Report 73

THE EFFECT OF COLORED LENSES UPON COLOR DISCRIMINATION

By

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ABSTRACT

Six commercial types of sun glass lenses were used in six laboratory tests to determine their effects on color perception, during and immediately after the wearing. Neutrals (types, Neutral and Polaroid) and greenish-gray lenses (types, Rayban and Calobar) produced little distortion of color perception as measured by any test. Brown lenses (type, Rose Smoke) caused considerable decrement in color discrimination and a yellow lens (type, Noviol) caused extreme decrement. None of the lenses increased color perception in any part of the color range. It is concluded that greenish-gray lenses of the Rayban and Calobar type do not seriously impair color perception when used for the observation of non-dichromatic materials.

A study was made on the after effects of wearing the lenses; it appears that adaptation proceeds rapidly and is half-completed in about 5 seconds. There are appendices on the measurement of spectral transmittance of polarizing film and on methods of specification of neutrality for sunglasses.

THE EFFECT OF COLORED LENSES UPON COLOR DISCRIMINATION

OBJECT

Answers are sought to the questions: (a) what are the general effects on color perception* caused by wearing colored sunglass spectacles? (b) what are the specific effects of six available glasses?

DISCUSSION

It is assumed that the function of a sunglass is to reduce intensity of illumination without materially impairing color perception. There is no possibility of increasing over-all discrimination of color differences by a filter. Special purpose glasses can be created which will increase visual differentiation in one limited chromatic region but such increase must be at the expense of decreased perception in other chromatic regions.

Therefore, the problem in the selection of color for sunglasses is to determine the amount and kind of deviation from neutral that can be permitted, keeping in mind that (1) the particular spectacle selected for a general utility sunglass will be used over an extremely wide range of color conditions, and (2) manufacturers find difficulty in making glass which is close to neutral specification.

Experimentally, there are two principle facts to be kept in mind:

1. The appearance of colors viewed through tinted lenses can be treated by the same techniques which would be used if we were to examine surface colors under lights of various colors. It does not matter whether the filter is put over the illuminant or over the eye.**

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* The word "perception" is used arbitrarily in the sense of "ability to discriminate or distinguish small differences in color". Color differences include brightness differences.

**Reprint Note: It has been pointed out that coverage of the visual field was practically complete in the present study whereas stray light usually enters from the sides when sunglasses are worn in actual use. In general the two situations should yield very similar results.

2. The human eye shows a rapid and amazing adaptability to changes in the color of illumination. In his analysis of these processes, Judd[1] noted that "The visual mechanism of a normal observer is so constructed that objects keep nearly their daylight colors even when the illuminant departs markedly from average daylight. The processes by means of which the observer adapts to the illuminant or discounts most of the effect of a non-daylight illuminant are complicated." Depending upon the conditions, the processes of adaptation are largely completed in from less than one second to more than five seconds.

It is known, in a general way, what effect a light of pronounced hue has upon a color series. The general formulation of the result may be diagrammed as a constriction of the color circle into an elipse, the minor axis of which represents the reduction of chromaticity discrimination. For instance, a greenish glass reduced green-to-gray-to-pink discrimination more than yellow-to-gray-to-violet discrimination. Unfortunately, there are a large variety of psychophysical factors which affect this simple tendency. Some of these follow:

1. Goggles reduce brightness and one effect of reduced brightness is that the light and dark objects in a visual field tend to take on the color of the illuminant and the complementary to the color of the illuminant, respectively.

2. Individual differences between observers' eyes have a marked effect on color discriminations. These differences are due, at least in part, to differences in retinas, coloring of the ocular media, and to density of pigmentation of the macular lutea.

3. There are complex interrelations resulting from variable spectral characteristics of all the media and colorants involved. Therefore, the effect of colored illuminants or filters on colored objects cannot be deduced from the apparent colors of the filters and objects.

DESCRIPTION OF SPECTACLES

Six pairs of spectacle lenses were supplied by the Bureau of Medicine and Surgery, each mounted uniformly in the same type of spectacle frame. In addition, there were added a Wratten neutral filter of 20% transmission and a compound of Calobar "C" and Calobar "D" in order to secure a transmission which approximated the other dense glasses. Table 1 lists the name of the glass, its color appearance, total transmission to Illuminant C (average daylight), and the x - y coordinates on the Mixture Diagram of the 1931 Standard Observer and Coordinate System.

Table 1

LIST OF FILTERS

Name	Appearance	% Trans.	x	y
1. B & L Neutral**	slightly green	15.8	.322	.358
2. Calobar C	pale green	51.0	.310	.348
3. Calobar D	pale green	34.1	.316	.367
4. Polaroid HN12-d	neutral*	14.0	.316	.344
5. Rose Smoke	reddish orange	16.2	.419	.406
6. Noviol	strong yellow	81.6	.444	.519
7. Wratten Neutral	neutral	20.0	.318	.320
8. Calobar C+D	dull green	15.6	.313	.397

The position of each of these filters is shown in Fig. 1 on a projective transformation of the Standard 1931 I.C.I. Diagram (Standard Observer and Coordinate System). A Rectilinear Uniform Chromaticity Scale Diagram is used in order to represent them in approximately their true visual relationships. The curves are the Munsell smoothes loci by Newhall, Nickerson and Judd[2]. These curves pass through regions of approximately equal chroma or saturation.

