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Influence on Color Perception of Adaptation to Illumination

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Six experienced observers made consistent determinations of various colors which appeared the same with adaptation to tungsten light and to artificial daylight. These observations were made with each eye viewing a different color patch and with the patches appearing juxtaposed at the middle of a fused binocular field. The method was to make the two juxtaposed patches match by adjusting one of them, sometimes when both eyes were adapted to the same illumination and sometimes to the different illuminations. Plots of the data in the CIE chromaticity diagram indicate a systematic shift in color appearance toward the blues when adaptation was changed from daylight to tungsten; or toward the yellows when adaptation was changed from tungsten to daylight. The magnitude of this color shift was substantial, at least in the considerable color region investigated, for here the average length of the representative vectors was 0.10 in CIE terms or of the order of 20 just perceptible color differences. Qualitatively, the results confirm those of Hunt and of Winch and Young. The theoretical implications will be discussed in a later paper.

INTRODUCTION

THE kind of illumination to which an observer happens to be adapted is an important determinant of his perception of the color sample at which he looks. This does not mean that a difference in perceived color is invariably detected when the observer is adapted to one illumination at one time as compared with another illumination at another time. On the contrary in everyday life, when no difference is expected and the observer is making no effort to check, frequently no color difference is noticed. Nevertheless, significant differences in color appearance can occur whether or not they are identified as such. Thus, many objects have a familiar appearance because they are usually viewed under a characteristic illumination; but occasionally when they are viewed under an extraordinary illumination, conflict with memory colors reveals obvious changes in appearance. Indeed, tungsten and daylight are such important illumination qualities, and their color-rendering properties are of such practical moment, that further consideration of visual effects of adaptation to these illumination qualities seems very desirable.

The few investigations of the problem which already have been carried out may be classified according to whether they employed the method of memory estimation or the method of binocular septum matching. The memory estimation method requires the observer to specify the appearance of each test color by reference to a memorized or subjective color scale; of course, a minimum of two different estimates of the appearance of each test color is required, one with the eyes adapted to the daylight illumination and the other with the eyes adapted to the tungsten illumination. The procedure by the binocular method involves the presence of an opaque septum which separates the monocular fields, permitting the two eyes to be adapted simultaneously either to different or identical illuminations; then with the test color before one eye and a variable color before the other, color matches can be made which will reveal the effect of the adaptation illumination. The memory method has the advantage of employing the normal binocular vision of everyday life, whereas the binocular septum method has the advantage of affording some of the objectivity and precision of juxtaposed color matches.

Studies by the Memory Method

The recent Helson-Judd-Warren study employed 6 observers who memorized Munsell colors as viewed under north sky light and on that basis evaluated various paper test colors subjectively in terms of the Munsell notation.[1] Sixty different test colors were used and 11 of these were presented at a time, sometimes against a white background, sometimes against gray, and sometimes against black. The corresponding background luminances were about 50, 15, and 2 ft-L. All evaluations were alternatively under Macbeth daylight (6700°K) and under tungsten light approximating CIE illuminant A. In either case, the observer was thoroughly adapted to the light reflected from the presentation. The difference in the estimated Munsell notations in the two situations served as the measure of how different the given reflecting test samples looked under the two different illuminations. This difference varied widely with the test colors, but it was of the general order of only a few Munsell hue steps and a fraction of a chroma step. The color differences ascribable to the background differences were of the same order of magnitude. Such results seem to indicate the operation of a high degree of color constancy.

In the somewhat similar Bouma-Kruithof study, 3 observers had viewed numerous paper color samples placed one at a time on an extended white background which was illuminated alternatively by approximations to daylight and standard CIE illuminant A.[2] The background luminance was 13 ft-L, and the test colors were the 100 cards in the nc circle of the old Ostwald atlas. These samples have been described as rather pure and fairly uniform with respect to saturation. The observers were asked only for hue judgments, these to be made in terms of a mental hue circle of 36 units including as subjective anchors the several psychological primaries. As in the Helson study, these hue evaluations differed little under the daylight and tungsten illuminations.

