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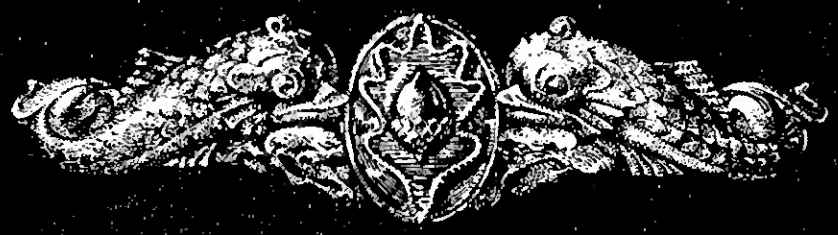

U. S. Submarine Base
New London

COMPARISON AND EVALUATION OF
AMERICAN OPTICAL CO. PSEUDO-ISOCHROMATIC PLATES
FIRST AND SECOND EDITIONS

Color Vision Report No.8
N.L. Sub.-1-CV-16
BuMed X-480 (Av-255-p)

Report no. 1

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19 March 1945

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COMPARISON AND EVALUATION OF AMERICAN OPTICAL CO. PSEUDO-ISOCHROMATIC PLATES FIRST AND SECOND EDITIONS

Work was conducted under
BuMed X-480 (Av-255-p)
Entitled "Comparison and Evaluation of the 'Pseudo-Isochromatic Plates for testing of Color Perception' American Optical Company, Second Edition, with the First Edition of these plates now in general use by the U.S. Navy"

This report is a final report
under this project

19 March 1945

Medical Research Department
U. S. Submarine Base, New London, Connecticut.

COMPARISON AND EVALUATION OF AMERICAN OPTICAL CO. PSEUDO-ISOCHROMATIC PLATES, FIRST AND SECOND EDITIONS

SUMMARY

1. A group of 510 men was examined on American Optical Company Pseudo-Isochromatic Plates, first and second editions, for the purpose of comparing the two editions especially with respect to their effectiveness in distinguishing between color-normal and color-anomalous individuals.

2. The two editions were shown to be of approximately equal validity in detecting defective color vision. The second edition, even after modification, was found to contain several plates too difficult for normals. When these were corrected, the revised second edition proved to be superior to both the first and second editions in dichotomizing between normal and anomalous color vision. These results are summarized in Fig. 1.

3. The tests are effective when scored on the basis of the number of plates failed (or passed) out of the total. An interpretation based on the number of plates failed (or passed) in each color group does not effectively segregate the color normal from the color anomalous.

4. The two editions were compared with respect to the time necessary to complete the test, and the difference proved to be negligible.

5. Sixteen men with anomalous color vision attempted to memorize both editions of the plates. The second edition proved increasingly more difficult to memorize as the degree of color deficiency increased. Three severely defective color blinds learned the first edition but were unable to learn the second edition.

HISTORY

Present physical requirements governing entrance into the Navy designate the use of American Optical Company Pseudo-Isochromatic Plates, first edition, for testing color perception. It has become increasingly evident, however, that these plates are not completely effective as a test for color vision in the Navy. Consequently a second edition was developed, embodying certain changes in composition and presentation, designed to reduce inaccuracies of screening. The principal innovations were (1) presentation of a single plate rather than four at a time, (2) introduction of a uniform dot pattern throughout the plates, and (3) replacement of the Germanic numerals of the first edition by block numerals. In addition, the printers' samples were checked at the Medical Research Department, U. S. Submarine Base, to make sure that the colors used were those most readily confusable by color blinds. The recommendations and colorimetric specifications are given in detail in Appendix B.

PROBLEM

Upon completion of the second edition, it was desired to compare the responses of a large population of both color normal and color anomalous individuals on the two editions, to ascertain whether the reliability of screening had been increased, and whether any further changes might be indicated to make the second edition even more effective.

This evaluation was made under Project No. X-480 (Av-255-p), Research Division of the Bureau of Medicine and Surgery. Opinion was desired on the following questions:

1. Do personnel showing hesitancy or difficulty with the old tests show similiar hesitancy with the new?
2. Are known color weak persons detected?
3. Are the new tests harder to memorize?
4. Is the new edition easier or harder to administer?

METHOD

A population of 298 men with normal color vision was tested on the first and second editions of the American Optical Company Pseudo-Isochromatic Plates, the Dimmick Anomaloscope, the Royal Canadian Navy Color Vision Lantern, and another anomaloscope and lantern now in the process of development. No results on these latter two instruments are presented in this study. The criterion of normal color vision was ability to pass both the Dimmick Anomaloscope and the RCN Lantern.

The testing procedure was as follows: The men were brought one at a time into a testing room illuminated by Macbeth daylight lamps, where they were tested first on the two anomaloscopes. They were then asked to stand upright before a table 28 inches high, on which the books containing the first and second editions of the AO plates were lying flat. The average distance from the book to the eye, as the subject looked down at the book, was 30 inches. The only instruction given was "Read the numbers." The page was turned as soon as a response was made, and a maximum of four seconds was permitted on each plate. The order of presentation of the two editions was systematically varied. Plates were shown consecutively through the books, to simplify the testing procedure. All responses were recorded, as well as the time required to complete the test on each edition. Following these readings, the man was taken into a darkroom and tested on the RCN and the experimental lantern. Initial errors on the lanterns were not counted if the man subsequently named the same combination correctly.

A group of 112 men, shown by an earlier battery of tests to have defective color vision, were given the above examinations, and in addition were tested on the Farnsworth Dichotomous Panel. Sixty-six of these men were not tested on the Royal Canadian Navy Lantern.

Preliminary inspection of the data showed that 9 of the plates of the second edition were too difficult for normals to read easily; certain changes were therefore made with the purpose of reducing the errors of normals on these plates without destroying their effectiveness in selecting color blinds. On 5 plates, these changes consisted of redistribution of the colors with respect to the dot pattern without altering the constituent colors of the plates. On the other 4 plates, color group #6, two colors were changed slightly. These alterations are described in full in Appendix A. A group of 100 men with normal color vision and 66 men with defective color vision were tested on this revised second edition.

RESULTS

Differentiation between normal and anomalous

The first function of a good screening test for color vision is to dichotomize clearly between two classes, normal and anomalous. The total error scores for the 512 men tested have therefore been plotted on one graph and are shown in Figure 1. This figure shows the number of errors made by color normals and by color blinds on the three types of tests. The figures are so drawn that the areas under all of the curves shown are equivalent. It is apparent from Figure 1 that the first edition has not adequately dichotomized between the partially color blind individual and the normal person with inadequate perception of the figures. It is also apparent that the second edition was better after revision. The revised second edition is apparently far superior to the other two, inasmuch as a cutoff could be made at 8, 9, or 10 errors, and it could be safely assumed that no person with anomalous color vision would be passed. This does not, of course, apply under non-standard testing conditions, nor to individuals who have had previous experience on the plates.

A breakdown of these figures is given in the following sections.

Normals - Difficulty of Individual Plates

The errors made by normals on the first edition correspond to the error frequency found in previous experiments on these plates, (Ref. 1) and are listed in Table I. The errors made by the same men on the second edition are of approximately equal frequency and are shown in complete detail in Table II.

Normals - Difficulty of Color Groups

The plates are divided into color groups, each of which has a certain intrinsic difficulty due to the particular colors used for the group. These color groups may be ranked in relation to each other according to the average number of errors made on each group. In calculation this rank order, each digit was counted separately. Since some digits are miscalled much more frequently than the others in their group, it could be safely assumed that such errors were the result of configurational, rather than color, difficulties; therefore the single most numerous error was dropped from the calculation in each group. The rank order of difficulty is consequently based on the increasing average number of errors on each color group, discounting the one digit most frequently miscalled.

Ref. 1. New London Submarine Base Color Vision Report #1, 12 September 1942.

Figure 1.

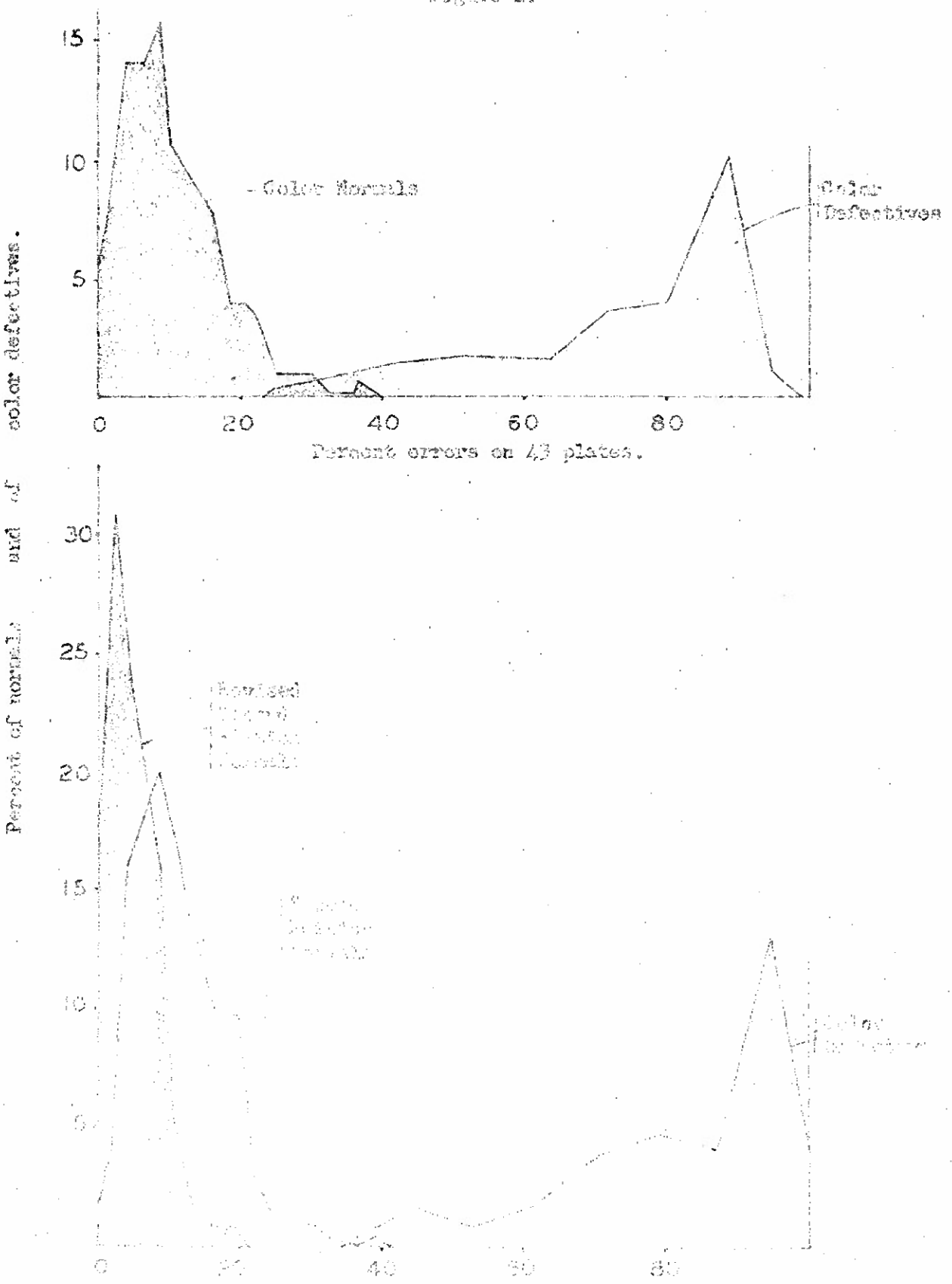

15
10
5
0
20
40
60
80
- Color Normals
Color Defectives
Percent errors on 43 plates.
Percent of normals and of color defectives.
30
25
20
15
10
5
0
20
40
60
80

TABLE I

Total Errors Made by 298 Men with Normal Color Vision on the First Edition of the A-O Plates

Plate #	Correct Response	Number of Errors
1	(89)	0
2	(43)	73
3	(56)	2
4	(27)	15
5	(8)	0
6	(6)	0
7	(39)	139
8	(42)	12
9	(56)	1
10	(27)	19
11	(29)	76
12	(57)	40
13	(86)	1
14	(75)	47
15	(7)	0
16	(9)	0
17	(25)	6
18	(68)	9
19	(5)	1
20	(3)	17
21	(97)	8
22	(34)	54
23	(56)	4
24	(27)	26
27	(89)	4
28	(43)	109
29	(86)	8
30	(75)	81
31	(52)	47
32	(96)	0
33	-	68
34	-	68
35	line	0
36	line	2
37	(052)	14
38	(394)	126
39	(23)	124
40	(65)	71
41	(15)	0
42	(74)	10
43	(47)	41
44	(98)	55
45	-	17

TABLE II

Errors on 2nd edition A-O plates. 298 men.
Breakdown of errors according to numbers miscalled
(the frequency appears below the numbers)

Correct Response	% Errors	Total Errors	Frequency of each erroneous response
(89)	0	0	
(43)	5	14	48 49 46 4- 7 5 1 1
(56)	1	3	58 3
(27)	0	0	
(8)	0	1	3 1
(6)	1	3	8 3
(29)	6	17	20 70 79 26 10 3 3 1
(57)	16	49	55 37 35 58 36 85 53 87 20 13 9 3 1 1 1 1
(75)	0	1	76 1
(27)	0	0	
(42)	0	0	
(56)	1	3	58 66 2 1
(25)	7	20	26 28 23 18 1 1
(68)	7	22	69 66 58 62 88 63 6 6 5 2 2 1
(97)	2	5	57 87 4 1
* (34)	41	123	94 84 54 24 04 64 104 12 3 2 1 1
(5)	0	1	4 1