*Polaroid HN12-d appeared neutral but was two-color transmitting. The measurement of spectral transmission of polarizing film is discussed in appendix A.

**Reprint Note: After original publication it was found that this glass was mislabeled when received. However, the Bausch and Lomb Neutral is even more neutral than the sample furnished so the conclusions in this report are not affected.

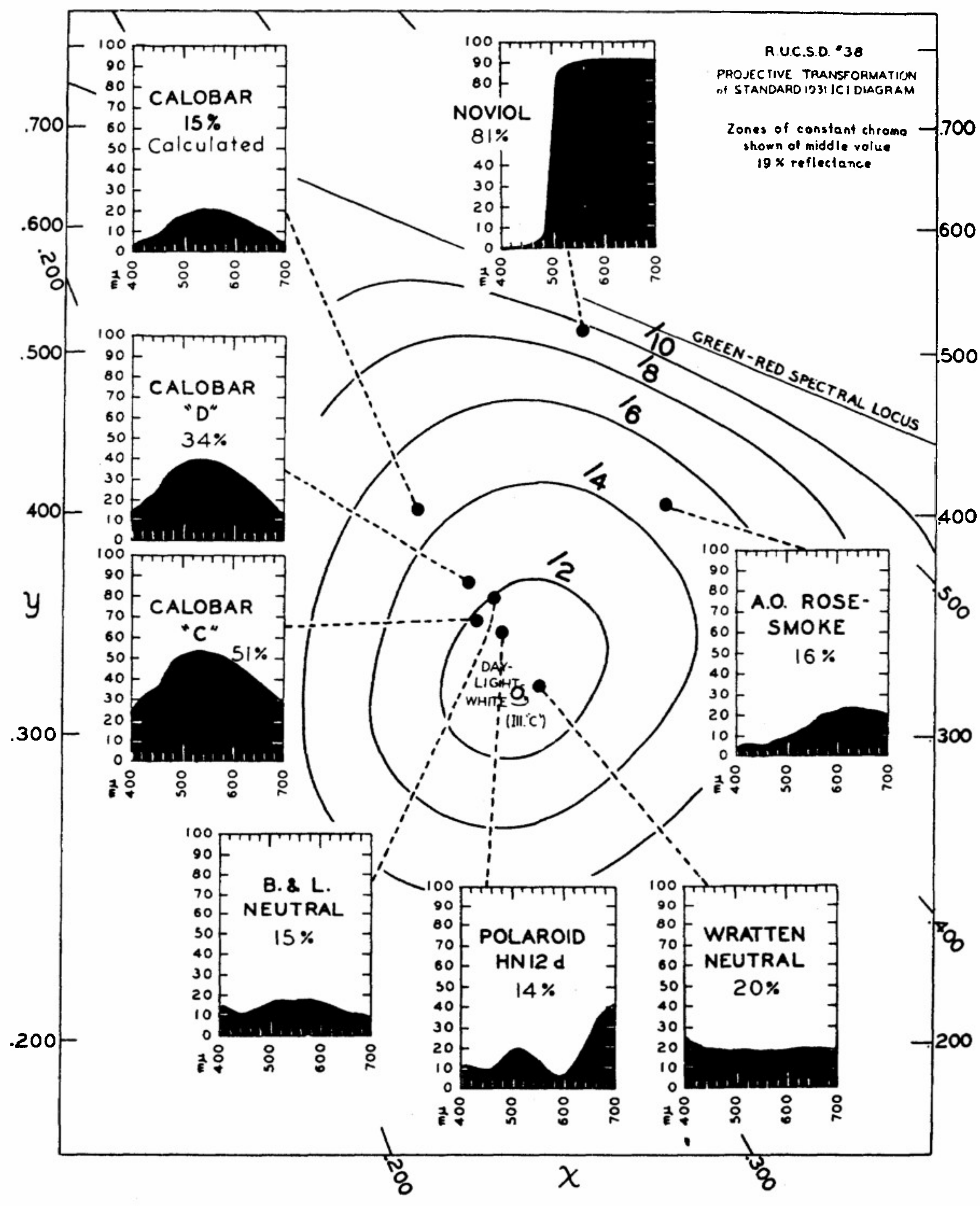


Figure 1

Spectral transmittance is shown for the eight goggles tested: six commercial types and two laboratory mock-ups. The percent of transmission for Illuminant C is given in each box. The chromatic position of the lenses are shown by the black dots plotted on the Farnsworth Projective Transformation of the Standard 1931 I.C.I. Diagram. The ovals designate zones of constant chroma at 19% reflectance (Munsell Value 5).

PRELIMINARY TESTS

Experimentally, it was necessary to find an approach which would give a general answer, independent, so far as possible, of special variables. Test methods were therefore inapplicable which involved the following features: (1) subjective responses, (2) dichroic materials, (3) mixtures of pure stimuli, (4) fields of dissimilar brightnesses, and (5) restricted color series.