In his recent study, Godlove judged over 150 dye samples presented separately against a black surround which was alternatively illuminated by approximations to CIE illuminants A and C.[3] In this instance, the evaluations were for saturation and dyer's shade or hue, the attribute of lightness being disregarded. At first, Munsell papers in daylight were necessary as reference standards, but after some practice only occasional glances at the material standards were required to estimate the perceived color of the given dye sample. Only about a minute was allowed for adaptation when changing illuminants. Godlove's results agreed with an earlier study of Helson and Grove in which the adaptation was only partial.[4]

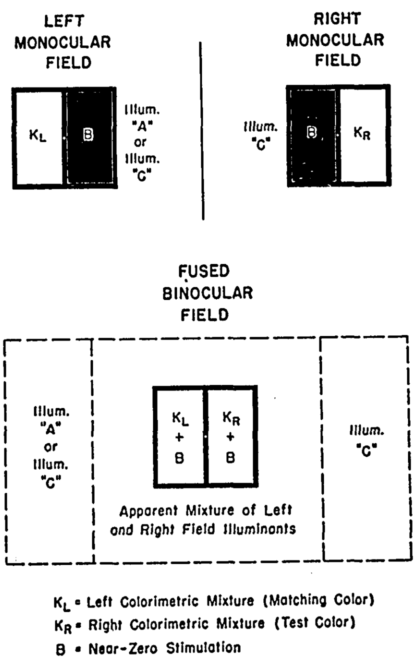

FIG. 1. Central portions of the viewing fields: monocular (upper) and binocular (lower).

Studies by the Binocular Method

Hunt's 4 observers viewed 11 transmitting test colors one at a time with the left eye and matched them with the right eye using a Donaldson colorimeter.[5] The left eye was thoroughly adapted to light reflected from an extended white surround which was alternatively illuminated by approximations to illuminants B and C. The right eye, however, was kept as nearly dark-adapted as feasible and served as the standard in matching the test colors presented successively to the left eye. Hunt plotted in the CIE chromaticity diagram those colors required by the right eye to match each test color as viewed with the left eye alternatively adapted to tungsten and to daylight. The distance on the diagram between the two points corresponding to each test color provides a measure of the effect of the illumination adaptation upon color appearance. The 11 color shifts varied widely with test color but the average was substantial, *viz.*, 0.12 in terms of the distance formula or somewhere around 30 just perceptible differences. The fact that the evaluating right eye was partially dark-adapted made the color shifts considerably greater than would otherwise occur. This is because colors appear less saturated to a dark-adapted than to a light-adapted eye and so larger colorimeter adjustments are required than would be necessary if the right as well as the left eye were light-adapted.

The Winch-Young study, unlike that of Hunt, employed fluorescent lamps as well as tungsten and standard illuminants for adaptation.[6] Another mark of difference was the use of reflecting rather than transmitting samples, and the samples were much

[1] Helson, Judd, and Warren, Illum. Eng. **47**, 221 (1952).
[2] P. J. Bouma and A. A. Kruithof, Philips Tech. Rev. **9**, 257 (1947–1948).
[3] I. H. Godlove, J. Opt. Soc. Am. **41**, 396 (1951).
[4] H. Helson and J. Grove, J. Opt. Soc. Am. **37**, 387 (1947).
[5] R. W. G. Hunt, J. Opt. Soc. Am. **40**, 362 (June, 1950).
[6] G. T. Winch and B. M. Young, G. E. C. Journal **18**, 88 (April, 1951).

larger (11 degrees subtense) than in any of the other studies. The standard operating procedure was to place identical samples before both eyes in a binocular septum viewing situation and, with different adapting illuminations on the two sides, to make the samples match by adjusting supplementary light projected on the right-hand sample by a trichromatic projector. The colorimetric measurements were made on the right-hand sample as illuminated to match the left-hand sample. As a preliminary control, the same illuminations as well as the same color samples were used in both sides to see whether a perceptual match would result under the similar conditions. An observer who reported a match under these control conditions participated in the experiment itself. Some of the observations were checked by a second observer. Only the limited data secured with adaptation illuminations approximating standard illuminants A and B seem of interest here. The average color shift with 9 test samples ascribable to this adaptation difference was nearly 0.05 in CIE terms or about 10 just perceptible color differences.

In brief, it may be noted that all five of these studies evince noticeable influence on color perception of adaptation to the quality of illumination; but there are marked differences both in procedure and degree of influence.

METHOD

The present experimental approach was simply to determine the psychophysical specifications of colors which look the same with adaptation to tungsten and to daylight illumination. The method of doing this was that of binocular septum matching which involved the division of the visual field by the opaque septum placed between the eyes and the presentation of two variable color patches, one to each eye. With appropriate binocular fusion, these patches could be perceived as a single vertically divided color comparison field lying in the midst of an extensive light surround.

