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Ivo Kohler[1] earlier reported what appeared to be long-lasting negative afterimages following extended exposure to colored lenses. These "afterimages" were present for periods of time considerably in excess of those experienced following relatively short exposure. Kohler's work, while highly stimulating and original, lacked some controls which might be desirable. In an unpublished pilot study, McCain and Whitcomb found a shift in color judgments following prolonged exposure to colored lenses. The present study was essentially an extension of the pilot study.

In the present study there were two main objectives: first, to check the earlier finding using a larger sample and better controls. Second, to determine whether the effect previously obtained was an increasing function of the period of exposure.

Method

Subjects: A total of 158 Ss participated in one or more stages of the study. It was necessary to drop 94 Ss for the following reasons: 14 were color blind; 9 dropped of their own accord; 71 were dropped due to failure to stabilize in their color judgments. This last group will be considered at greater length in the Procedure and the Discussion sections.

Apparatus: Tests were run in a windowless, air conditioned room. Two Munsell color discs [5 PB 3/12 (4773); 5 Y 9/14 (6210)] were used on the

[1]Ivo Kohler, Über Aufbau und Wandlungen der Wahrnehmungswelt, 1951, 1-118.

Gerbrands Differential Color Rotator. A sketch of the test area and equipment is shown in Figure 1. The color rotator was enclosed in a plywood box

Fig. 1 about here

which was painted flat black inside. The S was seated in a booth, formed of black cloth, which was lighted by a 25-watt bulb placed above and behind the S. A section of the color wheel was viewed through a tube painted flat black. The tube had a rubber facepiece and was 6 in. wide, 3-1/2 in. high, and 48 in. long. The rotator was placed approximately 8 in. from the end of the tube so that the distance between the S's cage and the color discs was 56 inches. The color wheel was illuminated by a Westinghouse 15-watt daylight fluorescent bulb (FIST 12/D) mounted in the top of the plywood box. The shutter from a large Ilex #5 camera was mounted on the end of the tube next to the color rotator. The shutter mechanism allowed E to control the time of exposure and the size of the aperture. The aperture in the shutter was approximately 2 cm. in diameter and was arranged so that the point viewed was approximately 1-1/2 in. above the center of the disc. Ss were seated in the booth and after a short period for adaptation, the shutter was opened and the Ss were required to give a judgment of blue or yellow.

The filters worn by the Ss were Wratten 16, and are more fully described in the Kodak manual[2]. These filters were fitted into pairs of welder's goggles (GW-400 F,S.4 Glendale Optical Co.).

[2]Kodak Wratten Filters for Scientific and Technical Use, 1957, Eastman Kodak Company.

Procedure: Ss were given printed sheets of instructions which set out the ground rules for testing, together with a vague statement regarding the nature of the project. (See Appendix 1).

Ss were tested for normal color vision; both Dvorine and H-R-R plates were used. Ss with normal color vision were scheduled for daily test sessions.

The object of the test period preceding exposure to the filters was to obtain a stable base line which could be compared to the posttest data.

The aperture remained open a maximum of 2 sec. on each presentation. Presentations were made as rapidly as the equipment could be reset. The general procedure used was a modified method of limits. Appendix 2 is a sample data sheet. A rough point of subjective equality (PSE) was obtained in the first session. In succeeding sessions each trial was started either above or below this point. Approach to the PSE was in discrete steps of 5 degrees in the amount of yellow exposed. A forced choice method was used, with the S required to respond "yellow" or "blue" on each trial. A trial was terminated when the S had given two successive responses different from the prior responses. On one trial out of each 10, E doubled back on the settings of that trial. The purpose of this was to prevent the S using the number of prior presentations as a cue. For example, if we started at 120 degrees of yellow, in a descending series we would decrease the amount of yellow 5 degrees each successive presentation. If the S gave a response of blue to 95 and 90 degrees, E would immediately present 90 again, followed by an ascending series terminated when two successive blue judgments were given. Trials

were started within a range of 20 to 45 degrees from the PSE. The beginning point and order of administration of ascending and descending trials were predetermined on a random basis. Randomization had the following restrictions: no more than three successive ascending or descending trials were used, and all possible 5 degree increments between 20 and 45 degrees from the PSE had to be used before any one could be repeated.