TABLE II (Continued)

Correct Response	% Errors	Total Errors	Frequency of each erroneous response
(3)	2	5	8 5 3 2
(74)	3	10	71 24 21 7 2 1
(15)	0	0	
# (56)	40	120	36 35 58 55 x 38 86 3- 47 17 15 12 8 8 4 2 26 39 96 65 59 53 33 1 1 1 1 1 1 1
# (27)	7	20	29 37 x 87 24 7 7 3 2 1
# (89)	31	83	69 39 59 x 29 88 99 83 16 14 11 9 7 6 6 2 85 86 98 27 28 36 63 68 -9 2 2 2 1 1 1 1 1 1
# (86)	53	160	88 66 x 98 96 36 85 65 59 23 19 9 9 9 8 4 56 38 95 83 39 5- 8- 6- 3 3 2 2 2 1 1 1 58 53 26 68 84 1 1 1 1 1
(52)	1	4	62 63 82 2 1 1
(96)	7	21	98 86 26 15 5 1
(052)	3	10	x -52 062 252 952 0-- 05- 2 2 2 1 1 1 1

TABLE II (Concluded)

Correct Response	% Errors	Total Errors	Frequency of each erroneous response
* (394)	82	246	894 084 x 004 304 804 103 36 23 14 13 13 694 604 --4 8-4 -94 994 10 5 5 5 3 2 864 364 2-4 404 -64 384 2 1 1 1 1 1 654 884 0-- 684 564 084 1 1 1 1 1 1 38- 1
* (23)	26	79	28 29 25 x 39 22 38 93 36 23 11 3 1 1 1 1 26 63 1 1
* (65)	32	98	66 55 68 85 86 56 88 58 30 22 15 8 6 5 4 3 x 35 25 1 1 1
(47)	0	0	
* (98)	9	28	99 93 96 88 94 95 6- 13 6 4 2 1 1 1
(Line)	0	0	
(Line)	3	9	x 9
(-)	21	54	45 54
(-)	22	56	73 23 75 29 78 79 39 6 6 2 2 1

The order of increasing difficulty by color groups for each edition based upon the responses of normals, is shown in Table III. A rank order correlation between the two editions is .81, showing that roughly the same relationships between the plates exist in both tests. It can also be noted from the table that, in general, the plates become progressively more difficult toward the back of the book.

TABLE III

Order of Difficulty of Color Groups in Ascending Order		
Color Groups	First Edition	Second Edition
1	1	2
2	6	5
3	4	1
4	3	4
5	2	3
6	7	8
7	5	6
8	8	7

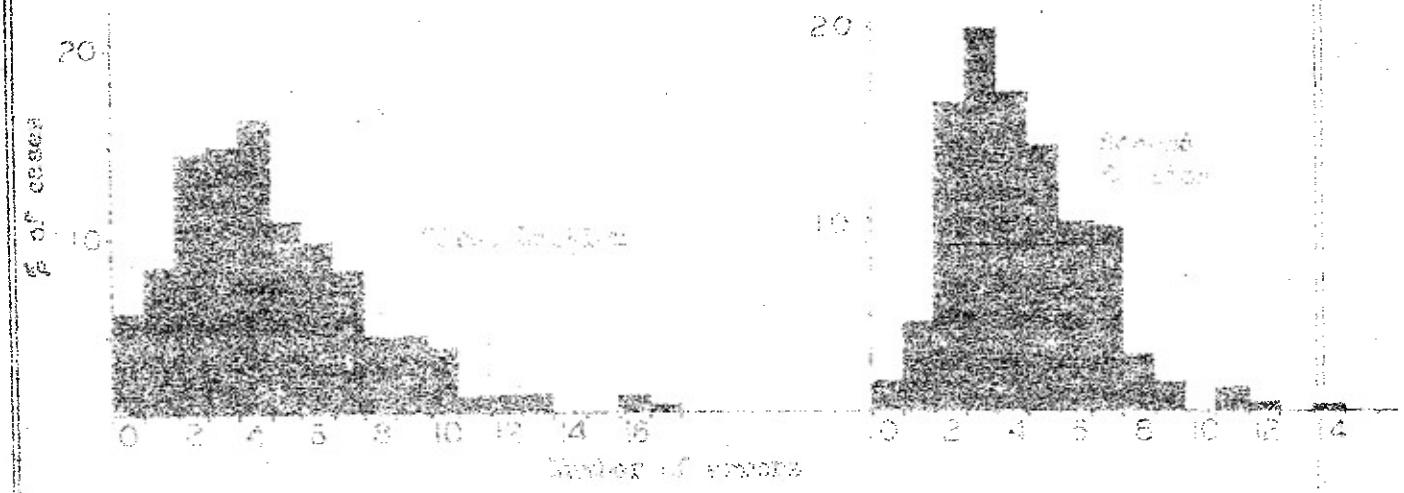
For the benefit of Services which use a selection of plates from the complete edition an evaluation is given in Appendix D of the rank order of diagnostic value of the plates in the Revised Second Edition.

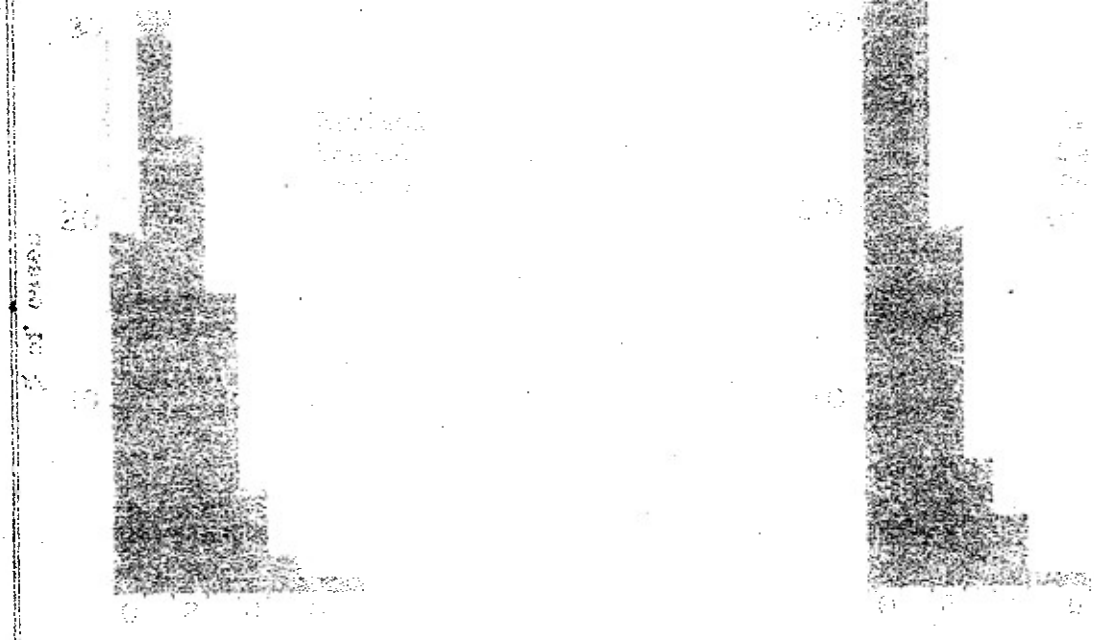
Normals - Distribution of Errors

The average total number of errors made by 298 men with normal color vision was 4.46 on the first edition, and 4.26 on the second. Figure 2a shows the number of errors on each book. These errors yield a product-moment correlation of .45. Fig. 2b shows the distribution of 100 men with normal color vision on the revised second edition (Appendix A)

Comparison of Scoring Methods

As a criterion of normal color vision, we used the ability to pass both the Royal Canadian Navy color vision lantern and the Dimmick anomaloscope. The use of these tests as a criterion stemmed from the ambiguity resulting from an attempt to use the plates themselves according to the following interpretations.


20
10
0 2 4 6 8 10 12 14 16
20
10
0 2 4 6 8 10 12 14



The responses of all subjects on the second edition of the American Optical Company plates were analyzed with respect to the interpretations placed by the Bureau of Medicine and Surgery upon existing regulations prescribed for color vision. There are two criteria for acceptable color vision, applying respectively to officers and enlisted men: correctly reading (1) not less than 3 plates in each color group, and (2) not less than 2 plates in each color group. The responses of the 298 normal subjects on the Second Edition and 100 normal subjects on the revised Second Edition, scored in accordance with both of these criteria, are shown in Figure 3. It is apparent from the large number of normals which these criteria would reject that these methods of screening are inaccurate. Out of 298 normal men, 112 would be failed by criterion (1) and 39 by criterion (2). In the revised second edition, 15 men out of 100 would be failed by criterion (1) and one by criterion (2). Scoring by number of errors made on any color group rather than by number of errors made on the whole test is not valid because of the "veto-power" given to a single group of plates over all the remaining plates.

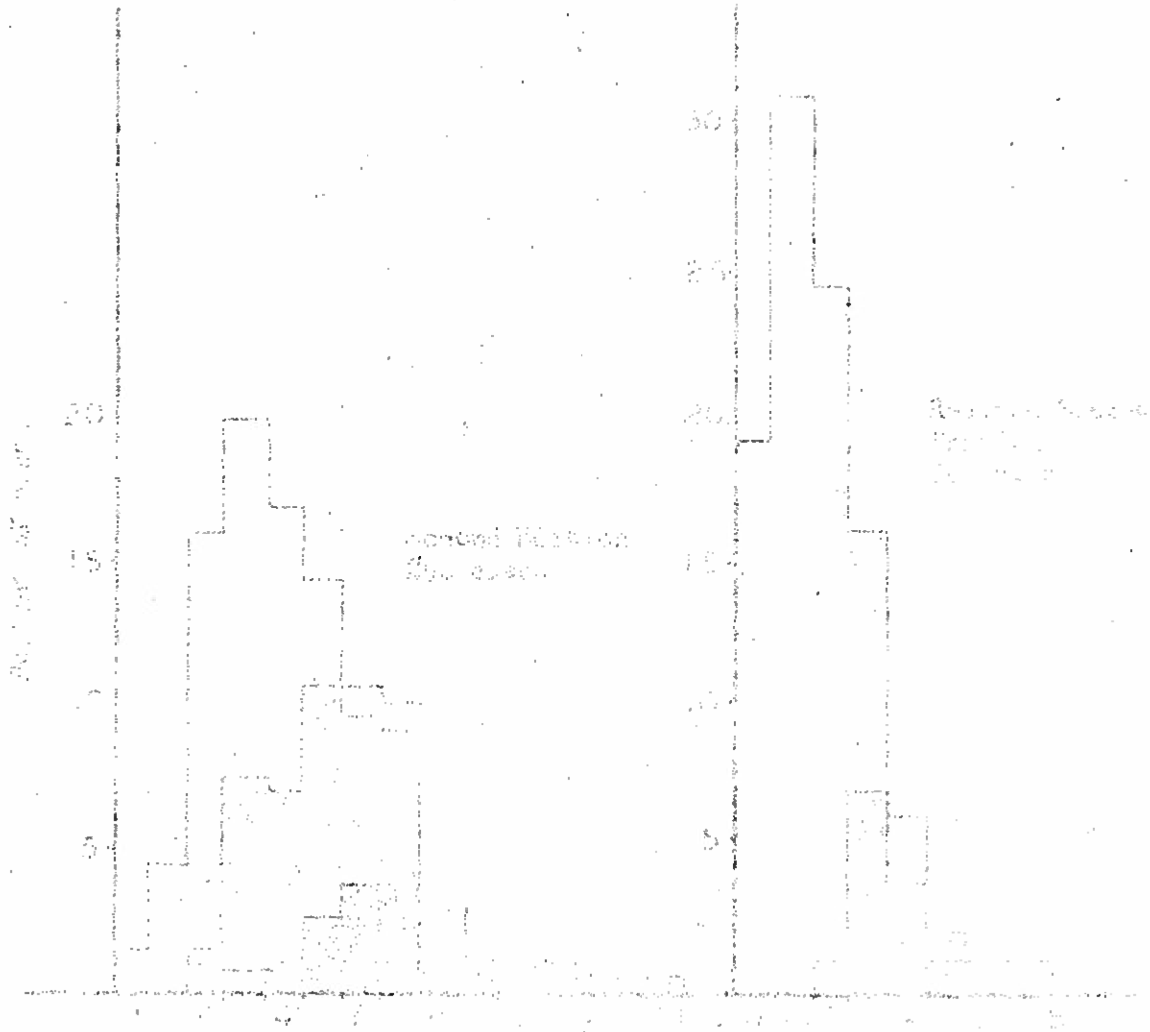
Time Required

The time required to complete a test on each edition was limited by the fact that only 4 seconds were allowed on each plate. The lower limit of time was similarly set by the rate at which the experimenter turned the pages. The average time required to complete the test was 77 seconds for the first edition and 75 seconds for the second; the average time on each plate, however, is larger for the second edition than for the first, since the former has only 36 plates as opposed to 43.

A product-moment correlation was run to compare the time taken by individuals to complete each tests; its magnitude of .60 shows that the subjects who hesitated and consequently took longer on one edition, gave the same reaction to the other.

The Pharmacist's Mate who gave the color tests reported that the second edition was slightly harder to administer because the pages had to be turned for each plate instead for every fourth plate. If individual plates were shown in chance order however the two editions were of approximately the same ease to administer.

Figure 3. Error scores of 393 color normals plotted according to suggested criteria for interpretation of the Second Edition.