The color patches used in this experiment were transmitting, not reflecting. Unlike reflecting color samples, the physical characteristics of the color stimuli were not susceptible to change by the adaptation illumination but only by intentional adjustment of the colorimeters which produced them.

Since the surface mode of appearance seemed the most important, the transmitting color samples were presented in that mode, that is, they looked like reflecting samples to the observer. The tungsten adaptation light was a good approximation to CIE standard illuminant A and the daylight to illuminant C, so the illumination qualities can be designated hereafter as A and C, respectively.

Only two juxtaposed chromatic color patches would be perceived in the visual field during a given determination. With the left eye in some trials adapted to the A illumination and in others to C, the color seen by that eye was matched to the given reference color perceived by the right eye as always adapted to C. Thus, with the right eye perception as the comparison standard, the observed difference between the color matches secured with the left eye adapted to the A and C illuminations, respectively, provided a measure of the influence of the adaptation illumination; the greater the difference between the specifications of the matching colors, the greater was the influence of the adaptation illuminations.

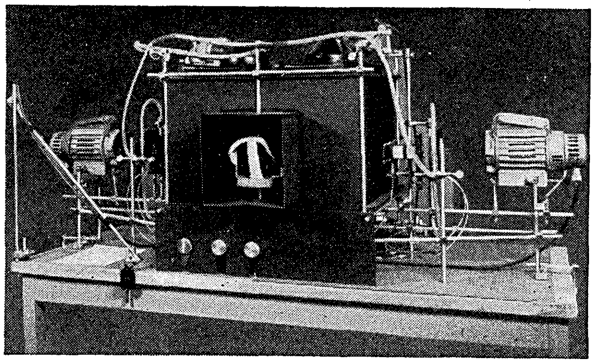

FIG. 2. General view of the apparatus.

PROCEDURE

The observer sat with his head in a hooded-rest against the forward edge of the binocular septum so that the adapting field of the left eye was supplied by the A or C illumination reflected from a 40-degree expanse of white, baryta-coated paper while the right eye was supplied by C illumination reflected from a similar light surround (Fig. 1). The two color patches, rectangular in shape and 1×2 degrees in subtense, were presented simultaneously but independently to each eye and were produced separately by Burnham integrating bar additive colorimeters.[7] Since light from the two patches necessarily fell on noncorresponding retinal areas, the corresponding retinal areas were unstimulated in one eye and stimulated in the other. The unstimulated, or dark, areas were achieved by making rectangular cut-outs in the surround material which prevented light reflection to the eyes in the corresponding areas. Stimulation of the corresponding areas was undesirable because that could have made either perceived color subject to the influence of both adaptation illuminations at once, which would confuse the issue and vitiate the experiment. Each color patch was also protected so that no light from its surround could affect it. The general view of the apparatus (Fig. 2) shows, at center, the observer's position and manual controls, at each end, the housings of the 1000-watt colorimeter-luminators, and above center, the reflectors of the adaptation-luminators.

When the observer fixated an appropriate reference

[7] R. W. Burnham, Am. J. Psychol. (to be published).

mark with each eye and converged his eyes to make these marks coincide, the field would become fused, and the two color patches would be perceived side by side forming an approximately 2 degree square, where they would be readily compared. The convergence was for an object 60 cm distant, and the reference mark for each eye was a white dot of 0.1° subtense. As a preliminary, the experimenter would set a desired test color in the right-hand patch by adjusting the right-hand colorimeter; and next he would adjust the left colorimeter to an approximate match. Then after the right eye had been adapted for five minutes to the C illumination (always) and the left eye to C (or A) illumination, the observer would match the left color to the right color by manipulation of the three manual controls of the left colorimeter. In a subsequent session, the observer made similar matches with the left eye adapted to the same luminance of the other illuminant. The experimenter recorded the left colorimeter readings under both adaptation conditions. Each observer made a series of five replicative matches per session with each of three of the test colors.

The matching technique involved the adjustment of three manual controls, one to vary brightness and two to vary chromaticness. As a precautionary preliminary to each match, the observer turned all three controls to gross mismatch, first in one direction and then in the other. Observers varied in the exact procedure of achieving the match itself. One procedure was to make first an approximate brightness match and then proceed to a chromaticness match. After this, a finer brightness match might be achieved and that might be followed by still closer matching. Other observers manipulated the controls in less systematic fashion; but each continued to work on the match as long as he considered necessary. An experimental session of 15 matches usually consumed around 20 minutes including the initial adaptation time.