Preliminary trials were made on a number of tests whose sensitivities proved insufficient to show results with the exception of the Noviol. These tests included: I the I.S.C.C. Experimental Color Aptitude Test; II, a specially designed set of Woefflin Charts; III, a set of Munsell Chroma 1 papers which were shown in random series against a neutral background; and IV, the Farnsworth Dichotomous test[3]. None of these experiments gave reliable results nor showed measurable effects of the tinted glasses (with the exception of the Noviol).

The conclusions from these results were informally reported to the Bureau of Medicine and Surgery. The "amazing adaptability" of the eye to change in color of illumination was confirmed and the tests indicated that the goggles of moderate saturation which were under consideration would not seriously disrupt normal perception of the color relations usually encountered in nature. However, it was still desired to discover a quantitative method of ascertaining the degree of reduction caused by tinted goggles and two other experiments were initiated: V, a liquid wedge method of matching film colors in a bi-part field; and VI, the scoring of the F-M 100 hue test with and without goggles. The last named test gave the most useful results.

EFFECT OF TINTED LENSES ON THE F-M 100-HUE TEST

The object of applying the Farnsworth-Munsell 100-hue test to normal individuals wearing tinted lenses is to determine the extent to which the color of the lenses makes normals "colorblind". The task set by the test is similar to the seeing task for which sunglasses are used -- the discrimination of small differences in pigmentation of the "dull" colors in nature.

The Farnsworth-Munsell 100-hue test[3] is a laboratory test for sampling color discrimination between all hues in the moderately saturated color regions. The series of eighty-five color caps differ, each from the adjacent, by a "Just Easily Perceptible Difference" (J.E.P.D.). That is, the colors are arranged easily in series with 95% accuracy by normal individuals, but the plotted errors show distinctive patterns for persons with various degrees of color defect.

Twenty young Navy men with normal color sensation were tested without spectacles and while wearing spectacles. The order in which the tests were given was varied for each observer. The illumination was Macbeth Illuminant C, which approximates average daylight.

The results are presented in Figure 2. Four of the five spectacles which were selected for test were of about the same transmission (14% to 16%), the other was a nearly monochromatic lens of high transmission (81%). Each plot is the average of four scores made by four men with and without goggles.

Inspection of Figure 2 reveals the following facts concerning the goggles, listed in order according to number of errors.

1. The wearing of the Bausch and Lomb "Neutral" produces a barely detectable decrement in color perception.

2. The effect of wearing Calobar "C" and "D" together is scarcely more appreciable. The slight decrement to perception is in the yellow-red to red-purple and in the green to blue series.

3. The wearing of Polaroid HN 12-d, in spite of its neutral appearance, causes more errors to be made in the yellow-red to red-purple and green to blue series than Calobar C plus

AO Co.Plates
(our selection)

	Test	Retest
8		
6		
29		
27		
42		
56		
25		
68		
97		
5		
3		
74		
47		
98		
Errors		

Farnsworth Lantern

1 GR	2 WG	3 GW	4 GG	5 RG	6 WR	7 WW	8 RW	9 RR

Retest

1 GR	2 WG	3 GW	4 GG	5 RG	6 WR	7 WW	8 RW	9 RR

Re-Retest

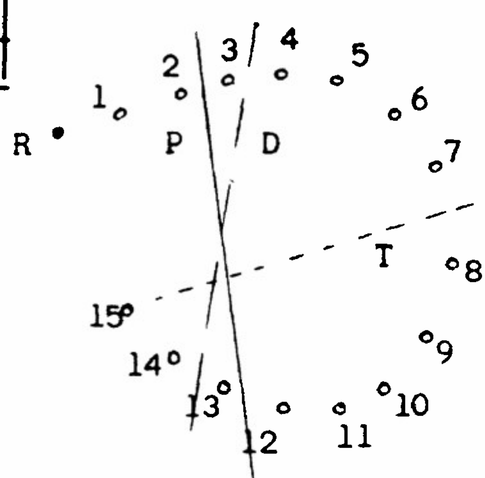
1 GR	2 WG	3 GW	4 GG	5 RG	6 WR	7 WW	8 RW	9 RR

MRL Tritan Plates

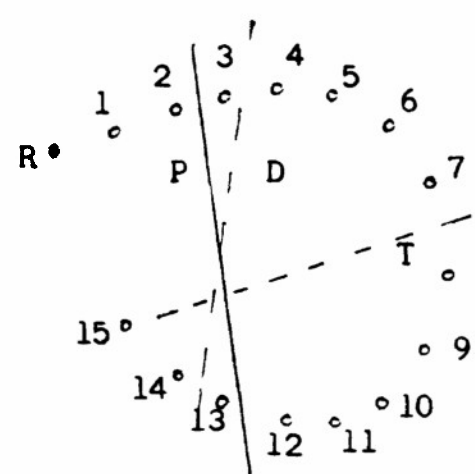
	Normal	C.D
7A	gy LR	UL
7B	✓ LL	UR
7C	✓ UL	LR
7D	ey LR	UL