Prior to wearing the goggles a base line was established for each S. The last five days of testing prior to wearing the lenses, which gave a total of 120 trials, were used as the base line. A graph of the daily averages was maintained. A S did not put on the lenses unless the trend of his last five days was not significantly different from the horizontal.

Ss put the goggles on shortly after the base line was established. In no case was the interval between the final pretest and beginning of the exposure period over 12 hours. Fitting the goggles was a compromise between exclusion of stray light and the S's comfort. Since the goggles were worn for an extended period, at least reasonable comfort was necessary. There was also a problem of "fogging" the lenses if the goggles did not allow some flow of air in addition to the shielded vents. Goggles were adjusted and re-adjusted on the basis of these problems.

Ss were instructed to wear the goggles at all times other than when they were in bed with the lights out. On two occasions we determined that a S removed the goggles for a period of several hours without reporting this fact. Data from these two Ss are not included in the report.

One hour after removal of the goggles Ss were given their first test on the color wheel. The procedure was the same as in the pretreatment period.

The one hour delay was used so that any very short-term effects would be dissipated. As is indicated later, this period may not be sufficient. Ss were tested three times at approximately 24 hr. intervals, beginning with the test one hour after removal of the glasses. A final test was given seven days after the third daily test.

The procedure may be summarized as including five steps: (1) color vision test, (2) establishment of a base line, (3) wearing the lenses, (4) three daily tests, (5) final test one week after daily tests.

Ss were exposed to the lenses for the following number of hours: 1, 6, 12, 18, 24, 36, 48 and 144.

As indicated, a large number of Ss were dropped for failure to stabilize. Due to the difficulty in obtaining stable data on the "test apparatus" an attempt was made to gather data with a color wheel set up in a brightly lighted room. Under these conditions, control over time for each trial, cues used by the S and other factors were somewhat sketchy. As indicated in the Results section, very few Ss failed to stabilize under these conditions. These conditions will be referred to as the "open-wheel" situation to distinguish them from Ss run on the test apparatus.

Results

One interesting aspect of the data has to do with the differences in base lines. In Table 1, the base lines range from approximately 35 to

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Table 1 and Table 2 about here

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215 degrees of yellow. Base lines in Table 2 range from approximately 64 to 156 degrees. In either case, this range is tremendous. This is particularly true since this is not a simple additive change. A change in yellow also changes the amount of blue. The basis of these differences is not at all clear. Viewing the extremes gives the impression that they do not even belong in the same series. The present project did not permit investigation of the differences in base lines, however. These differences do seem worthy of further study.

Table 1 shows individual data at various levels of exposure. As may be noted from Table 1 and Figure 2, Ss exposed for one hour show a slight in-

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Fig. 1 about here

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crease in the number of degrees of yellow required for a match. Individuals who wore the goggles six or more hours show an average decrease in the number of degrees of yellow at the PSE. There does not appear to be a consistent relation between the number of hours of exposure and the extent of the change in the postexposure measures. Figure 2a includes all Ss from the test apparatus situation. Three things are apparent: first, the one-hour group and the groups given longer exposure are almost mirror images of one another. Second, measurements taken one hour after removal of the goggles differ from those taken on succeeding days, both in the case of the one-hour group and the combined groups. Third, there is a rather remarkable similarity between measures taken 49 hours after removal of the goggles and those taken 217 hours after removal. This stability does seem to indicate that the changes observed are probably not attributable simply to the lapse of time between testing

while the S was wearing the goggles. The increase in amount of yellow for the one-hour groups may be only a chance deviation. Direct difference t-tests were run between the base line measure and the mean of the postexposure measures. Comparison was also made between the base line measure and the postexposure measures eliminating the measure taken one hour after removal of the goggles. In neither case is the difference significant ($p > .2$) for the one-hour group. The size of the group (n=4) is a handicap in such comparisons.