The matching experience with binocular septum and fused field differs considerably from either monocular or natural binocular matching. Initially, neither rapid nor precise matching was possible because the observer was preoccupied with the problems of holding the fusion of the field and reducing the retinal rivalry in one or both color patches. This rivalry was between the color of the left (or right) patch and the darkness of the right (or left) corresponding area. After sufficient practice, these difficulties became negligible and attention could be concentrated fully on the matching operation itself. Interestingly enough, practiced observers discovered that the small eye-movements associated with focusing attention first on one juxtaposed sample and then on the other were entirely feasible in the fused field. The patch receiving special attention became momentarily a little more vivid but the eye-movements did not disrupt the fusion. Fusion was favored and rivalry reduced by the presence of a narrow (0.1° subtense) black border about the test patches.

Twenty-two test colors, distributed in Munsell space, were selected for use in investigating the influence of adaptation illumination on perceived color. Though it is convenient to describe the test colors by reference to Munsell renotation, no color papers were used in the experiment.[8] These colors included two chromas each of the five major Munsell hues, R, Y, G, B, P, as well as one neutral, all at the value levels 5/ and 8/. The two chromas were /4 and /12 in the case of all hues except Y where they were /4 and /6. The observations on all colors were carried through at three different luminances of the left adaptation surround, *viz.*, 35 ft-L, 3.5 ft-L, and 0.35 ft-L. The luminance of the right adaptation surround was held constant throughout at 35 ft-L. The two Munsell values of the test colors were set relative to the 35 ft-L luminance of the surround taken as the maximum value 10/. Thus, the luminance for value 8/ was 20 ft-L and for value 5/ was 6.8 ft-L. The relatively low luminances of the test colors favored their perception as surface colors, especially in the primary situation with both surrounds at 35 ft-L.

Each of six observers completed the main series of observations representing a total of 3960 color matches (22 colors×2 illuminations×3 luminances×5 replications×6 observers=3960). These observations were preceded by a substantial preliminary training period in which all six of the observers participated, and which confirmed the main series by yielding very similar results. The similarity in results also justified the employment of replication series as small as five. Following the main series, there were two experimental control series, one on the effect of adaptation to the stimulus patches and the other on the effect of binocular septum viewing. These controls will be considered after the main results.

RESULTS

The five replications by each observer in each color matching situation were averaged, and these averages were transformed to the CIE standard coordinate system. Then the x, y, data were plotted in chromaticity diagrams in the form of vectors extending from the match point with C illumination to the match point with A illumination. The two ends of any vector thus represent the specifications of the colors which looked the same with the different adaptation illuminations. This measured amount of color difference required to maintain the visual match with the two adaptations constitutes a measure of the difference in perceived color ascribable to the two adaptations.

The vectors in the first series of charts (Fig. 3) represent the main results as averaged over the six observers, with each vector-extremity based on 30 determinations. Some of the approximately equi-

[8] Newhall, Nickerson, and Judd, J. Opt. Soc. Am. 33, 385 (1943).