triangles

Dichotomous-15 Test



Retest



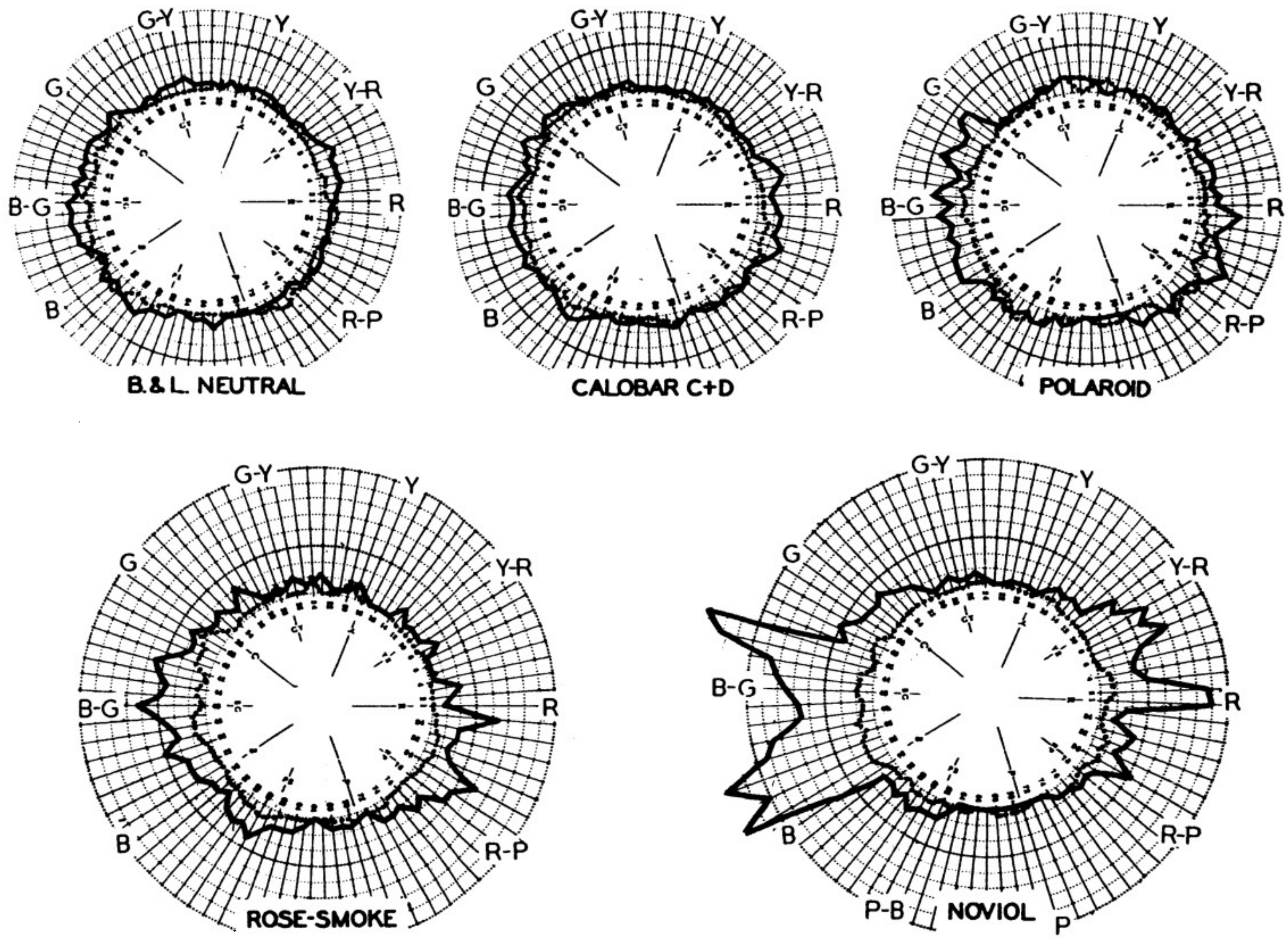


Figure 2

Mean scores on F-M 100-Hue test made by 20 observers with five colored sunglasses. Solid lines show mean scores made while wearing glasses; dotted lines show mean scores made without glasses.

D, which is distinctly greenish. Even these errors, however, are not sufficiently great to cause a man with similar vision to be termed "colorblind".

4. The wearing of Rose Smoke produces a score which is typical of a "colorblind" observer. Not a complete colorblind (dichromat), to be sure, but one with a defect which, if in the red-green region, would eliminate him from Naval service by authorized tests.

5. The wearing of Noviol produces scores which are as deficient as those made by extreme color blinds.

Since the saturation of Calobar C or Calobar D alone must be less than the compound, the effect of either on color-sensation can be assumed to be negligible.

The first three glasses, Bausch and Lomb Neutral, Calobar C plus D, and Polaroid HN12-d, caused normals to make fewer errors than are made by many "low normals" or "low discriminators" -- a class of people whose vision is scarcely to be distinguished from normal.

The latter two glasses, Rose Smoke and Noviol, caused normals to make errors which are as extensive as those made by "color blinds".