Since there was no substantial difference due to increased exposure to the lenses, the groups from 6 - 144 hours were combined. Again, direct difference t-tests were used as above. When all postexposure measures are averaged the difference ($p < .06$) does not quite reach the usual standard for significant differences. If comparison is made eliminating the one hour post-exposure test, the difference is significant ($p < .025$).

Figure 2b is based on those Ss who showed a change in the same direction as most others in their group (Ss, C.R., B.E., and G.R. omitted). In this case the change is clear and remains relatively stable from the first measure through that taken ten days later. As might be expected, comparisons of Ss in this group with their base line gives significant differences using the first measure alone ($p < .01$) or any combination of the measures. The one-hour exposure group, as indicated in Figure 2b, does not differ greatly from the condition of Figure 2a.

Data from the Ss in the "open-wheel" situation was also analyzed using a direct difference t-test. There were no significant differences.

Discussion

The results suggest that prolonged exposure to a part of the spectrum may change color judgments and that this change may persist over extended

periods of time. The data suggest that the effect may not be present until about six or more continuous hours of exposure to the particular light source. These conclusions must be regarded as highly tentative and should be further examined in other situations. Some suggestions and problems relating to future work in this area will be presented later.

It was considered possible that the wide range of base lines might be related to the size of the image on the fovea. To check this possibility the aperture in the test apparatus was varied with several Ss who were not used in the test. Aperture size did not seem to be effective. Also, the data in Table 2 indicates a rather large range of values for base lines, even though the only restriction was the size of the color wheel itself. The source of these differences remains obscure.

As indicated in the Results section, measurements taken in the "open-wheel" situation failed to show any shift during the postexposure period. There is a tendency in these Ss to decrease the amount of yellow on measures taken after the one-hour test session. In general, however, there is no reliable change to be observed.

There are several possible reasons as to the difference in the results from this condition and those from the "test-apparatus" situation. First, it is obvious that the "open-wheel" condition contains a large number of uncontrolled factors. Second, it was much easier to get a stable base line using the "open-wheel" than in the "test-apparatus" situation. This could indicate that the "open-wheel" was a relatively insensitive measure of changes. Third, and related to the second point, it was necessary to drop a large portion of the Ss on the "test-apparatus" since they were unable to achieve a stable base line.

This resulted in a selected group which quite possibly differed from the "closed-wheel" group. Any or all of these factors could account for the differences in results.

A further point is raised by the above. It is quite possible that the Ss who do change can be detected only by very sensitive measures, indicating that the changes may be of rather limited magnitude.

There are a number of problems in the present study. First, the method of exposing Ss to the lenses is clumsy and inefficient. The goggles are uncomfortable and permit at least some light leaks. Second, the various periods of exposure may be misleading. Ss in the 24, 48 and 144 hr. groups have a different situation due to the intervals of sleep. During the periods of sleep some stimulation does occur and this stimulation would ordinarily be "white" light altered as it passes through the eyelids. Third, there are a number of possible extraneous variables which may have influenced the results. For example, during establishment of a base line we noted a sharp departure from normal by one S. Questioning indicated he had "a few beers" the previous evening. There may be no causal relation, but a question is raised. Fourth, some of the Ss may not be reliable. Two Ss were dropped in the present study when they were discovered without the goggles during a period of supposed exposure. Whether there were some undiscovered cheats cannot be answered. Fifth, only one type of lenses and color discs have been used. This was done on the basis of previous experience. Whether the present results are generalizable to other combinations remains an open question. There are other possible sources of variation, such as the type and intensity of light Ss were exposed to outside the test situation.

In view of the problems cited, the results of this study should be interpreted with caution. If further work is warranted, some improvements in procedure might be useful. Suggestions regarding such work are listed below:

1. The goggles should be abandoned. A reasonable substitute might require maintaining the Ss in a room which was continuously flooded with light of the desired wave length.
2. Different combinations of filters and test surfaces seem desirable.
3. Some attempt should be made to devise an alternative type of test apparatus.
4. Testing should begin at various periods following exposure.
5. Consideration should be given to the use of infrahuman primates.