Performance of Color Blinds

The population of color blinds shown in this study is drawn from two groups and is not representative of color blinds in general, but emphasizes the two extremes of defective color vision. The group of color blinds contains first, those cases who appear to be not normal on the rigorous examination for color blindness given at the Submarine Base. These men have all been examined at least once before, and in many cases have had several previous examinations, sometimes as many as five. The second group of color blinds is drawn from an Induction Center at New Haven, Connecticut. These men were judged to be color defective by a very easy criterion. These two groups taken together therefore serve admirably to show how the two editions of the American Optical Company plates work on men with severe and with mild color defects. The errors made by both groups of color blinds on each plate are summed, and the errors on both editions are presented in Table IV. These errors on the second edition do not include the revised series of that edition. There is evidence, however, that the revision would not have significantly altered the performance of color blinds on the changed plates. A check on this was made in the study of color blind men selected at the Induction Center. While all of them failed all the revised plates before they were revised, they also failed them after revision.

Memorization

Individuals whose color vision alone was not adequate to pass the Navy color vision examination, have nevertheless succeeded in getting into the Navy. One way of accomplishing this has been to obtain a copy of the Navy color vision test, and memorize it. Three types of cues for memorization which were present in the first edition were minimized in the second, making it more difficult for color blinds to learn. These were (1) the distinctive dot pattern that each digit or group of digits presents, (2) the extraneous white "river" which runs around many of the digits, and (3) the grouping of four plates on any single page. The plates in the second edition are all made up of the same dot pattern with different dots emphasized or colored to form different digits. For this reason it was assumed that the color-blind examinee would be unable to recognize a plate by any specific individual dots, for example the pattern in a corner. Because of the uniform dot pattern the second edition also eliminated any clues to the identity of the digit, arising from the position of the dots rather than from the colors.

TABLE IV

Errors made by 112 men with Color Defcctive Vision on American Optical Company Pseudo-isochromatic plates

First Edition			Second Edition		
Plate No.	Correct Response	Total Errors	Group No.	Corrcct Response	Total Errors
1	(89)	51	1	(89)	63
2	(43)	64		(43)	67
3	(56)	62		(56)	30
4	(27)	80		(27)	39
5	(8)	74			
6	(6)	99	2	(8)	87
7	(39)	103		(6)	102
8	(42)	99		(29)	100
9	(56)	80		(57)	112
10	(27)	92			
11	(29)	112	3	(75)	54
12	(57)	106		(27)	65
13	(86)	68		(42)	59
14	(75)	103		(56)	86
15	(7)	23			
16	(9)	32	4	(25)	93
17	(25)	79		(68)	108
18	(68)	81		(97)	103
19	(5)	103		(34)	109
20	(3)	110			
21	(97)	87	5	(5)	102
22	(34)	101		(3)	104
23	(56)	102		(74)	100
24	(27)	106		(15)	36
27	(89)	109			
28	(43)	106	6	(56)	112
29	(86)	109		(27)	112
30	(75)	110		(89)	109
31	(52)	67		(86)	111
32	(96)	3			
33	-	87	7	(52)	102
34	-	92		(96)	103
35	line	89		(052)	106
36	line	106		(394)	110
37	(052)	77			
38	(394)	80	8	(23)	112
39	(23)	108		(65)	105
40	(65)	104		(47)	95
41	(15)	79		(98)	111
42	(74)	100			
43	(47)	108	9	line	90
44	(98)	110		line	110
45	-	65		-	78
				-	102

The single plate presentation eliminates the cue of other plates in the same group. In the first edition recognition of any one plate out of the group of four sufficed to identify that group of plates and enable a color blind to name the other three because of their position. In the second edition, only when the individual was being tested straight through the series of plates would this relative position give him any cue, and if a random order presentation were shown him it was expected that he would be unable to identify the plates.

A group of eight color blinds ranging from mildly to severely anomalous, was given daily learning trials on both editions of the AO series. The subjects were shown the plates in each edition in a direct sequence and asked to identify the number. Errors were corrected by the examiner, and the proper response was indicated. The digit was also traced out, to help them discover what they were supposed to see. All responses were recorded, and the subjects were tested daily until they made no errors on both tests, or, as in the case of several subjects, their error curve flattened out into a plateau making it apparent that little learning would take place for a considerable period of time. One severely defective color blind never did learn the plates by this technique.

Great improvement took place on all subjects, and many of them reported that they actually had not memorized the plates as such, but had merely refined their technique of looking and sharpened their perception of color. These cases are similar to those reported in the ophthalmological journals where an investigator finds that a man who was not actually coached on the plates as such but merely given instruction as to what to look for improved his performance very markedly. It was also noted that the men who were least severely defective in color vision improved most rapidly in their recognition of the digits, and that those who were severely color blind had to memorize each individual plate as though it were perfectly blank. It is therefore to be expected that differences between the two editions with respect to ease of memorization were minimal in the case of mildly anomalous men and maximal in those who were severely color blind.

The results of the first experiment are presented graphically in Figure 4. In no case was the rate of learning slower on the first edition than on the second.

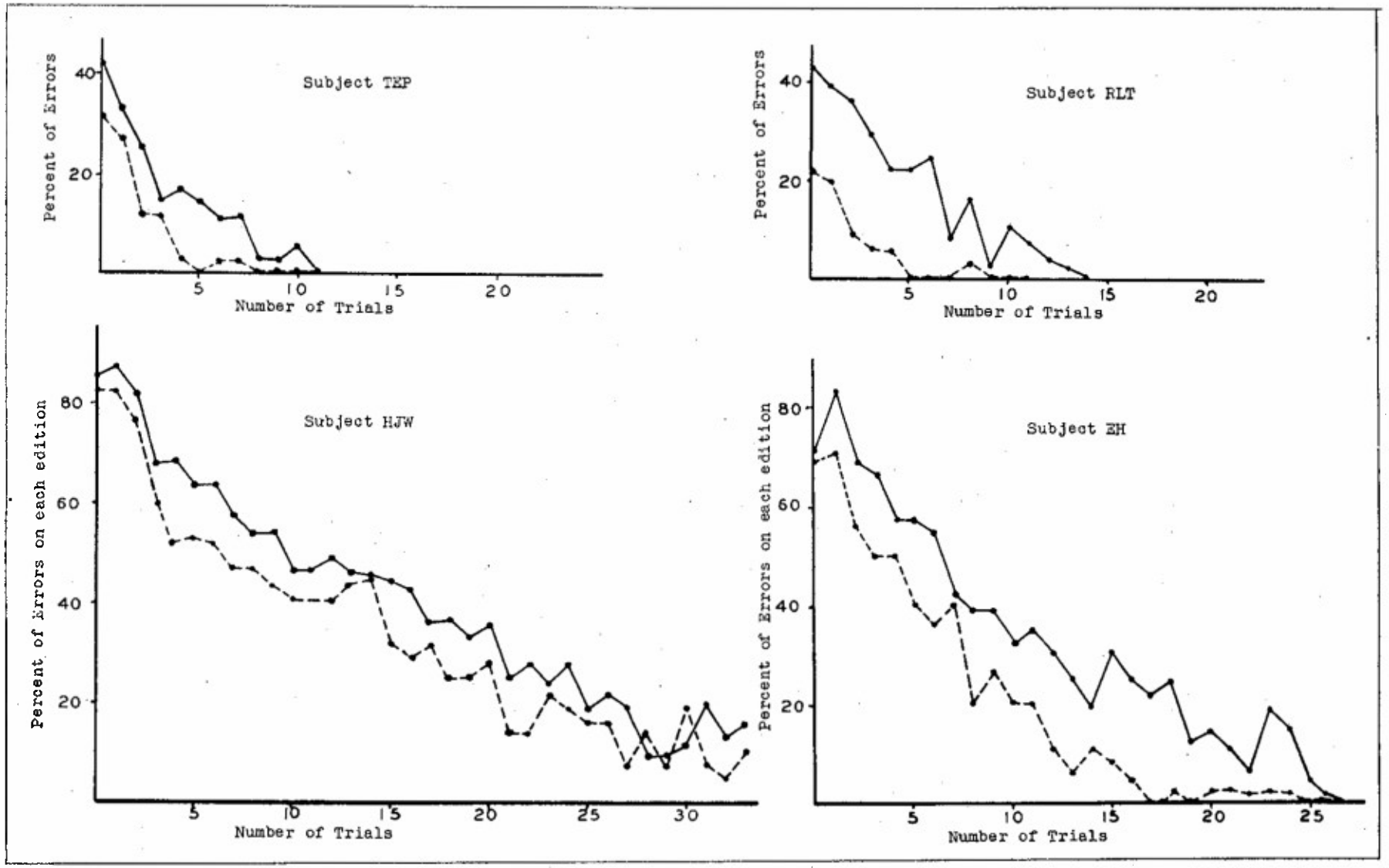


Figure 4. Percent errors on each trial made by color defectives in memorizing both editions of the American Optical Company Plates.

—●—●— = FIRST EDITION

—●– – – = SECOND EDITION

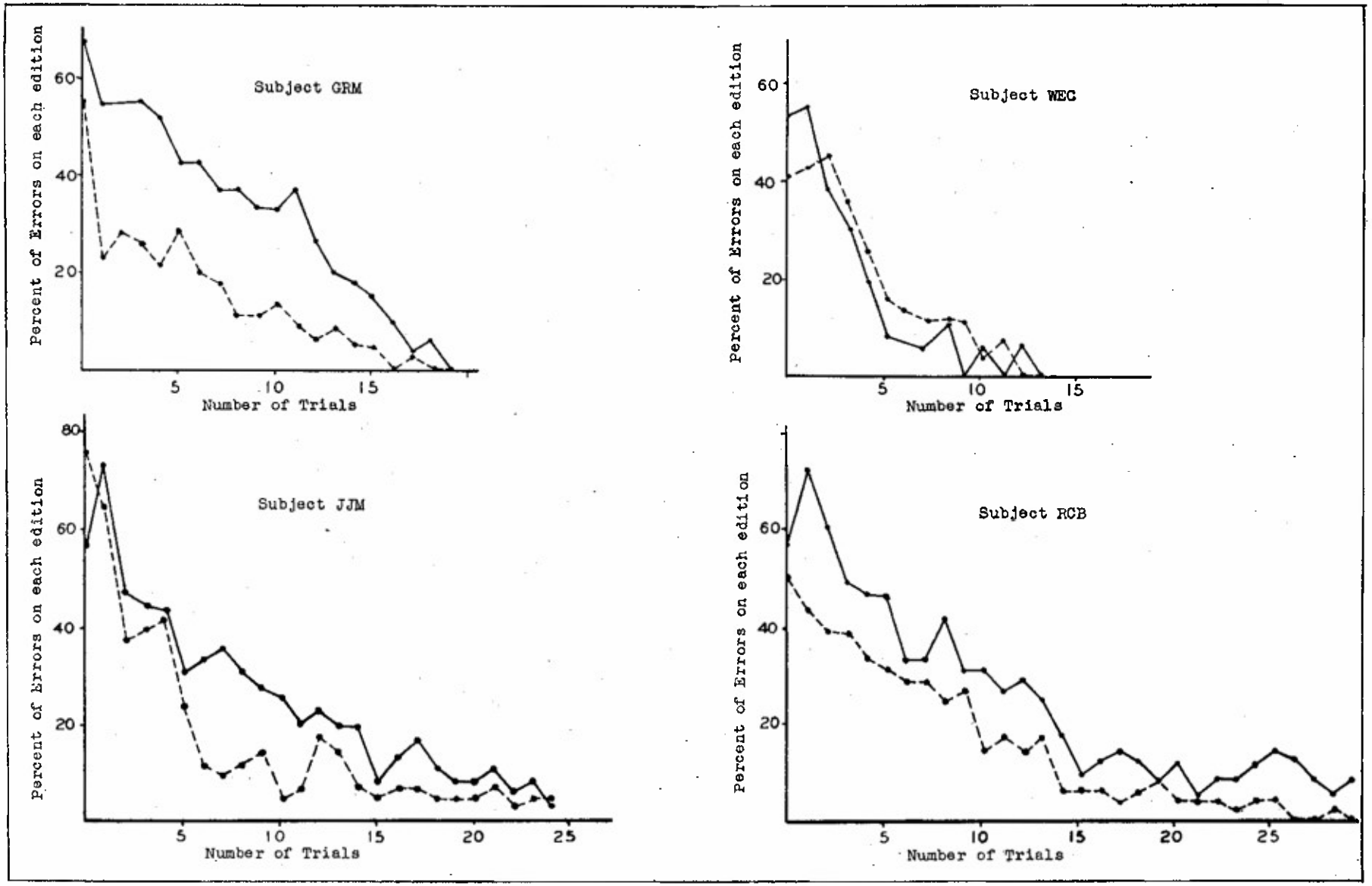


Figure 4 (continued)

To check the verbal report from subjects in the first experiment on memorization, the second group of subjects were run on a slightly different set-up. This experiment attempts to duplicate the optometrist's technique of improving performance on the color vision test. The men were given multiple vitamin pills, and were told that they were not really color defective but merely lacked training in color. They were "trained" by being asked to look at individual dots in the plates, to identify the colors of various dots, and finally to name the colors of which the plates were composed. The observers spent an approximately equal amount of time on both editions, although due to the very nature of this experiment, that condition was not well controlled. They were tested twice, at the end of one and a half weeks and at the end of three weeks at the finish of the experiment. Figure 5 shows graphically the results of this group. Here again considerable improvement is noted, and it should be pointed out that this improvement is not due to memorization as such, although the experience with the plates undoubtedly has considerable bearing on it. It was rather due to a refinement in the technique of seeing. Only one of these men is severely color blind, and it is notable that on the whole he showed much less improvement than the rest of the group.