Chroma (saturation, deviation from neutral) apparently is not a reliable indication of the effect of tint on color perception. Reference to Figure 1 shows that Calobar C plus D has approximately the same equivalent chroma as Rose Smoke, about Munsell Chroma 5. It was therefore unexpected that color perception differed considerably. However, as a check on this evidence, eight more men were run with and without spectacles and the results confirmed the first set of data.

It is noteworthy that not one of the glasses showed signs of increasing color perception in any color region. Even Rose Smoke, which has been defended for its ability to set off fine graduations of blue to violet, caused somewhat more errors in this region.

RESULTS FROM MAKING COLORIMETRIC MATCHES WITH COLORED SPECTACLES

In this experiment observers matched the two halves of a 2 degree divided field. The variables consisted of liquid wedges which were matched to standards of the same spectral composition. The readings were treated by the method of Average Error. The Standard Deviation of the observer's matches for each color of goggle was taken as an indication of his chromatic sensitivity in the color ranges of the wedges.

It is believed that most of the results are applicable only to very small color differences which are distinguishable by laboratory methods. Therefore, the data are not presented in detail. However, this experiment brought out two significant findings which were not demonstrable by other tests:

(1) In the discrimination of small color differences at small subtense, there was great variation between observers; the differences of perception between observers under indentical conditions were often greater than the differences caused by the several goggles worn by one observer. Such variation has been predicted because of the wide physiological differences in the macula lutea of human observers and because of the high spectral selectivity of the coloring media. The phenomena required further study which was not possible under this project.

(2) The effects of wearing colored spectacles largely disappear within a period of seconds. When matches were made within 5 seconds of removal of the spectacles, the standard deviation of the matches were usually intermediate between the scores made without spectacles and after spectacles had been worn for fifteen minutes. Average scores of the two observers are graphed in Figure 3. It appeared that, with the exception of Noviol, about half the effect of the goggles disappeared within 5 seconds.

Since the effect of putting the spectacles on, as against taking them off is simply to effect a change of apparent illumination in the opposite chromatic direction (except for increase or decrease of overall brightness), we may conclude that adaptation to spectacles after they are put on will also be about half accomplished within a few seconds.