At present there is no clear theoretical explanation of the shift in color judgments. The effect does resemble, at least casually, aftereffects found in other sense modalities.

In the present study both eyes were exposed to stimulation; in the prior pilot study by McCain and Whitcomb an effect similar to the present one was obtained when only one eye was stimulated. Stimulation of one eye affected both eyes in a similar way in that study. This was interpreted at the time as evidence that the effect was due to some process above the retinal level. While this aspect of the previous study was not checked in the present study, it would be of some interest if confirmed.

Table 1

INDIVIDUAL RECORD OF SUBJECTS RUN ON THE TEST APPARATUS

No. of hrs. in goggles	Ss	Base Line (PSE)	Degrees and direction of change 1 hr. after removal of goggles	Degrees and direction of change 25 hrs. after removal of goggles	Degrees and direction of change 49 hrs. after removal of goggles	Degrees from base line 217 hrs. after removal of goggles
1	R.A.	105.2	+ 7	+12.8	+10.8	+ 3.3
	B.C.	82.3	+ 0.2	+ 1.2	+ 6.7	+ 6.7
	B.S.	131.8	+ 7.7	+ 4.2	+18.2	+32.0
	A.A.	120.1	- 1.6	+ 7.4	- 0.9	-15.1
6	W.W.	82.8	- 10.8	-13.3	- 1.3	- 5.8
	J.D.	143.8	- 16.8	-21.3	--	-39.3
	D.Y.	214.8	- 29.8	-19.3	-32.8	-45.8
12	M.J.	83.4	- 6.9	-18.4	-17.4	- 3.4
18	C.R.	121.9	+ 17.1	+11.1	+16.1	+11.1
	R.W.	180.1	- 10.6	-15.6	-22.6	--
24	C.H.	120.7	+ 16.3	+ 6.8	--	--
	B.B.	149.7	- 33.2	-24.7	-35.2	+ 6.8
36	T.H.	84.4	- 6.9	-28.4	-24.4	-11.9
	G.M.	140.1	+ 6.9	- 5.6	- 4.1	-13.6
48	L.G.	62.4	- 2.9	-12.4	- 2.4	- 3.4
144	J.H.	64.8	- 30.8	-29.3	-25.8	-21.3
	B.E.	143.7	+ 45.3	+ 6.3	+ 6.3	+ 1.8
	G.R.	131.9	+ 38.6	+35.6	+19.6	- 8.4

Table 2

INDIVIDUAL RECORD OF SUBJECTS RUN ON THE "OPEN-WHEEL"

No. of hrs. in goggles	Ss	Base Line (PSE) in degrees of yellow	Degrees from PSE 1 hr. after removal of goggles	Degrees from PSE 25 hrs. after removal of goggles	Degrees from PSE 49 hrs. after removal of goggles	Degrees from PSE 217 hrs. after removal of goggles
1	L.W.	155.8	+ 4.7	+ 6.8	- 3.8	- 4.3
	J.H.	134.7	+ 7.8	+ 1.8	- 5.2	--
	K.S.	93.3	+ 5.7	+ 3.7	+ 5.7	+ 3.7
	G.B.	64.0	+ 4.5	+ 5.5	+ 3.0	+11.5
6	J.M.	90.8	- 0.8	- 6.8	- 4.8	- 5.3
	S.H.	81.8	- 0.8	+ 0.7	- 4.3	+ 0.7
	C.P.	117.9	+ 3.6	+ 3.1	+ 1.6	- 4.4
12	S.P.	108.1	- 0.6	- 3.6	- 8.6	- 1.1
	W.C.	99.8	+ 3.2	+ 0.7	- 5.3	+ 8.7
	R.B.	106.2	+ 1.8	+ 3.3	--	+ 5.3
48	W.W.	101.6	+ 5.4	+ 0.9	- 2.6	+ 3.4
	H.K.	107.8	- 7.8	-17.3	-13.8	- 9.8
144	R.	94.2	+12.8	4.8	- 9.7	- 4.7
	J.N.	130.1	+ 0.9	- 0.6	+ 8.9	+ 4.4