Since it was apparent that for mildly color-defective men, improvement on pseudo-isochromatic plates is rather a question of change in technique of seeing than one of memorization, we prepared three severely defective observers directly in terms of memorization on each book. These men were given a list of the plates in both editions, and they were told that they were to memorize them so that they could identify the numbers when the tests were presented in any order. It is here, with the severely defective color blinds, that the difference between the two editions really shows up. All three could not identify the plates in the second edition when shewn in random order. These subjects would get 100% on both editions going through in direct sequence, but in a chance order, the first edition would remain 100%, and the second edition would show a considerable number of errors. These scores are shown in Table V, following.

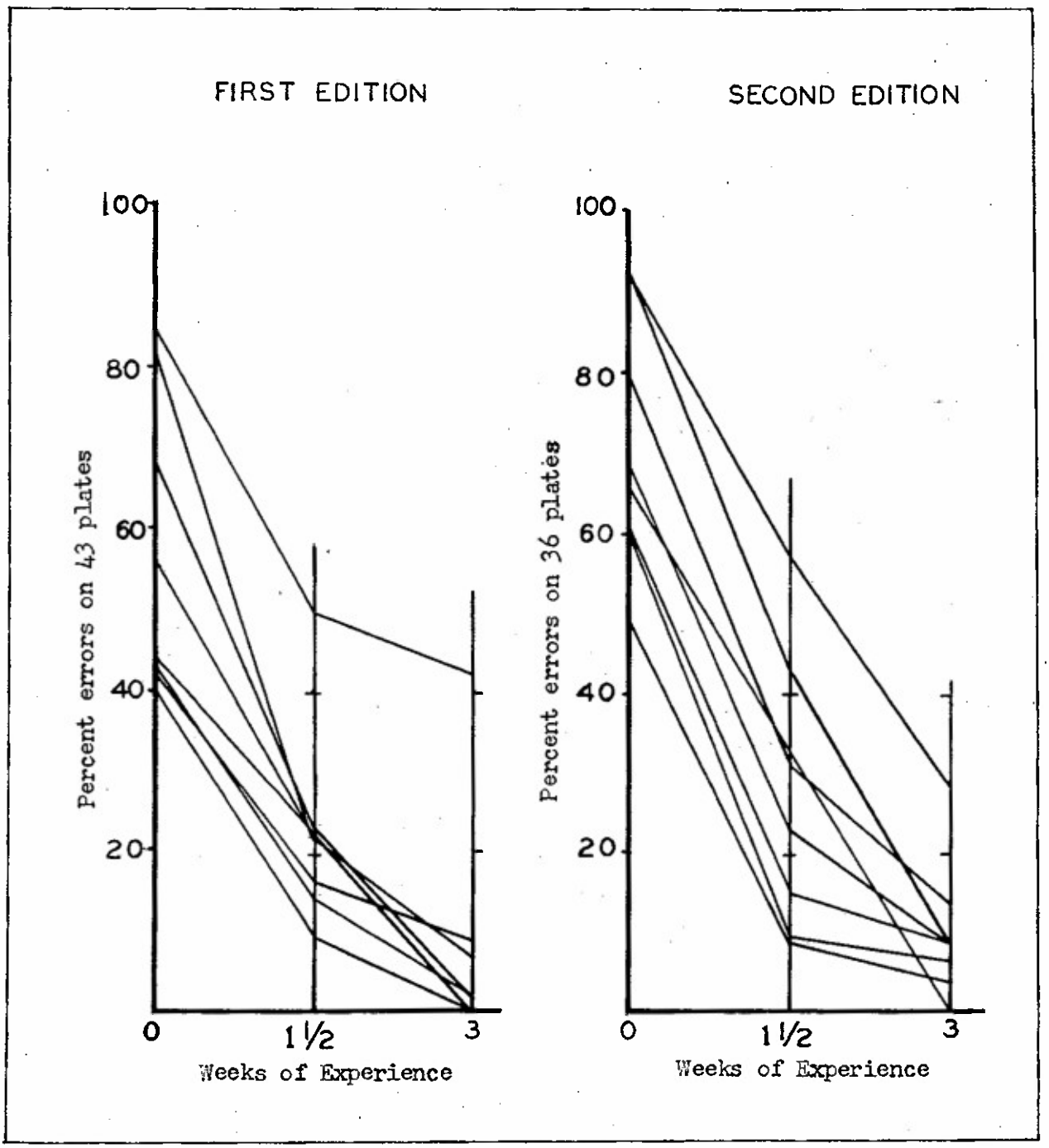


Figure 5.

Performance of 8 color blinds on First and Second Editions after experience with both editions.

TABLE V

Scores of 3 severely color defective men on both editions. 1) before memorization, 2) after memorization, direct order and 3) after memorization, chance order.

Case / Edition	% Errors					
	R.C.		E.W.		L.H.	
	1st	2nd	1st	2nd	1st	2nd
Before Learning	84	86	84	86	81	75
After Learning						
Direct	100	100	100	100	100	100
Chance	100	17	100	45	100	25

It is thus apparent that as far as memorization itself is concerned, the second edition is less easy to memorize than the first edition, but that most individuals who are only mildly color blind will improve their scores on pseudo-isochromatic plates, not specifically by memorization as such, but rather by a refinement in their technique of seeing. These results are similar to those reported by optometrists, but the interpretation placed upon them is different. We used no radical technique for "curing" color vision, but merely attempted to familiarize the man being tested with what he had to see, with the names, background colors and figural colors in the plates, and the specific shapes of the numbers that he was to look for. The possibility of improvement in reading specific plates by "training" is inherent in any pseudo-isochromatic test of the Stilling type. There is no indication, of course, that thie "training" results in any actual improvement in color vision as such.

CONCLUSIONS

1. The second edition of American Optical Company plates is the same type of test and of the same order of difficulty as the first edition.

2. Known color-weak persons are detected. The ambiguous characteristics of the first test have been reduced so that the second edition, with suggested revisions, will dichotomize clearly between the color normal and the color anomalous.

3. Analysis of the data of men with normal color vision shows that a criterion of normalcy based upon total errors is superior to a criterion based upon color groups.

4. Personnel showing hesitancy or difficulty with the old tests show similar hesitancy with the new, using time required to complete the test as a criterion of hesitancy.

5. The new tests are harder to memorize.

6. The second edition takes slightly more time to administer per plate.

APPENDIX A

Inspection of Table II shows that the starred plates of the second edition and all plates in color group #6 (indicated by #) are miscalled by normals a disproportionate number of times. Two types of changes were introduced to reduce these errors; (1) changing specific dots to another color already present in the plate, and (2) changing all dots of one color to a slightly different shade. The alterations were made by pasting circles of the desired color on top of the dots in the book. All changes are detailed in Fig. 6 and its accompanying table.

The first type of change was made with the purpose of strengthening the configuration of the number to be read. For example, in Plate 4, Group #4, the number 34 is often called 94 because of the emphasis on the top of the digit 3. Three dots were changed to a background color, thus cutting off the top end of the 3 and reducing the impression of 9. Similar changes were made in four other plates, as illustrated in Figure 6.

The second type of change was used to correct errors in the colors used to print Group #6. The changes in color in two ink runs were carefully traced down and found to be due to unusual "burning out" in two ink samples furnished by the International Printing Inks Corporation. The false colors are apparently not due to errors in specifications, wrong samples, errors in color matching, nor in the spectrophotometric department of the Interchemical Corporation.

The configurational importance of these two colors is such that the slight error in shade makes this group of plates too difficult for a screening test. In revision, the individual dots of these colors were covered with Munsell colors 5R 7/2 and 5R 8/2. Numerals made up with the new colors are still confused with the background by color blind men, but are distinguished by men with normal color vision.

Table VI shows the change in percent of errors on each plate. All differences except for 98 in color group #8 are statistically reliable.

TABLE VI

Pattern changed Group	Number	% Errors Before change	After change
4	34	41	15
7	394	82	51
8	23	26	11
8	65	32	19
8	98	9	6
Color changed			
6	56	40	9
6	27	7	1
6	89	31	3
6	86	53	20

The effect of these changes on the total errors made by normals is presented graphically in Figure 2b. Only 4% of the population tested make more than 4 errors, as compared with the first edition where more than 40% make more than 4 errors. One plate, 394 in Group #7 still needs further improvement. If it is eliminated from the test, the distribution of error scores becomes more desirable.

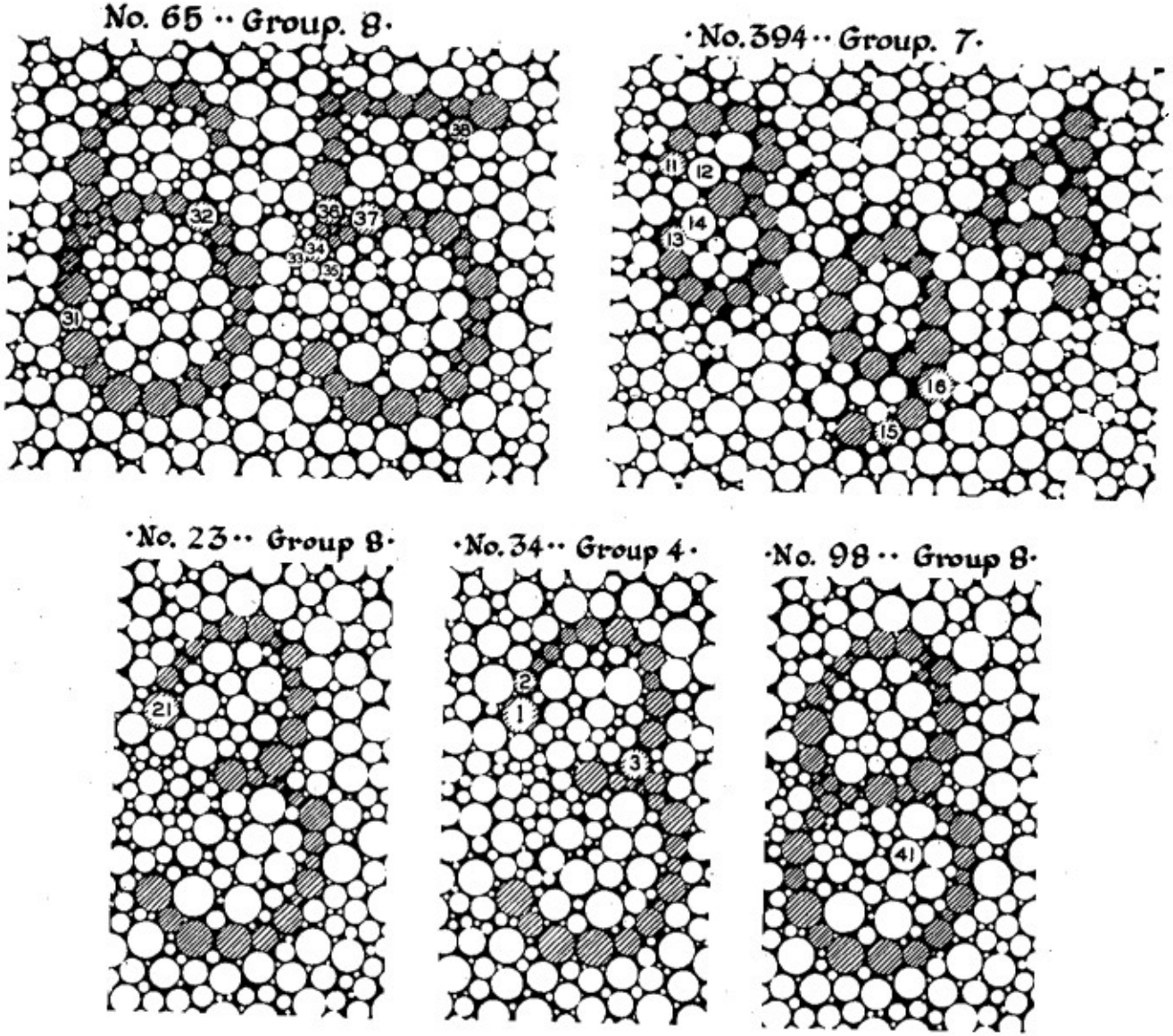


Figure 6. Color changes made in certain dots in the revised edition.

TABLE VII

Changes in Printer's Samples shown in Figure 6

COLOR GROUP #	CORRECT RESPONSE #	REF. NO. ON DIAGRAM	PRODUCTION NO. CHANGED FROM	PRODUCTION NO. CHANGED TO
4	34	1	21976	23479
		2	21977	21976
		3	21977	21976
6	56, 27, 86, 89	all dots	21915	Munsell 5R 7/2
		all dots	21917	Munsell 5R 8/2
7	394	11	23480	21872
		12	21870	21873
		13		21871
		14	21870	21873
		15	21867	23480
		16		21867
8	23	21	22011	22014
8	65	31	22012	22011
		32	22011	22013
		33	22014	22009
		34	22011	22014
		35	22009	22014
		36	22012(3)	22011
		37	22012(3)	22011
		38	22014	22009
8	98	41	22009	22015

APPENDIX B

The eolors in the second edition were eheeked by the Color Vision Laboratory of the Submarine Base, New London, and the colors were plotted on Rectilinear Uniform Chromaticity Seale Diagrams derived from the 1931 Standard Observer and Coordinate System. A diseussion of the technique of eonstruetion of pseudo-isoehromatic plates was given in the following extract from a memorandum written by the senior author to Captain C. W, Shilling (MC) and sent to Captain J. C. Adams (MC) on June 23, 1944.