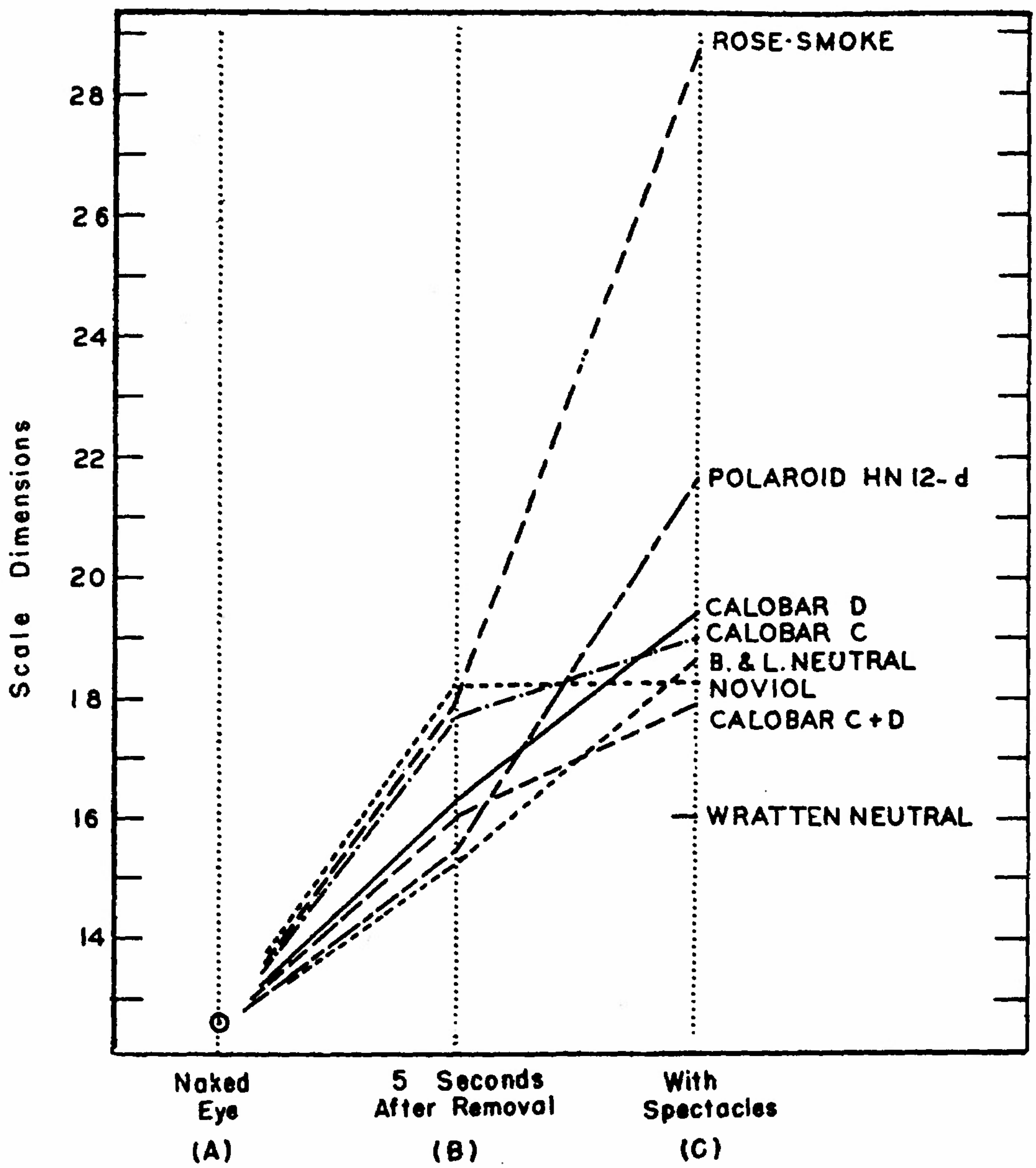


Figure 3

Adaptation effects. Comparison of the accuracy of color matches made with, without, and five seconds after removal of colored spectacles. Data is shown in terms of standard deviation of matches. Data are relative; the ordinant is in arbitrary machine scale divisions. Averages from two observers:

A - Observations made without spectacles (N=100-200)
B - Observations made without spectacles 5 seconds after removal, after 20 minute adaptation to spectacles (N=50-100)
C - Observations made with spectacles after wearing spectacles for 20 minutes (N=100-200)

METHODS OF SPECIFICATION

(1) There are two factors which prevent the specification of color of glasses by chroma alone. First, chroma is a summation of appearance and gives no clue to possible irregular spectral characteristics which may produce effects entirely different from a glass of the same appearance but with a "smooth" transmission. The Polaroid HN12-d illustrated this point neatly in the present experiment. Second, the higher seltiveness of red and violet glasses over green glasses means that the effect of degree of chroma is not independent of hue. The different effects of Rose Smoke and of Calobar C plus D, both of which approximated the same chroma, illustrated this point in the present experiment. Arguing from this single case it appears that loci of constant purity might more accurately specify glasses of equal effect on color perception.

(2) It is also necessary to decide if the specifications should be developed for glasses which will not distort perception for colors with fairly smooth spectral curves such as are commonly found in nature (chlorophyl excepted), or whether the specifications should be restrictive enough to define glasses which render accurately the appearance of dichromatic colorants. Tests and conclusions in this report refer only to discrimination differences between the more common, smooth-curve, colorants.

(3) If the F-M 100-hue test were used as described in this paper for determining acceptable glasses two steps are necessary: (1) a limit would be set for the permissible ratio of increase of error score, with and without goggles; (2) a physical specification or formula would be devised which would differentially describe the acceptable and non-acceptable glasses.

(4) Deane B. Judd, in 1939, developed a system known as the Judd Duplication Index for obtaining definitions and tolerances for artificial daylight. It utilizes metameric pairs of sample colors of known spectral reflectances, which when observed under different illuminations, will exhibit color differences which may be used as a measure of the effective difference between the illuminants. In a report by the National Bureau of Standards[4] it is suggested that this technique, or the modification described by Dorothy Nickerson in 1941, might be applicable to this problem. The section on specification is quoted in full in Appendix B and followed by a brief description of both methods.

(5) The examination of these suggestions for acceptance-specification is not considered to be within the scope of this experiment.

SUMMARY AND CONCLUSIONS

1. Six commercial types of sunglass lenses were used in several laboratory tests to determine the effects on color perception, during and immediately after the wearing.

2. Neutral and greenish tint lenses --- Bausch and Lomb "Nuetral", "Calobar C" and "D" used separately and together, and "Polaroid HN 12-d" -- produced little distortion of color perception as measured on any test, no more than is found in "low discrimination normals".

3. One reddish-orange lens, "Rose Smoke", caused considerable decrement in perception, equivalent to that of moderate color blindness as measured on the F-M 100 hue test. One strong yellow lens, "Noviol", produced the effect of extreme color blindness as measured on the F-M 100 hue and Farnsworth Dichotomous tests.

4. It is concluded that greenish lenses of no greater saturation than that of Calobar at 15% transmission would not impair color perception seriously when used for the observation of non-dichroic materials.

5. After-effects of wearing the lenses diminished rapidly. Attempts to match a bi-part field made within 5 seconds after removal of the glasses gave discrimination limens intermediate between those made with glasses and with the naked eye.

6. None of the lenses increased perception in any part of the color range as measured on the F-M 100 hue test.

7. Two possible methods of specification are suggested by the use of the F-M 100 hue test or by the use of the Judd Duplication Index.

REFERENCES

1. D.B. Judd, "Hue, saturation and lightness of surface colors with chromatic illumination", J. Opt. Soc. Am. 30, 2 (1940).

2. "Final report of the O.S.A. Subcommittee on the Spacing of the Munsell Colors", J. Opt. Soc. Am. 33, 385, (1943).