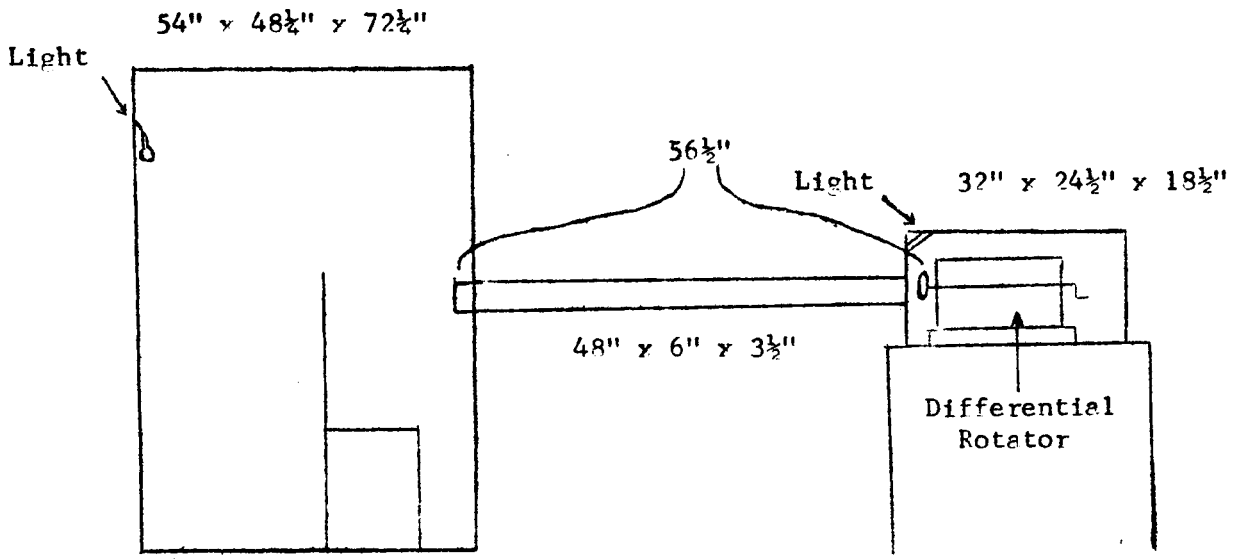

Fig. 1. Test Apparatus

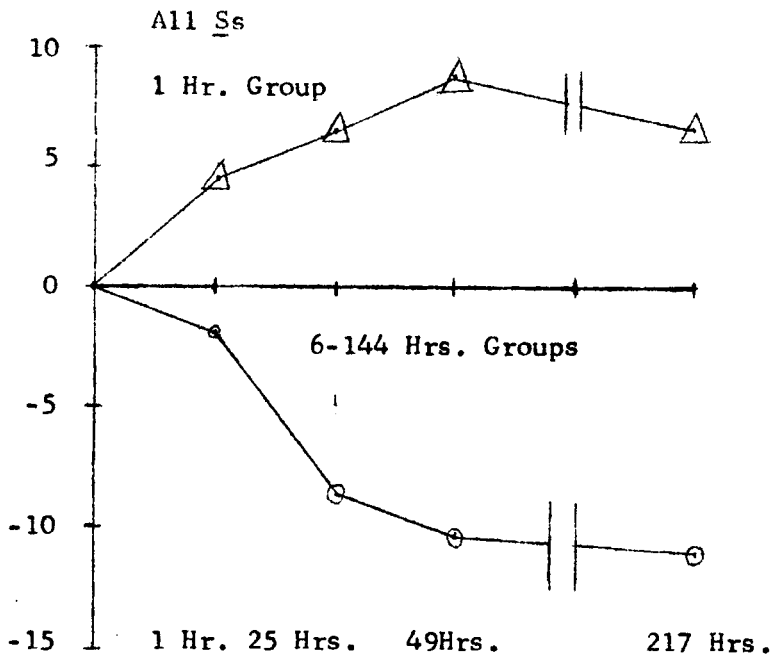

Fig. 2a. Mean Deviations from the Base Line Plotted by Individual Test Sessions.