> A pseudo-isochromatic plate is based upon the prineiple that the eolor differenee between the figure and the background is so small that he (a eolor defeetive) cannot distinguish between the two. Confusion zones on a color chart indieate whieh eolors are eonfused by a color blind. The effieieney of sueh plates depend upon the aceuraey with whieh the eolors fall within those zones. The zonos for deuteranopes and protanopes are not identieal. Most of tho Stilling plates and the Ishihara platos aro based on the average of these two types of color bl:ndness... The direction of these zones as we have determined them in the New London Laboratory,.... agree closely with the less extensivo data eollected by Pitt, Wright, Heeht and the Color Blindness Committee of the Inter-Society Color Counеil. Enelosure 2 is an enlarged seetion of this ehart showing in dot-dash lines tho preeise average of these eonfusion zonos.
>
> In other words, you will note that all ehanges have been made in tho direetion of greater aeeuraey of reproduetion of the original plates, or, whero the original plate was in some way out of line with the original plan of Ishihara or Stilling, (presumably due to Printer's errors), that we have suggested changos whieh will bring it into line with the original mothod and thus mado a more diagnostie plate. This has involved a study of suceessive editions of Stillings and Ishihara as woll as review in terms of our own Laboratory work.
>
> Some of the first edition A-O platos were found to be extremely weak. This was eonfirmed by the researehes of the Canadians, the British, and by Rowland, Griffis and Webster in our own Air and Naval serviees. Certain plates were as often miscalled by normals as by color blinds, - in brief, whatever tho reasons, those plates were not diagnostic of color deficiency.

Plates No. 1, 2, 3, 4. Second Edition group #1

This is an easy series of plates and has never been too effective. 1) The reds in general are too low in value. 2) The plate would be unequally difficult for two types of color blind; most difficult for one type of deuteranomaly. These things may be remedied by remixes of two colors, raising the brightness of one of the reds and changing its color; and changing the color of one green and darkening it.

Plates No. 5, 6, 11, 12, Second Edition Group #2

1) The last edition of the Ishihara experimented with light reds which did not prove to be as effective as the plates in the earlier editions. Both normals and color-blinds tended to "see both numbers."

2) Submitted inks tend toward the deuteranopic lane. Recommended remixes compromise on value, remedy the off-center matches, and make the blue-green spots effective as "stoppers" at the ends of the "3". (Plate #5).

The printing plate for which color #3 was intended should be used to run color #2.

The printing plate for which color #2 was intended should be used to run color #1.

The printing plate for which color #1 was intended should be used to run the remix of #3 (now darker)

Plates No. 7, 8, 9, 10, 13, 14. Second Edition Group #3

These are fairly easy plates. Submitted samples fall within the median color lane. A moderate color blind, however, could distinguish the figures by the nearly uniform darkness of the yellow-reds. It is therefore suggested that a lighter YR be used, yellowed somewhat in order to lie in the confusion lane with #8. The notation is slightly beyond the Munsell samples but can be easily mixed in inks and easily estimated beyond the sample.

Plates No. 15, 16. Not in second edition

This plate is intended to detect only protanopes. The uniform reds in the figure are a "dead give-away", however, to the observant or instructed testee. The additional color is darker, intended to be confused with the dark background spots and should be exchanged for the lighter reds at points adjacent to the dark background spots.

(The rivers between figure and background must be broken up in the engraved plate.)

Plates No. 17, 18, 21, 22. Second edition Group #4

These colors are in the third worst group of plates by evaluation of the performance of normals and color blinds. The reason for this is apparent from tho diagram. Note how colors No.4 and 5 are far removed from the axis of Nos. 1, 2 and 3. Both 4 and 5 will have to be changed to better the plate.

Plates No. 19, 20, 41, 42. Second edition Group #5

These plates have always been fairly successful. The primary difficulty with them is in brightness. The confusion pattern of the color blind is composed of light pinks and dark blue-greens. This difference in darkness makes the configuration more confusing to the color blind, and as a result he is often able to see both configurations. One change should correct this difficulty of brightness. The other change is recommended because of an incorrect color.

Plates No. 23, 24, 27, 28, 29, 30. Second edition Group #6

This is a very good series of plates. It is difficult for normals, but impossible for color-blinds.

The colors are all right.

Plates No. 31, 32, 37, 38. Second Edition Group #7

This is the worst of all groups. Even a dichromat can tell the configuration by the dark reds. One change to lighten it should greatly improve the plates. Even at best they will be fairly easy.

Plates No. 33, 34, 45. Second edition Group #9

The pattern in these plates is supposed to be visible to a color blind but not to a normal. It is expected that the normal will not perceive the light-grayish configuration because he will see the other colors. This is not invariably true. Furthermore, all color blinds do not see the figure. Consequently the group of plates is unsatisfactory. They would need to be completely redesigned to be useful. No changes recommended.

Plate No. 35. Second Edition Group #9

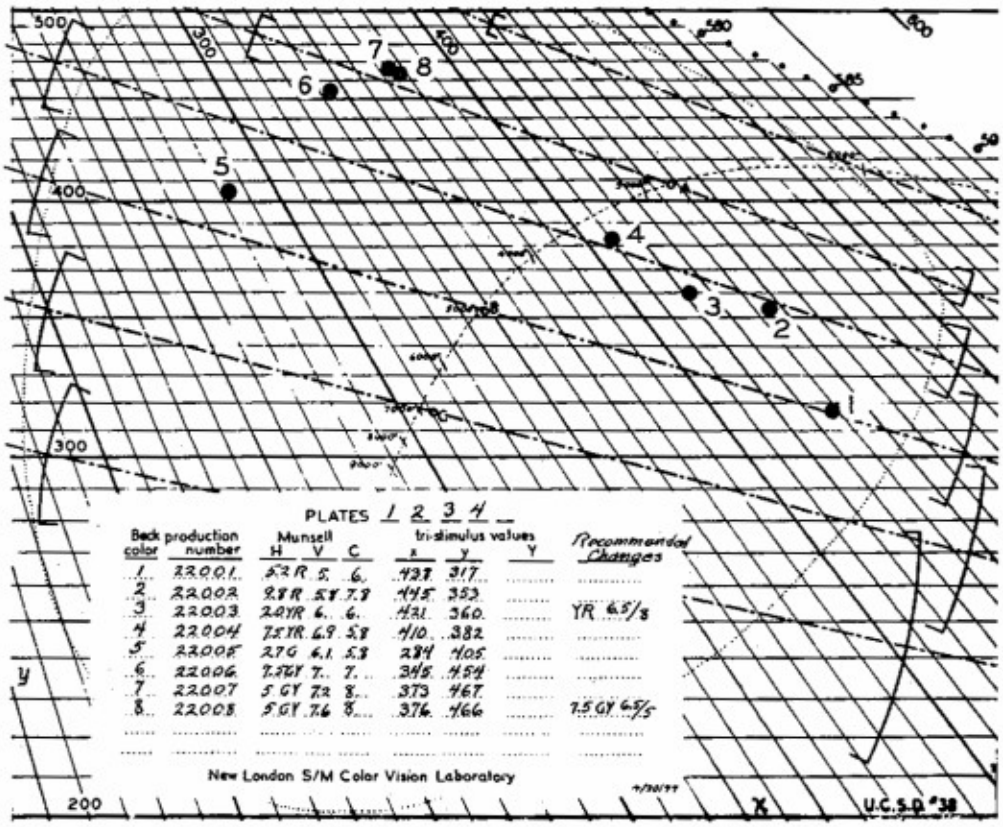
These colors are correct. Nos. 7 & 8 are not designed to be confused with any of the others. This plate is slightly easier than the succeeding one.

Plate No. 36. Second Edition Group #9

This plate has always been fairly successful. The green line, however, is too dark for the background. Under standard daylight the darkness of the line is not so apparent as under artificial light. Then the green becomes relatively much darker, and thus the minor defect under daylight becomes a very serious difficulty. One change should remedy this--No. 6 to YR 6/2. The change of 6 is particularly desirable because it had little more function than a blank white spot.

Plates No. 39, 40, 43, 44. Second Edition Group #8

This group of plates is difficult for normals but almost impossible for color blinds. The figure is very similar to the background. No changes are necessary.



PLATES 1 2 3 4

Back color	production number	Munsell H	V	C	tristimulus values x	y	Y	Recommended Changes
1	22001	5.2 R	5.	6.	437	317	.....	.....
2	22002	9.8 R	5.1	7.9	445	353	.....	.....
3	22003	2.9 YR	6.	6.	421	360	.....	YR 6.5/8
4	22004	7.5 YR	6.9	5.8	410	382	.....	.....
5	22005	2.7 G	6.1	5.3	284	405	.....	.....
6	22006	7.5 GY	7.	7.	345	454	.....	.....
7	22007	5 GY	7.2	8.	373	467	.....	.....
8	22008	5 GY	7.6	8.	376	466	.....	7.5 GY 6.5/5
.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....

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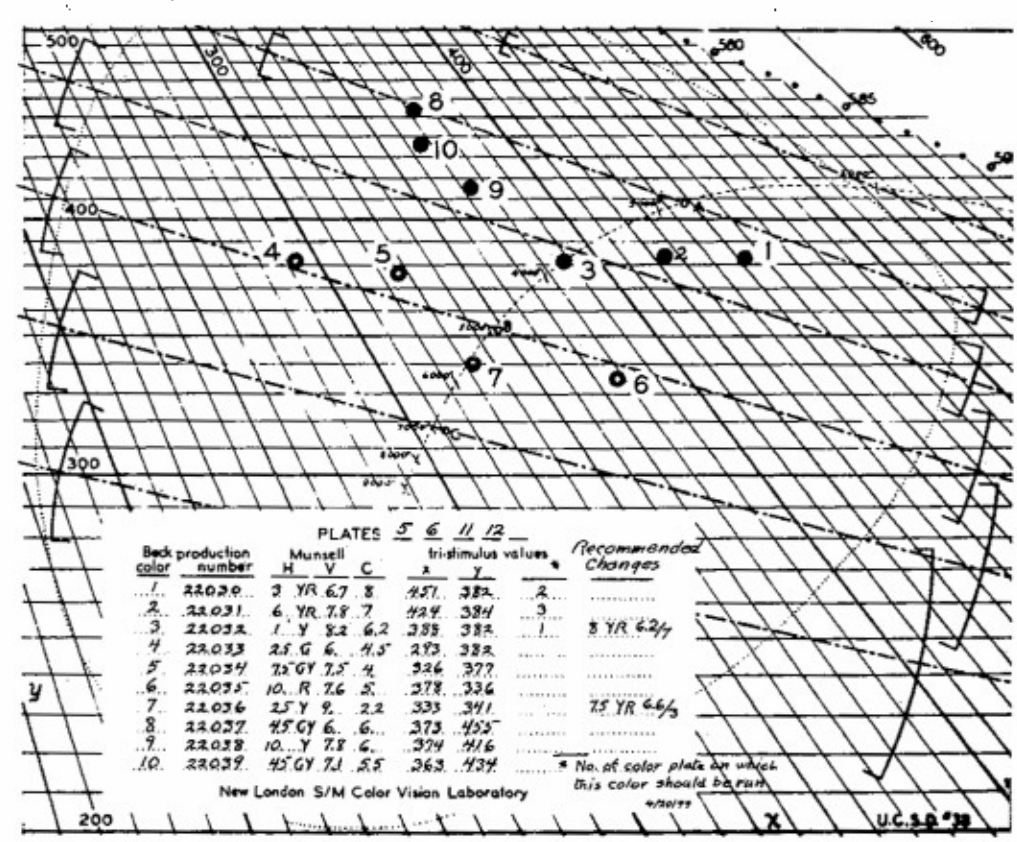
4/30/77

U.C.S.D. #38



PLATES 5 6 11 12

Back color	production number	Munsell H	V	C	tristimulus values x	y	%	Recommended Changes
1	22030	3 YR	6.7	8	451	382	2	.....
2	22031	6 YR	7.8	7	424	384	3	.....
3	22032	1 Y	8.2	6.2	385	382	1	8 YR 6.2/7
4	22033	2.5 G	6.	4.5	293	382	.....	.....
5	22034	7.5 GY	7.5	4	326	377	.....	.....
6	22035	10. R	7.6	5.	378	336	.....	.....
7	22036	2.5 Y	9.	2.2	333	341	.....	7.5 YR 6.6/3
8	22037	4.5 GY	6.	6.	373	453	.....	.....
9	22038	10. Y	7.8	6.	394	416	.....	.....
10	22039	4.5 GY	7.1	5.5	363	434	.....	.....

