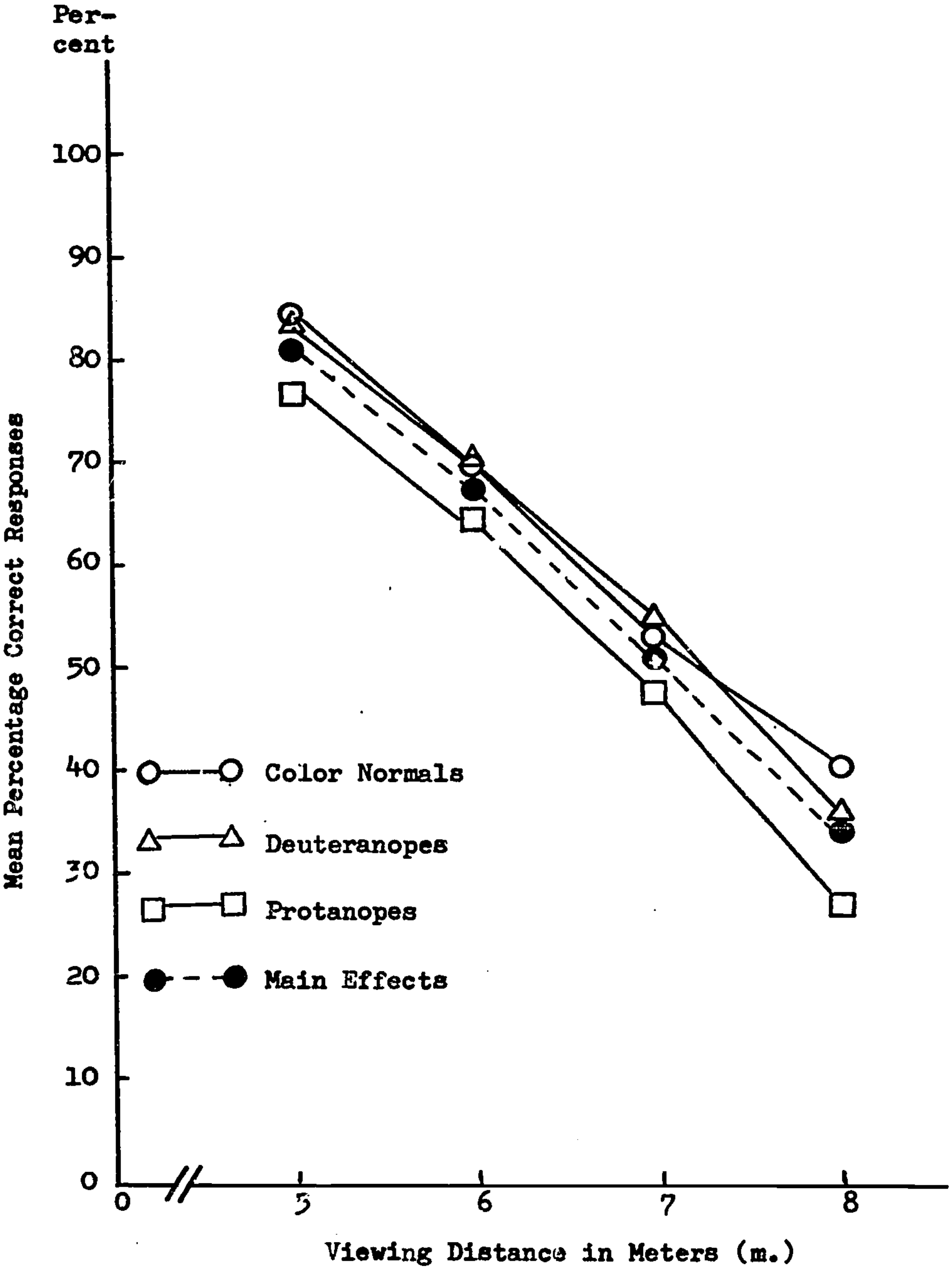

Fig. 5. Profiles of the Main Effects and the Simple Main Effects of Viewing Distance

TABLE 16

Analyses of Variance for the Main Effects and the Simple Main Effects of Viewing Distance for Each Type of Color Vision

Source	df	MS	F	Percentage of the sum of squares for overall trend
MAIN EFFECTS				
Overall trend	3	13333.64	109.68*	
Linear	1	39921.34	178.35*	99.80
Quadratic	1	78.13	1.71	.20
Cubic	1	1.47	.02	.00
Between individual trends	45	121.57		
Linear	15	223.84		
Quadratic	15	45.72		
Cubic	15	95.15		
COLOR NORMALS				
Overall trend	3	3827.38	20.61*	
Linear	1	11427.01	27.15*	99.52
Quadratic	1	22.04	.26	.20
Cubic	1	33.08	.65	.29
Between individual trends	15	185.71		
Linear	5	420.89		
Quadratic	5	85.04		
Cubic	5	51.20		
DEUTERANOPES				
Overall trend	3	4426.82	45.38*	
Linear	1	13209.01	74.78*	99.46
Quadratic	1	70.04	2.80	.53
Cubic	1	1.41	.02	.01
Between individual trends	15	97.55		
Linear	5	176.65		
Quadratic	5	25.04		
Cubic	5	90.97		

*$p < .01$

TABLE 16 (Continued)

Source	df	MS	F	Percentage of the sum of squares for overall trend
PROTANOPES				
Overall trend	3	5192.49	63.75*	
Linear	1	15436.01	208.63*	99.09
Quadratic	1	135.38	5.00	.87
Cubic	1	6.08	.04	.04
Between individual trends	15	81.45		
Linear	5	73.99		
Quadratic	5	27.08		
Cubic	5	143.30		

*$p < .01$

Results of Newman-Keuls tests revealed that color normals', deuteranopes' and protanopes' discrimination accuracy decreased significantly each step as viewing distance was increased from 5 to 8 m.