3. Dean Farnsworth, "The Farnsworth-Munsell 100-hue and dichotomous tests for color vision", J.O.S.A. 33, 568, (1943).

4. National Bureau of Standards, Report on spectral transmission of one Polaroid goggle lens, 43C-61/45, May 14, 1945.

APPENDIX A

The Measurement of Spectral Transmittance of Polarizing Film

There has been considerable dispute over the proper method of obtaining transmittance curves of polarizing materials. It has even been claimed that polarizing materials "cannot be measured"; and, in particular, that the General Electric Recording Spectrophotometer cannot be used for the measurement of polarizing filters. The curve which was furnished for the Polaroid HN 12-d used in this experiment was fairly flat and neutral appearing. Other Polaroids which were furnished to activities of the American and Canadian Navies were also claimed to be near-neutral on the basis of spectrophotometric analysis. In Figure 4, curve A represents the measurements obtained by a special technique on a Beckman Spectrograph which was devised for the Polaroid Corp. and was supposed to agree with a method used by the Naval Research Laboratories. However, the experiments described in this report indicated that the apparent neutrality of the HN 12-d goggles was spurious.

Whatever was the story on this curve, it seemed that the extensive applications which were being made with Polaroid indicated that a survey should be made of the available techniques for spectral measurement. Therefore, a single sample of Polaroid HN 12-d was sent, successively, to several laboratories for independent measurements. The data which were obtained are plotted in Figure 4 as curves A,B,C,D and E.

A. Curve furnished for HN 12-d goggle.

B. and C. <u>G.E. Recording Spectrophotometer:</u> These two curves are from the Research Laboratories of Interchemical Corporation. The same sample was run on June 5 and again on August 6; they are identical to the width of the stylus line.

"The procedure used in measuring the spectral transmittance for unpolarized light by means of G. E. recording spectrophotometer was to orient the sample normal to the beam, with the plane of polarization of the sample parallel to the plane of the sample beam leaving the Wollaston prism. While the instrument was recording the curve, it was found necessary, occasionally, to eliminate 'blocking' by altering the phase adjustment on the field of the flicker rochon motor. While the shape of the spectral transmittance curve obtained by this pro-