* No. of color plate on which this color should be run

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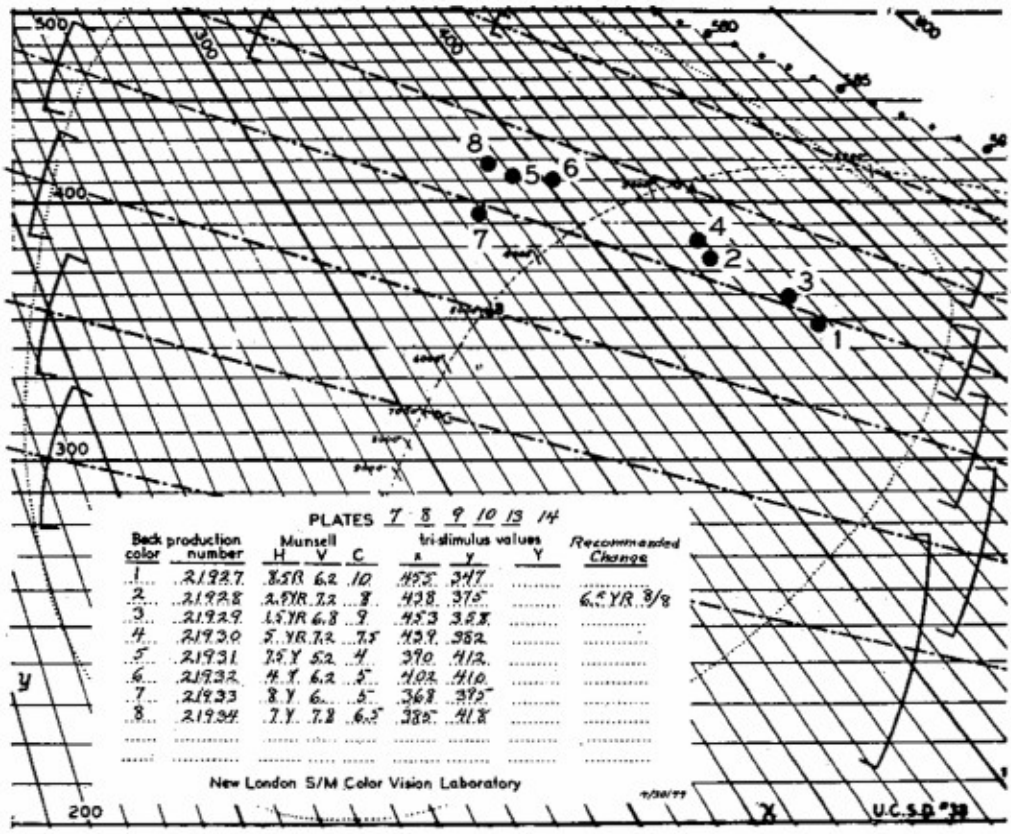

PLATES 7 8 9 10 13 14

Back color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	Recommended Change
1	21927	8.5R	6.2	10	495	347		
2	21928	2.5YR	7.2	8	438	375		6.5 YR 8/8
3	21929	1.5YR	6.8	9	453	358		
4	21930	5 YR	7.2	7.5	429	382		
5	21931	7.5 Y	5.2	4	390	412		
6	21932	4 Y	6.2	5	402	410		
7	21933	8 Y	6	5	368	395		
8	21934	7 Y	7.2	6.5	385	418		

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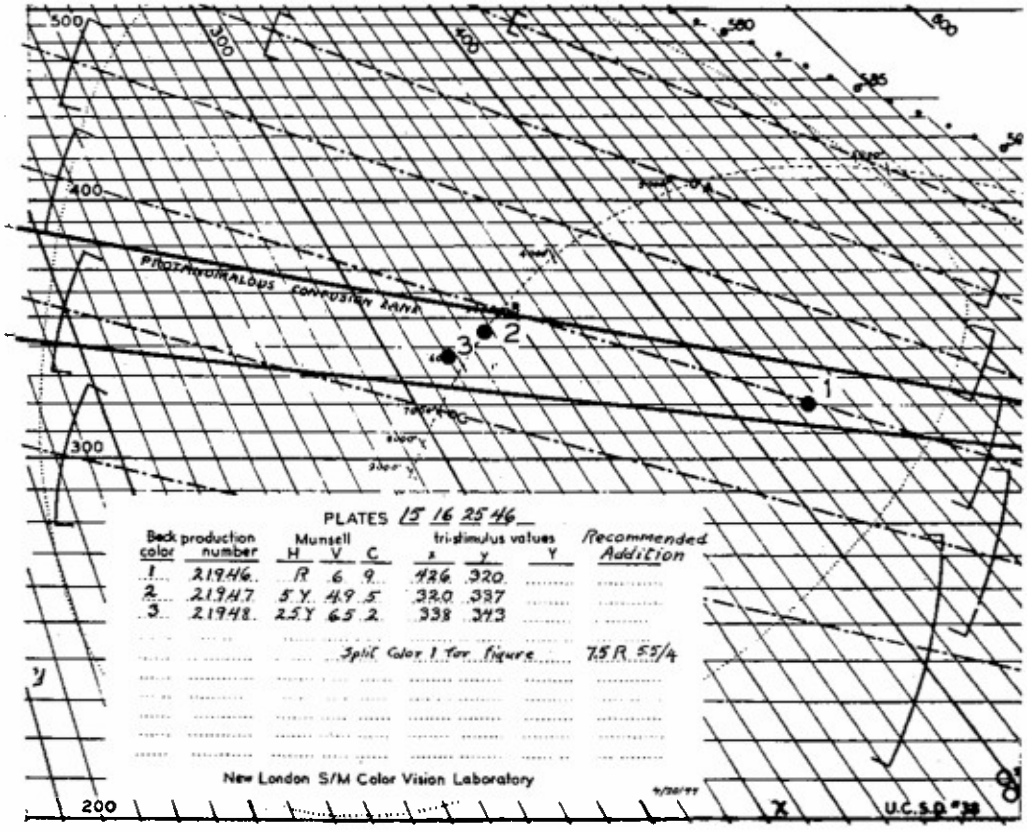

PLATES 15 16 25 46

Back color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	Recommended Addition
1	21946	R	6	9	426	320		
2	21947	5 Y	4.9	5	320	337		
3	21948	2.5 Y	6.5	2	338	343		
					Split Color 1 for figure			7.5 R 5.5/4

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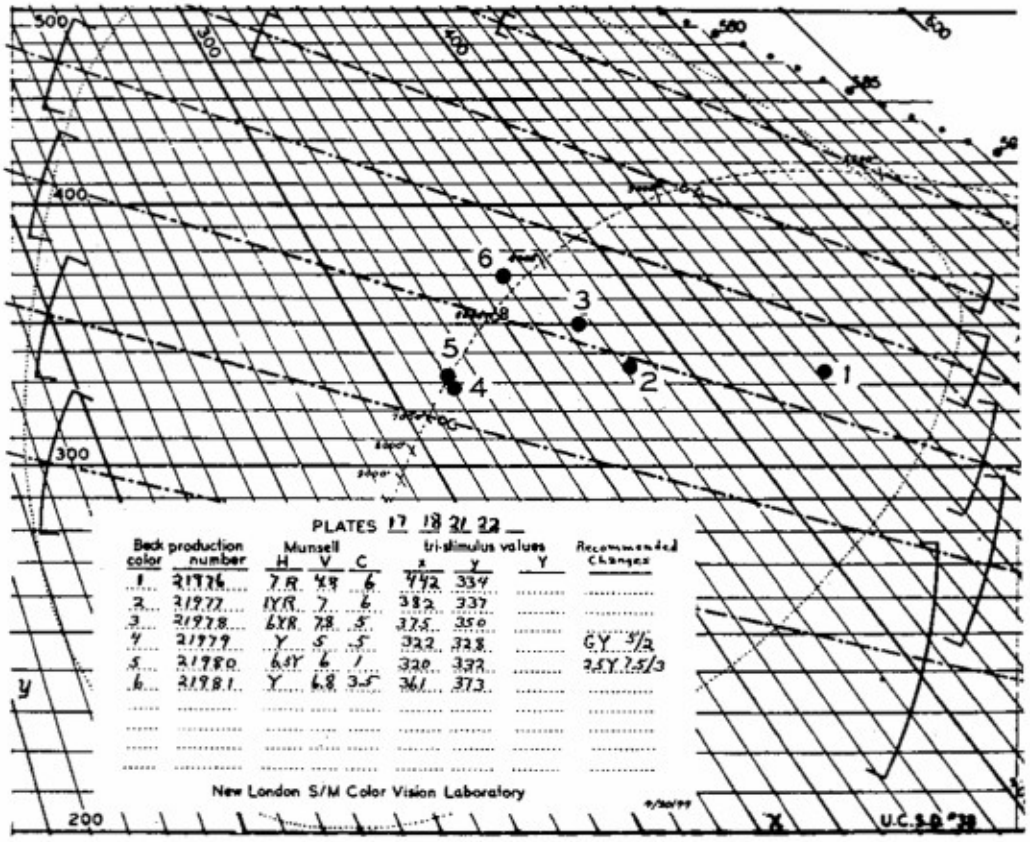

PLATES 17 18 21 22

Back color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	Recommended Changes
1	21976	7.R	4.8	6	442	339		
2	21977	1YR	7	6	382	337		
3	21978	6YR	7.8	5	375	350		
4	21979	Y	5	5	322	328		GY 5/2
5	21980	6.4Y	6	1	320	332		2.5Y 7.5/3
6	21981	Y	6.8	3.5	361	373		

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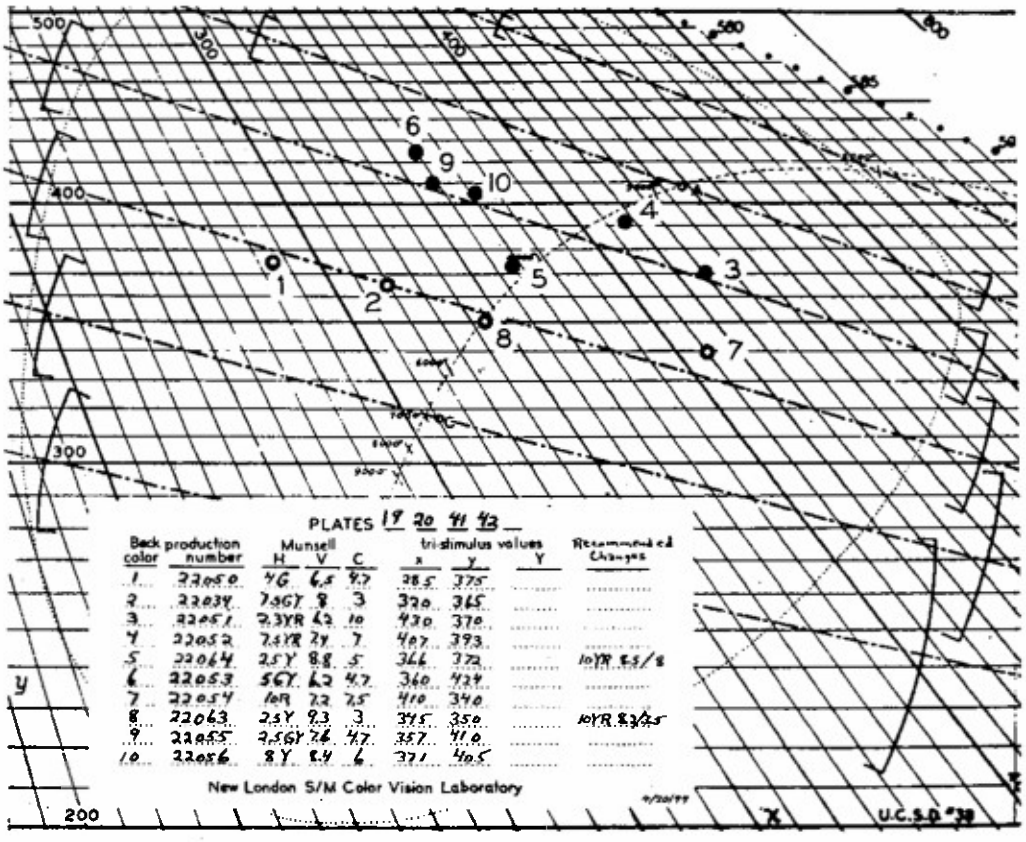

PLATES 19 20 41 43

Back color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	Recommended Changes
1	22050	4G	6.5	4.7	28.5	375		
2	22051	7.5GY	8	3	320	365		
3	22052	2.3YR	6.2	10	430	370		
4	22053	7.4YR	7.4	7	407	393		
5	22064	2.5Y	8.8	5	366	372		10YR 8.5/8
6	22053	5GY	6.2	4.7	340	424		
7	22054	10R	7.2	7.5	410	340		
8	22063	2.5Y	9.3	3	375	350		10YR 8.3/2.5
9	22055	2.5GY	7.6	4.7	357	410		
10	22056	8Y	8.4	6	371	405		

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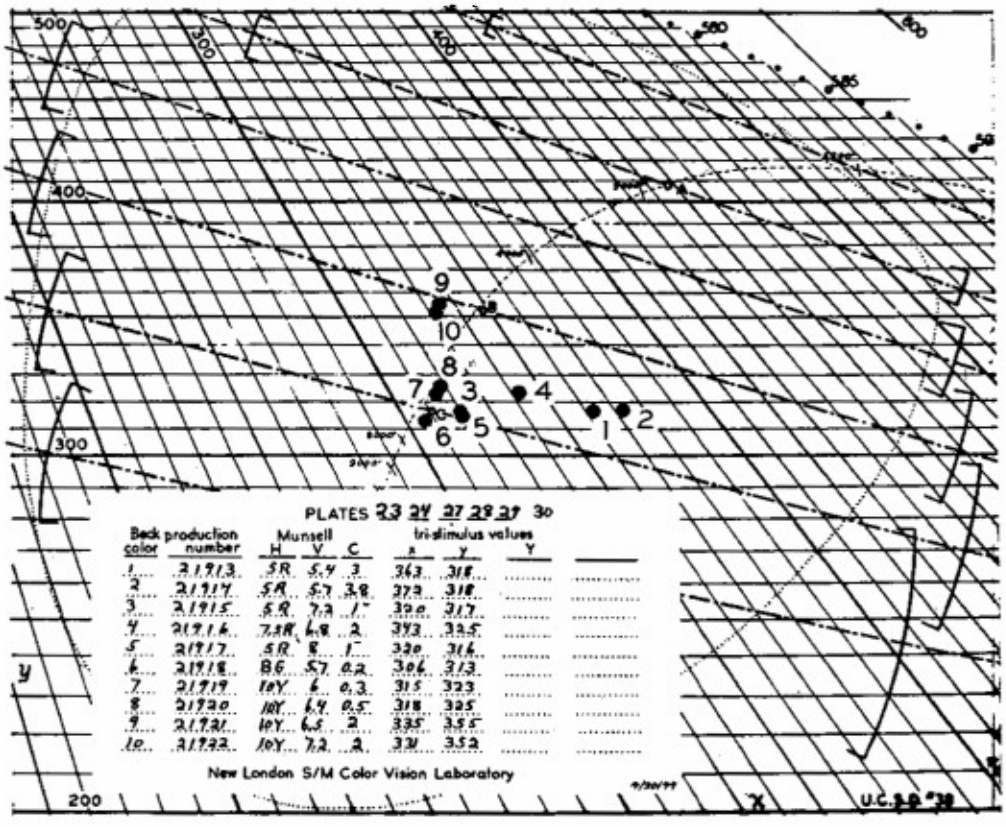