Interaction

The mean percentage correct responses for each brightness contrast at each viewing distance is shown in Table 17.

Profiles corresponding to the simple main effects of viewing distance for each brightness contrast are shown in Fig. 6.

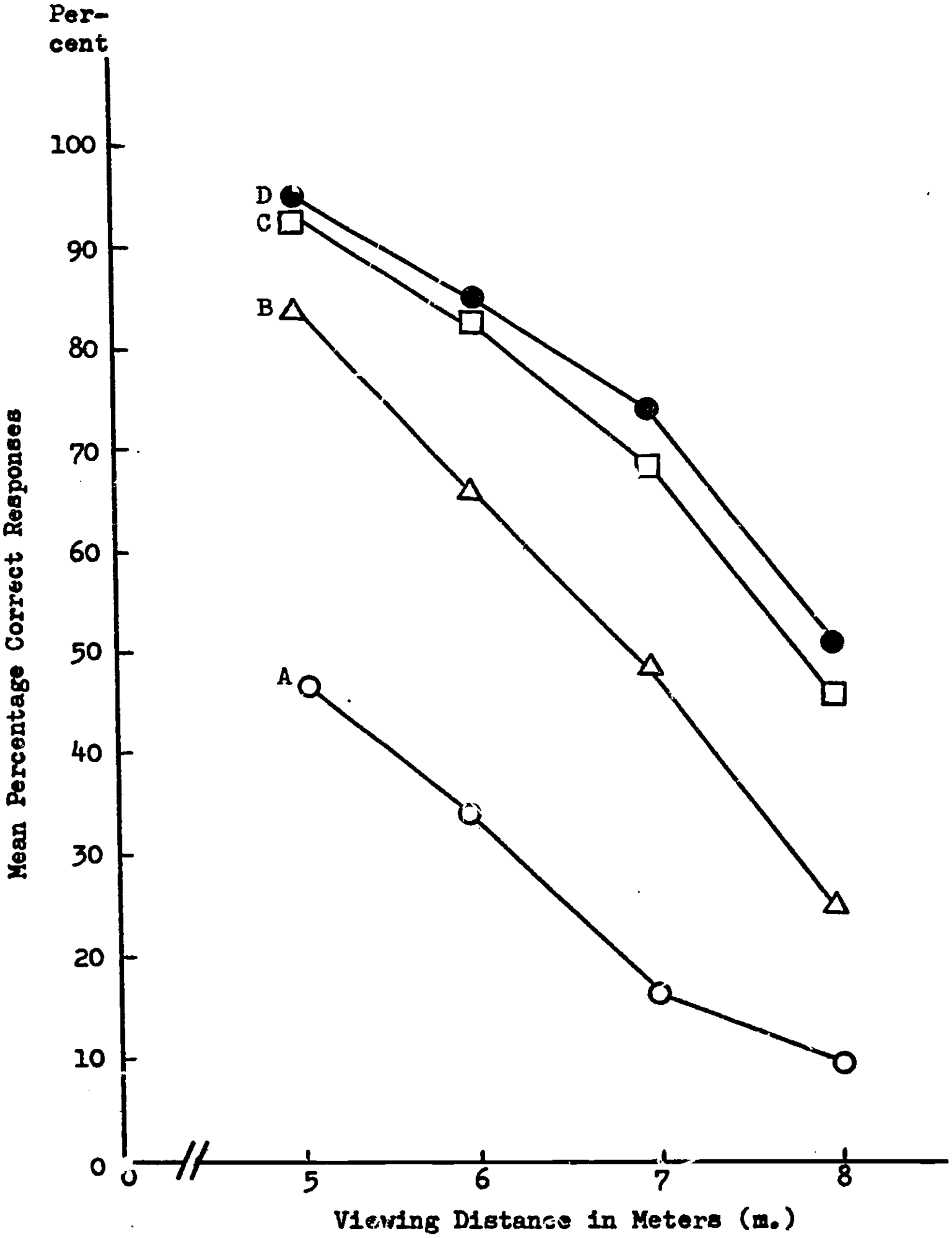

Fig. 6. Profiles of the Simple Main Effects of Viewing Distance for Each Brightness Contrast

NOTE: Profile A represents a brightness contrast of 30.23 percent, Profile B 53.49 percent, Profile C 72.09 percent and Profile D 83.75 percent.

TABLE 17

Mean Percentage Correct Responses for Each Brightness Contrast at Each Viewing Distance

Brightness contrast in percent	Viewing distance in meters			
	5	6	7	8
30.23	47.31	33.33	14.93	11.11
53.49	83.33	67.84	48.99	26.82
72.09	92.76	82.83	68.35	45.62
83.75	95.45	86.36	73.06	50.67

Analyses of trends for each of the four brightness contrasts are shown in Table 18.

TABLE 18

Analyses of Trends Over the Simple Main Effects of Viewing Distance for Each Brightness Contrast

Source	df	MS	F	Percentage of the sum of squares for overall trend
30.23 PERCENT (PROFILE A)				
Overall trend	3	810.35	40.16*	
Linear	1	2255.00	60.42*	92.76
Quadratic	1	165.01	14.71*	6.79
Cubic	1	11.03	.92	.45
Between individual trends	51	20.18		
Linear	17	37.32		
Quadratic	17	11.22		
Cubic	17	12.01		

*$p < .01$