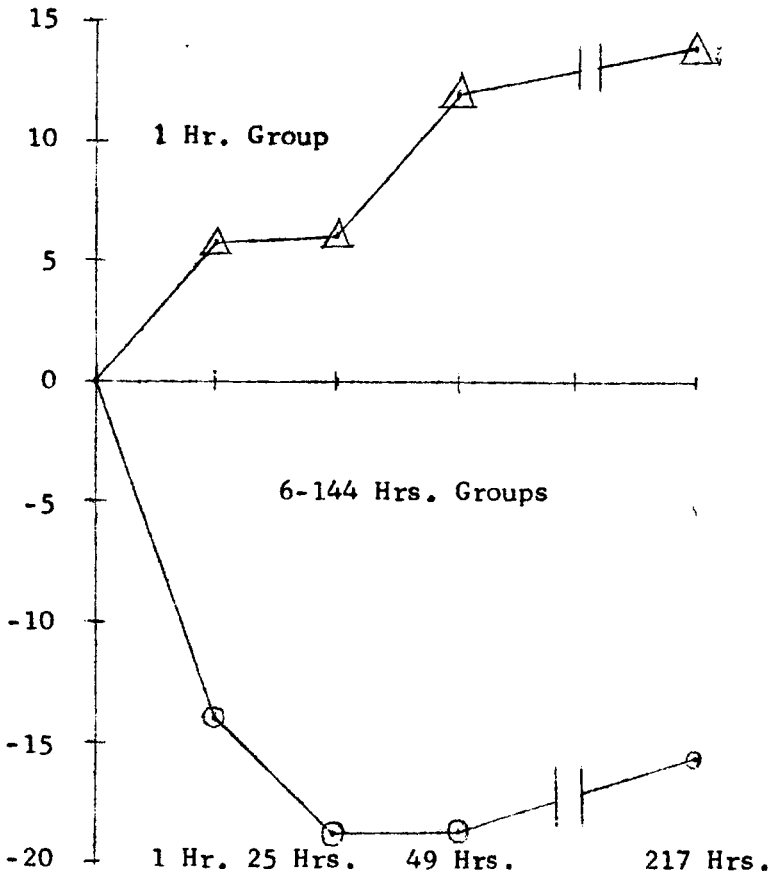

Fig. 2b. Mean Deviations of Selected Sample of Subjects Plotted by Individual Test Sessions.

APPENDIX 1.

NASA - COLOR VISION

Instructions for Subjects

1. We are working on a tight schedule as far as testing is concerned. It is very important that you make your appointments. If, for any reason, you expect to be late call the Psychology Dept., Ex. 221 and Let us know.

2. We cannot give you any information regarding test results until the project is complete.

3. Verbal reports from subjects can be very useful. If you notice anything out of the ordinary please let the experimenter know.

4. When you put the glasses on, arrangements will be made to test you at a particular time. It is important that the test take place as scheduled. If for any reason you find it necessary to remove the glasses and expose your eyes to normal light, let us know immediately no matter what the hour of day or night. We will not be unhappy or critical if you do have to remove the glasses before the allotted time unless you fail to inform us so that we can make the proper tests.

5. This experiment is a study of human color vision supported by a NASA research grant.

6. Subjects in the experiment will be tested 30 minutes a day for a period up to two weeks.

7. Subjects will then wear Welder's goggles with yellow filters for a period of from one to 144 hours. Goggles will be worn all the time the subject is awake (about 16 hours a day) until the specified number of hours is completed.

8. Subjects will then be tested again, once a day for 3 days, then once a week for a period of 3 or 4 weeks.

9. Subjects will need to schedule 30 minutes a day, 5 days a week for two weeks, and be available (in Ft. Worth-Dallas area) for two months after the experiment begins.

10. While you are wearing goggles, driving an automobile would be very unwise.