PLATES 23 24 27 28 29 30

Beck color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	
1	21913	5R	5.4	3	363	318		
2	21914	5R	5.7	3.8	373	318		
3	21915	5R	7.2	1"	390	317		
4	21916	7.5R	6.8	2	393	325		
5	21917	5R	8	1"	390	316		
6	21918	8G	5.7	0.2	306	313		
7	21919	10Y	6	0.3	315	323		
8	21920	10Y	6.4	0.5	318	325		
9	21921	10Y	6.5	2	335	355		
10	21922	10Y	7.2	2	331	352		

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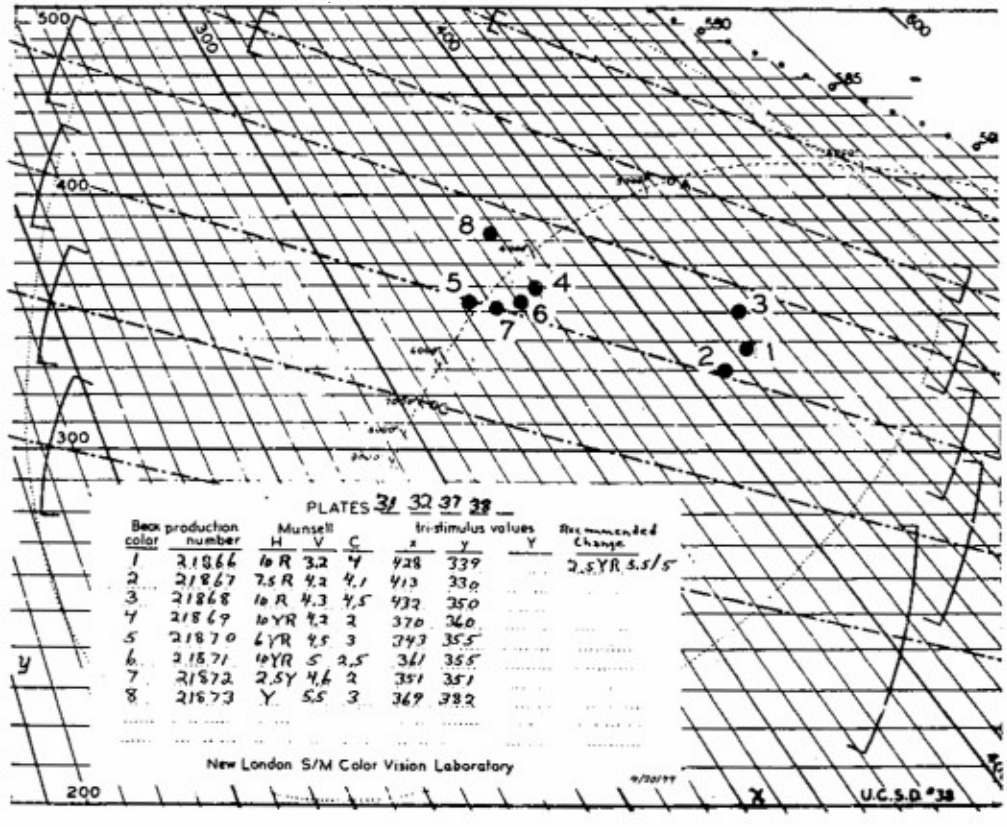

PLATES 31 32 37 38

Beck color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	Recommended Change
1	21866	10R	3.2	4	428	339		2.5YR 5.5/5
2	21867	7.5R	4.2	4.1	413	330		
3	21868	10R	4.3	4.5	432	350		
4	21869	10YR	4.2	2	370	360		
5	21870	6YR	4.5	3	393	355		
6	21871	10YR	5	2.5	361	355		
7	21872	2.5Y	4.6	2	351	351		
8	21873	Y	5.5	3	369	382		

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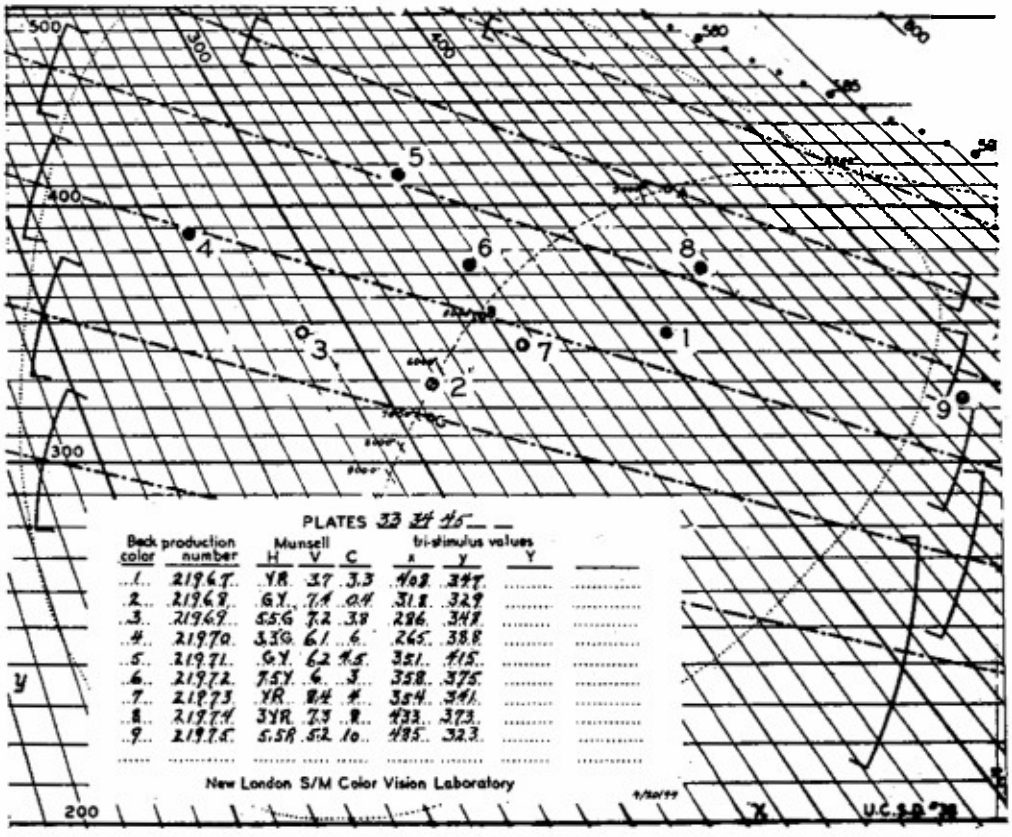

PLATES 33 34 45

Back color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	
1	21967	YR	3.7	3.3	402	344		
2	21968	GY	7.1	0.4	318	329		
3	21969	5.5G	7.2	3.8	286	348		
4	21970	3.3G	6.1	6	245	388		
5	21971	GY	6.2	9.5	351	415		
6	21972	7.5Y	6	3	358	375		
7	21973	YR	8.4	4	354	341		
8	21974	3YR	7.3	8	433	373		
9	21975	5.5R	5.2	10	485	323		

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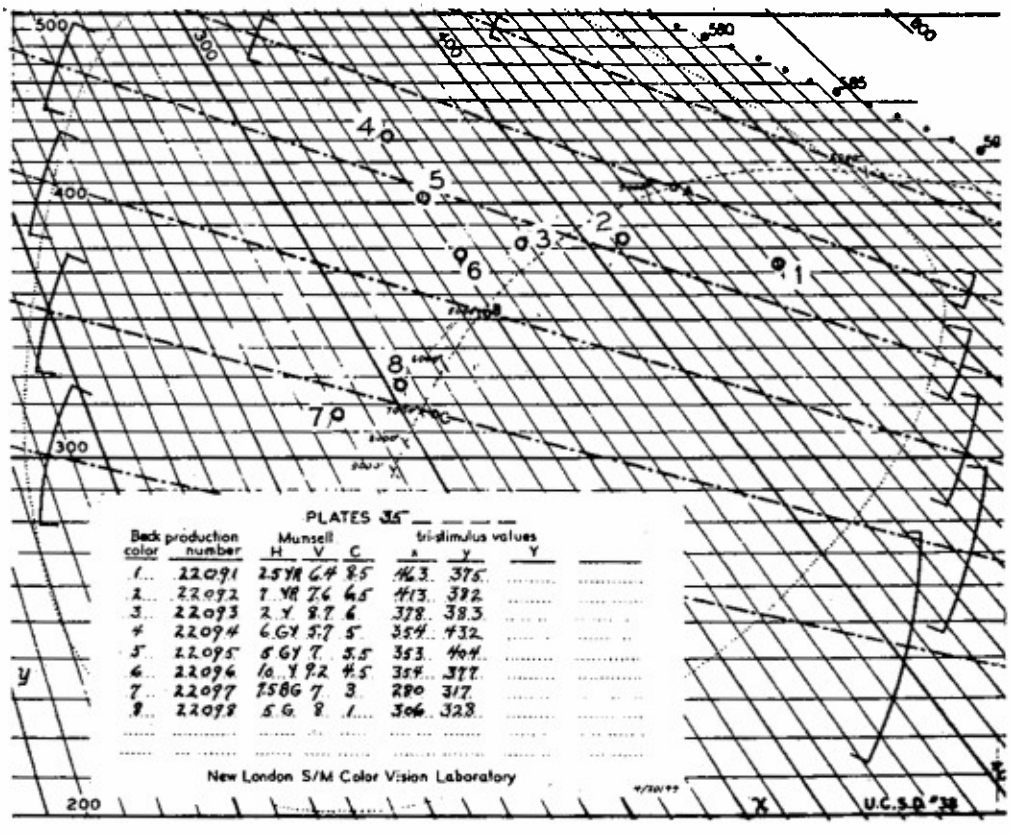

PLATES 35

Back color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	
1	22091	2.5YR	6.4	8.5	463	375		
2	22092	7.5R	7.6	6.5	413	392		
3	22093	2.5Y	8.7	6	378	383		
4	22094	6.GY	5.7	5	354	432		
5	22095	5 GY	7	5.5	353	404		
6	22096	10.Y	8.2	4.5	359	377		
7	22097	7.5BG	7	3	280	317		
8	22098	5 G	8	1	306	328		

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4/20/49

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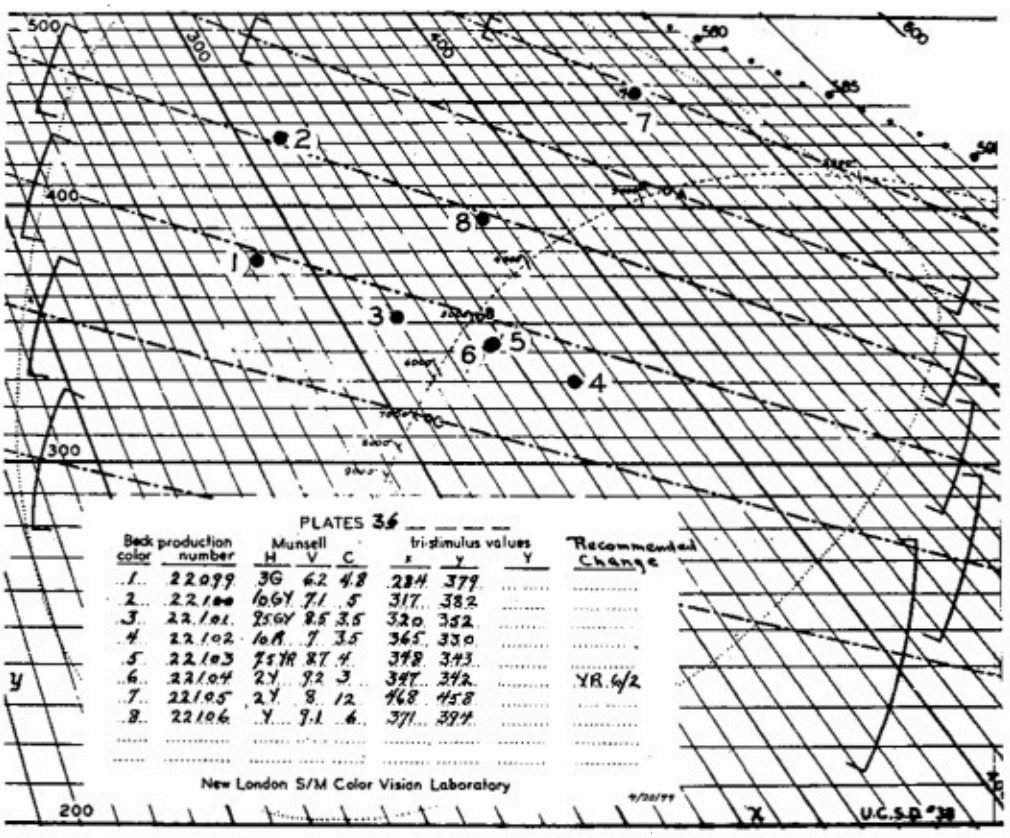