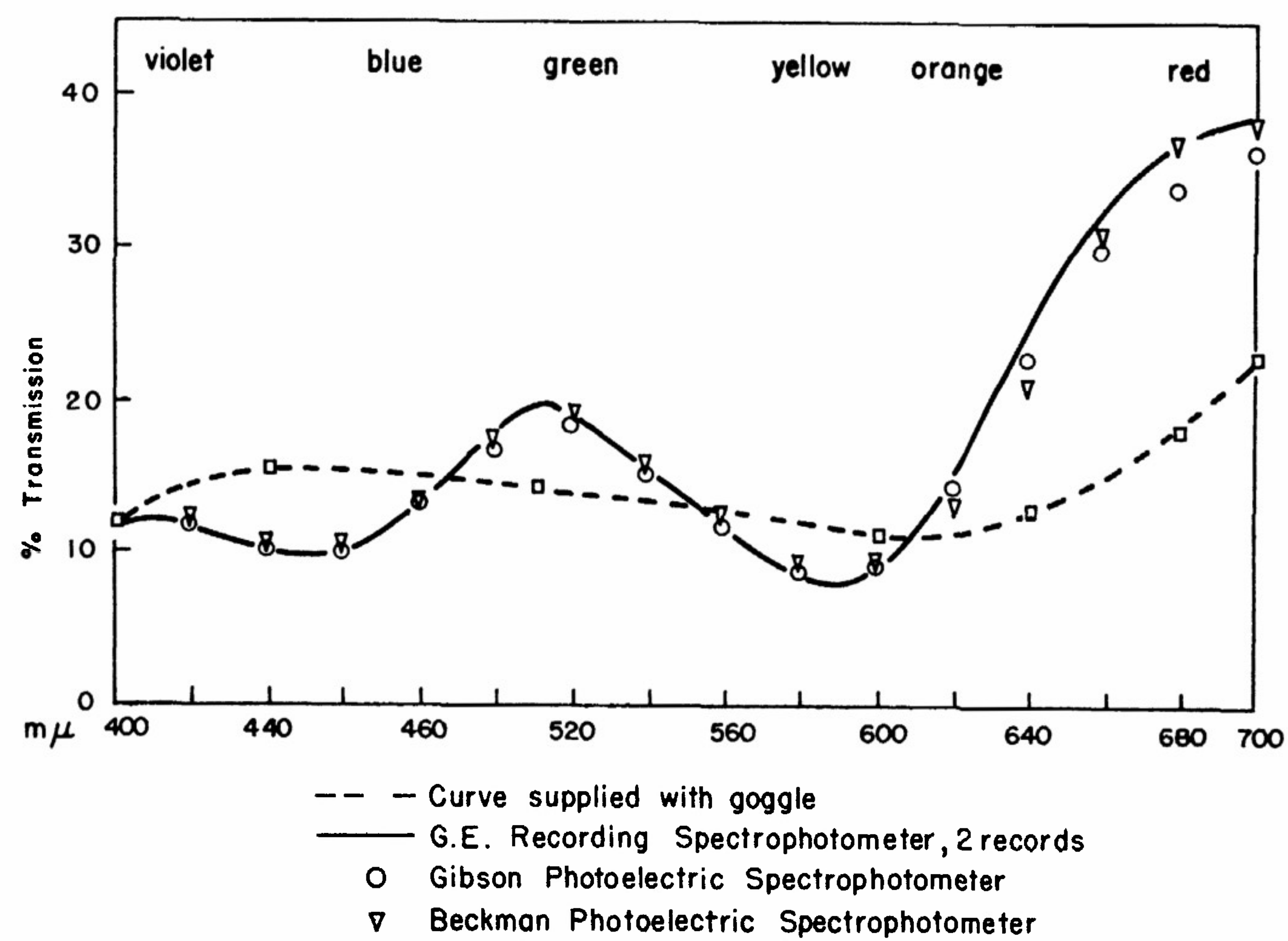


Figure 4

Transmittance curves on one polarizing lens, HN 12-d, secured by four spectrophotometric methods.

cedure is believed to be correct, and would be satisfactory for determinations of chromaticity, it should be noted that the correct photometric values are obtained by multiplying the values of transmittance indicated on the ordinate scale of the graph sheet by the factor 0.5". Letter of 6 June 1945 signed by Walter C. Granville.

D. Gibson Photoelectric Spectrophotometer ±.15: The Bureau of Standards report on the Gibson values were obtained in the following manner: "The sample was oriented to obtain both maximum and minimum transmission measurements at 700, 580 and 500 mu on the Gibson Photoelectric Spectrophotometer, JOSA and RSI 7, 693 (1923). Then, with the sample in an intermediate position, measurements of transmission were made on this spectrophotometer at every 20 mu between 400 and 760 mu." --Letter of 14 May 1945.

E. Beckman Photoelectric Spectrophotometer check readings: "Transmission values obtained on the Beckman photoelectric spectrophotometer, JOSA, 31, 682 (1941), were found to approximate those reported and to lie within the range given by the maximum and minimum values, determined on the Gibson Spectrophotometer to be in the ratio of about 1.3 to 1." -- N.B.S., same report.

It is evident that the three latter methods investigated agree closely with each other. Until new techniques are available, the use of the G.E. Recording Spectrophotometer is indicated because of its reliability and convenience.

APPENDIX B

Use of Duplication Indices for Manufacturing Specification

From "Report on the Spectral Transmission of Polaroid Goggle Lens" to Medical Research Laboratory, U.S. Submarine Base, New London, Connecticut, by the National Bureau of Standards, IV-31, 43C-61/45, dated May 14, 1945. "The degree to which usual object-color differences under standard illuminant C are duplicated for viewing through the Polaroid lens HN 12-d may be judged by computations based upon four pairs of samples selected as representative; see Fig. 5 of a paper, The Illuminant in Color Matching and Discrimination, Dorothy Nickerson, Illuminating Engineering, March 1941. By these computations may be obtained a duplication index, Id, based on a weighted mean of the second differences, D, defined in J. Opt. Soc. Am. 29, 145 (1939), thus: $Id = 100(1-10D)/(1+100D)$. The duplication index for a perfectly nonselective goggle lens is seen to be 100; that for a lens converting illuminant C into illuminant A (2,842°K) would be about 50. The duplication index for Polaroid lens HN 12-d was found to be 31. It is probable that a satisfactory degree of freedom from object-color distortion by a goggle lens could be insured without undue arbitrary restriction of the spectral characteristics of the lens by specifying a minimum value of the duplication index, Id, in purchases of such lenses. If it is desired to pursue this line of inquiry, we would be glad to furnish computation forms for duplication index." Lyman J. Briggs, Director.

Use of Judd Duplication Index

From "The Illuminant in Color Matching and Discrimination", by Dorothy Nickerson, Illuminating Engineering, March 1941: "In a report before the Optical Society at Niagara Falls in 1938, a method for obtaining definitions and tolerances for artificial daylight for color matching was suggested by Judd (Definition and Tolerances for Artificial Daylight for Color Matching, J.O.S.A 29, 145, Abstract, 1939). This method is based upon the principle that if one illuminant is to be considered a duplicate of another for color matching, it must preserve the same object-color differences. In other words, if one of two samples appears just noticeably redder than the other in daylight, and if one illuminant shows a color difference to be zero, the difference should remain zero for the illuminant which is intended as a duplicate. Four pairs of samples were selected to typify those known to require accurate duplication of daylight for proper rendering of the daylight color difference. Color differences were indicated for each pair by taking differences of apparent reflection, Y, and trilinear coordinates, r, g, b, for the uniform-chromaticity-scale (UCS) triangle. (Judd, Deane B.; A Maxwell Triangle Yielding Uniform Chromaticity Scales, J.O.S.A. 25, 24, 1935). The variations in these object-color differences corresponding to a change in illuminant were found by taking second differences. If pairs of samples can be found which adequately represent those to be examined under the artificial daylight, then an average of the largest of the second differences for each pair is 'an adequate measure of the failure of the artificial illuminant to duplicate natural daylight and a value of this average may be set as a tolerance'."