PLATES 36

Back color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	Recommended Change
1	22099	3G	6.2	4.8	284	379		
2	22100	10GY	7.1	5	317	382		
3	22101	2.5GY	8.5	3.5	320	352		
4	22102	10R	7	3.5	365	330		
5	22103	7.5YR	8.7	4	398	343		
6	22104	2Y	9.2	3	387	342		YR 6/2
7	22105	2.Y	8	12	468	458		
8	22106	Y	9.1	6	371	394		

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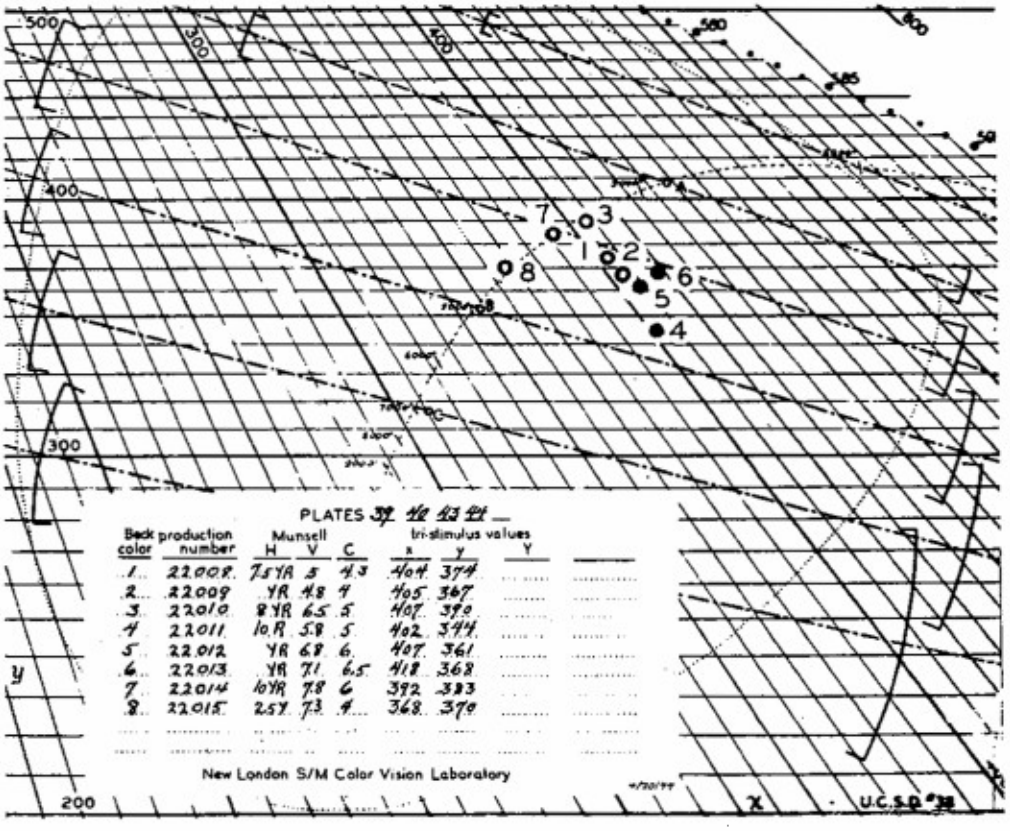
U.C.S.D. #38



PLATES 39 42 43 44

Back color	production number	Munsell H	V	C	tri-stimulus values x	y	Y	
1	22008	7.5YR	5	4.3	404	374		
2	22009	YR	4.8	4	405	367		
3	22010	8YR	6.5	5	407	390		
4	22011	10R	5.8	5	402	394		
5	22012	YR	6.8	6	407	361		
6	22013	YR	7.1	6.5	418	368		
7	22014	10YR	7.8	6	392	383		
8	22015	2.5Y	7.3	4	368	379		

New London S/M Color Vision Laboratory

U.C.S.D. #38

APPENDIX C

TESTING AND INTERPRETATION OF SCORES

The present report, previous reports by the Research Laboratory, Submarine Base, New London, Conn., and the opinion of the majority of recent workers in the Color vision field indicate that the following conclusions are justified with regard to the use of the Stilling and Ishihara pseudo-isochromatic plates of the type which are incorporated in the American Optical Co. test. (These statements apply to the types of color defects which have been termed "Red blindness" and "Green blindness")

1. The Stilling and Ishihara type of plates make a dichotomizing test capable of separating normal from defective color vision with very high reliability.

2. This type of test does not distinguish between degrees of deficiency with a high degree of reliability, that is, the "number of plates" missed is a poor index of the extent of color deficiency.

3. Because of its convenience, speed and efficiency in distinguishing normal from anomalous vision, this type of test is unexcelled for quick "screening" examinations.

4. Personnel who read correctly not less than 26 of the 36 plates in the Revised Second Edition of the A.O. Plates may be considered to have normal color vision. Such vision will be of the high degree of color sensation required for the classes of personnel noted in paragraphs (b) and (c) under "Interpretation of Results", which is given in the trial book of the Second Edition.

5. If it is desired to establish a less rigid standard of color sensation for applicants for enlistment, a somewhat easier test may be given to those who have failed the A.O. Plates. Several lanterns have been designed and used for this purpose, by various Services in the United States as well as by the Canadian Navy and Air Forces. A carefully designed lantern for this purpose is now undergoing final trials at the Medical Research Department, Submarine Base, New London, Conn. A quantity of any one of several such lanterns could be made available within a few weeks.

Appendix C

6. Incorporation of the above suggestions would make the interpretation of results read as follows:

INSTRUCTIONS FOR TESTING
COLOR PERCEPTION
By means of
PSEUDO-ISOCHROMATIC PLATES
AMERICAN OPTICAL COMPANY, SECOND EDITION

Paragraph 1. No change
Paragraph 2. No change
Paragraph 3. No change
Paragraph 4. No change
Paragraph 5. No change

INTERPRETATION OF RESULTS

The Bureau of Medicine and Surgery places the following interpretation upon existing regulations prescribed for color vision:

(a) Applicants for enlistment who read incorrectly more than 10 plates but who pass the Navy Lantern meet the requirements of the Manual of the Medical Department, Para. 1428 (2).

(b) The following personnel who read correctly not less than 26 plates are considered as meeting the requirements of the Manual of the Medical Department, Para. 1428 (b) and 1558.

1. Candidates for primary appointment to commissioned or warrant rank; nurses;
2. Candidates for entrance to the U. S. Naval Academy;
3. Candidates for training leading to commissioned rank;
4. Candidates for training leading to designation of Naval Aviator or Aviation Pilot.

(c) Enlisted candidates for special duties requiring a higher degree of color perception than is required for original enlistment will be considered to have normal color perception if they correctly read not less than 26 plates.

Paragraph (d) No change.

APPENDIX D

DIAGNOSTIC VALUE OF EACH PLATE

The efficiency of each plate in categorizing men into normal or defective color vision may be determined in several ways. The method selected consists of subtracting the error frequency of normals from that of color blinds on each plate. The rank of diagnostic value may then be determined from these differences. This is done in Table VIII. In the last column the plates are relisted in order of diagnostic order.

A graphic illustration of the difference between plates is shown in Figure 7. The plates are ranked in two orders: (1) that of ease for normals, and (2) that of difficulty for color blinds. Each plate is listed by color group (in Roman numerals) and by digits (in Arabic numbers).

It should be noted that this study is done on only 100 men with normal color vision and 112 with defective color vision. Furthermore this selection, while it will be correct in general, will not hold precisely on the reprinted second edition.

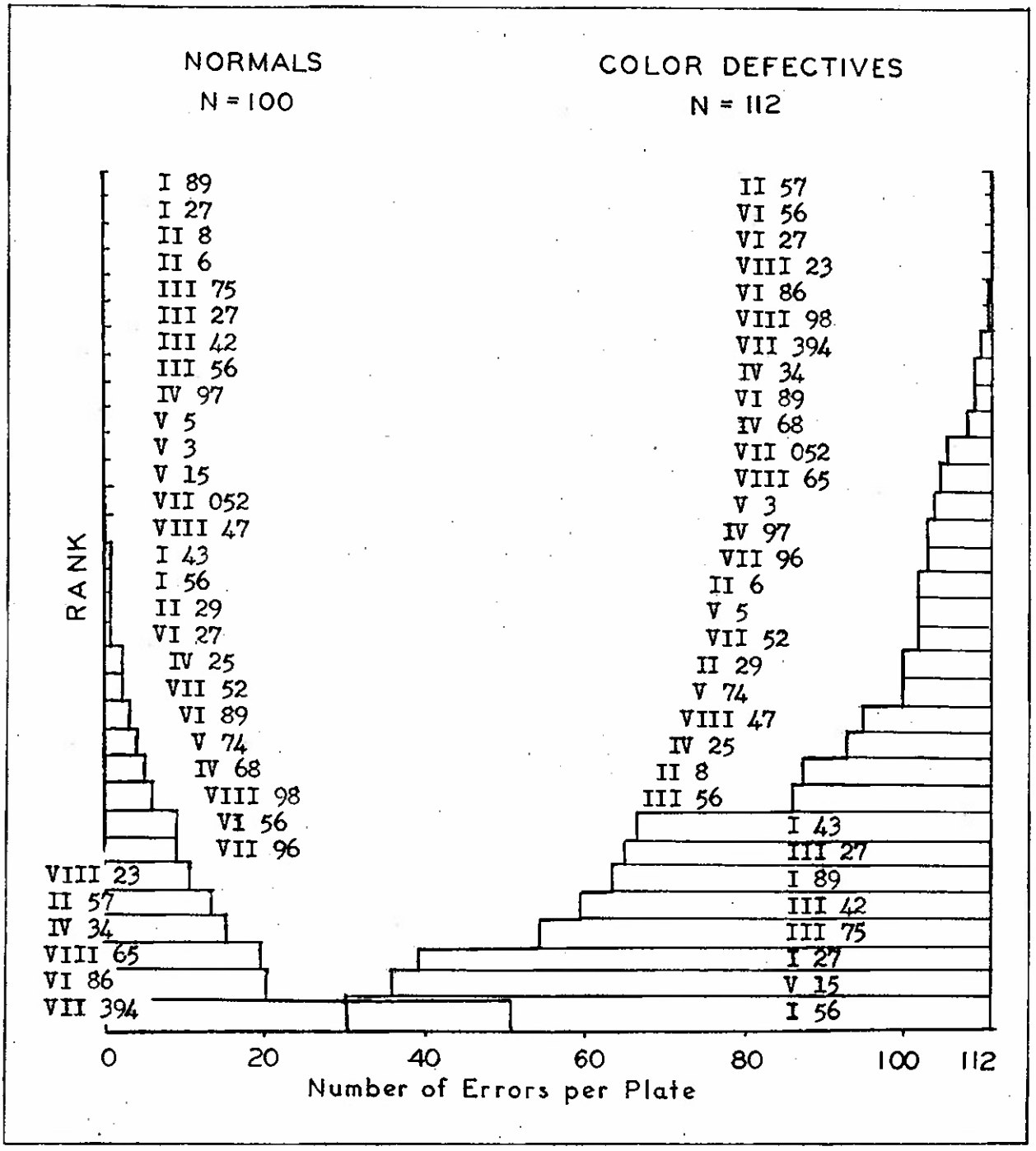


Figure 7.

The first 8 groups of plates in the Revised Second Edition plotted according to rank of (1) ascending errors of normals, (2) descending errors of color defectives.

TABLE VIII

The Diagnostic Rank of the Plates in the Revised Second Edition

Group No.	Correct Response	% error by 112 anomals	% error by 100 normals	Rank of Difference	Rank	Plates listed in rank order	
I	89	57	0	27	1	VI	27
	43	60	1	24.5	2	VII	052
	56	27	1	32	3	VI	89
	27	35	0	30	4	(V	3
II	8	78	0	21.5	5	(VIII	98
	6	91	0	8.5	6	IV	97
	29	89	1	13	7	(II	6
	57	100	13	14	8	(IV	68
III	75	49	0	28	9	(V	5
	27	59	0	24.5	10	(VI	56
	42	58	0	26	11	(VII	52
	56	78	0	21.5	12	(VIII	23
IV	25	84	2	18.5	13	II	29
	68	96	5	8.5	14	II	57
	97	92	0	6	15	VIII	47
	34	97	15	18.5	16	V	74
V	5	91	0	8.5	17	VII	96
	3	93	0	4.5	18	(IV	25
	74	89	4	16	19	(IV	34
	15	33	0	31	20	VI	86
VI	56	100	9	8.5	21	(II	8
	27	100	1	1	22	(III	56
	89	97	3	3	23	VIII	65
	86	99	20	20	24	(I	43
VII	52	91	2	11.5	25	(III	27
	96	92	9	17	26	III	42
	052	95	0	2	27	I	89
	394	98	51	29	28	III	75
VIII	23	100	11	11.5	29	VII	394
	65	94	19	23	30	I	27
	47	86	0	15	31	V	15
	98	99	6	4.5	32	I	56