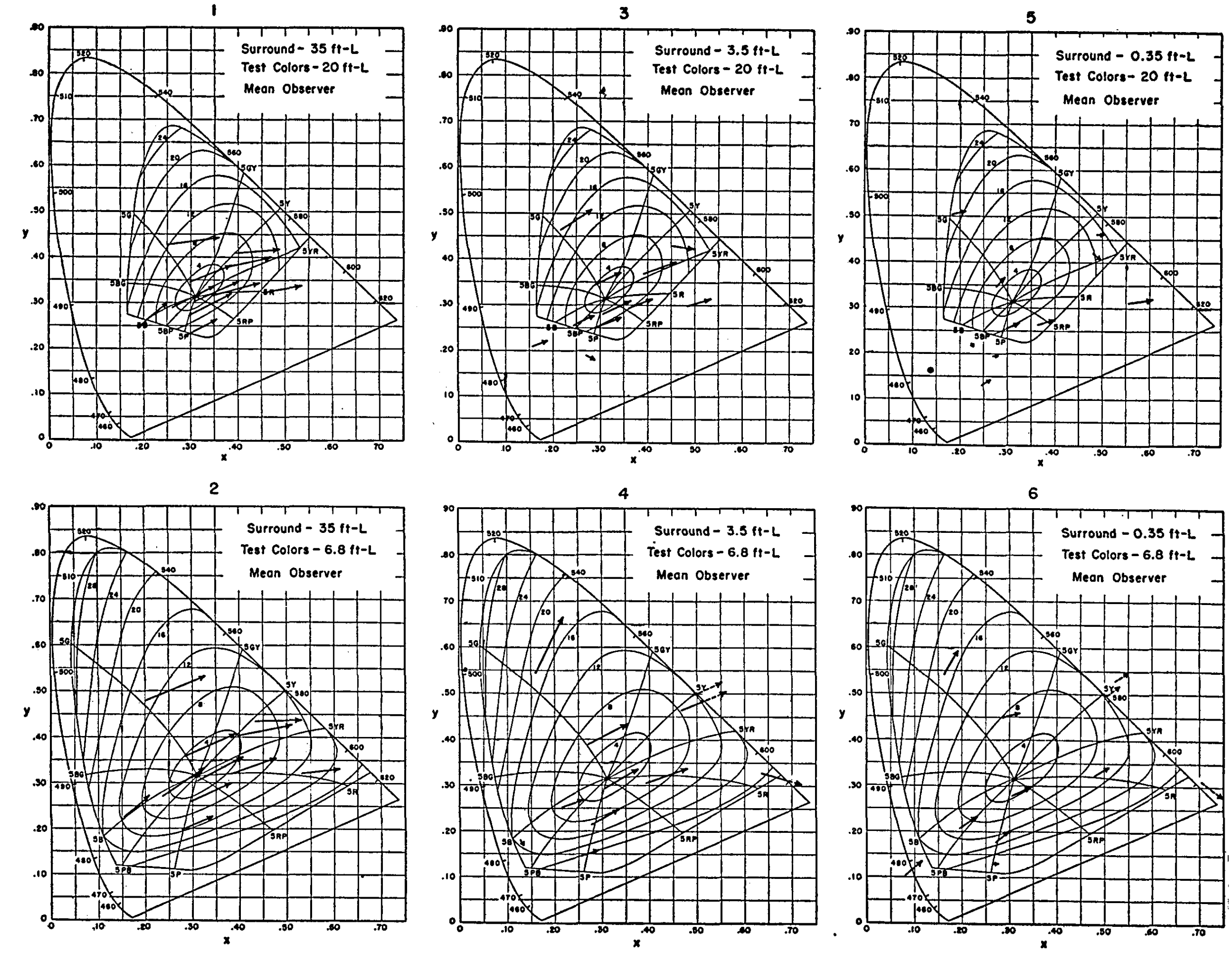

FIG. 3. Changes in perceived color ascribable to changes in adaptation illumination. Average results of 6 observers. Each vector represents the amount of change in the corresponding color which was required to maintain a visual match when changing from daylight adaptation to tungsten adaptation, or vice-versa.

spaced hue and chroma contours recommended by the OSA Subcommittee on the spacing of the Munsell colors have been added to all diagrams to facilitate the direct estimation of visual magnitudes.[8]

The most obvious and important result is the general, regular shift in color stimulus specification from blue toward yellow when adaptation to C illumination is replaced by adaptation to A illumination. In terms of the color appearance of a fixed stimulus patch, this would mean a shift in the opposite direction, *viz.*, from yellower toward bluer; for, in changing from C to A illumination, the observer becomes relatively less sensitive to yellow and more sensitive to blue so that a fixed stimulus patch becomes less yellow or more blue in appearance. By a "fixed stimulus" is meant a fixed energy distribution incident at the eye. Therefore, the vectors point the direction of shift in color appearance when going from the A adaptation to the C adaptation.

The marked and consistent color shift is not only apparent in the general charts of Fig. 3 but also in all the individual observer plots, some of which are shown in Fig. 4. These latter plots can be seen to resemble Chart 1 which is based on the averaged observations with the 35 ft-L surrounds and the test colors of value 8/. Generally, the magnitude of color shift is substantial. This is apparent from the lengths of the vectors relative to the size of the chromaticity diagram or the equispaced chroma contours.

Comparison of the charts in Fig. 3 reveals an important consequence of relative dark adaptation. Thus, comparison of Charts 1, 3, and 5 (or 2, 4, and 6) shows that the lower the luminance of the left surround, the shorter the vectors tend to be; that is, the smaller the differences between chromaticities which match with respective adaptations to A and C illuminations. Plausibly enough, this suggests that with decreasing luminance the color adaptation to the A and C illuminations becomes decreasingly effective.

Another comparison of the same charts (Fig. 3) demonstrates the related result that relative dark adaptation reduces saturation. Thus, for instance,

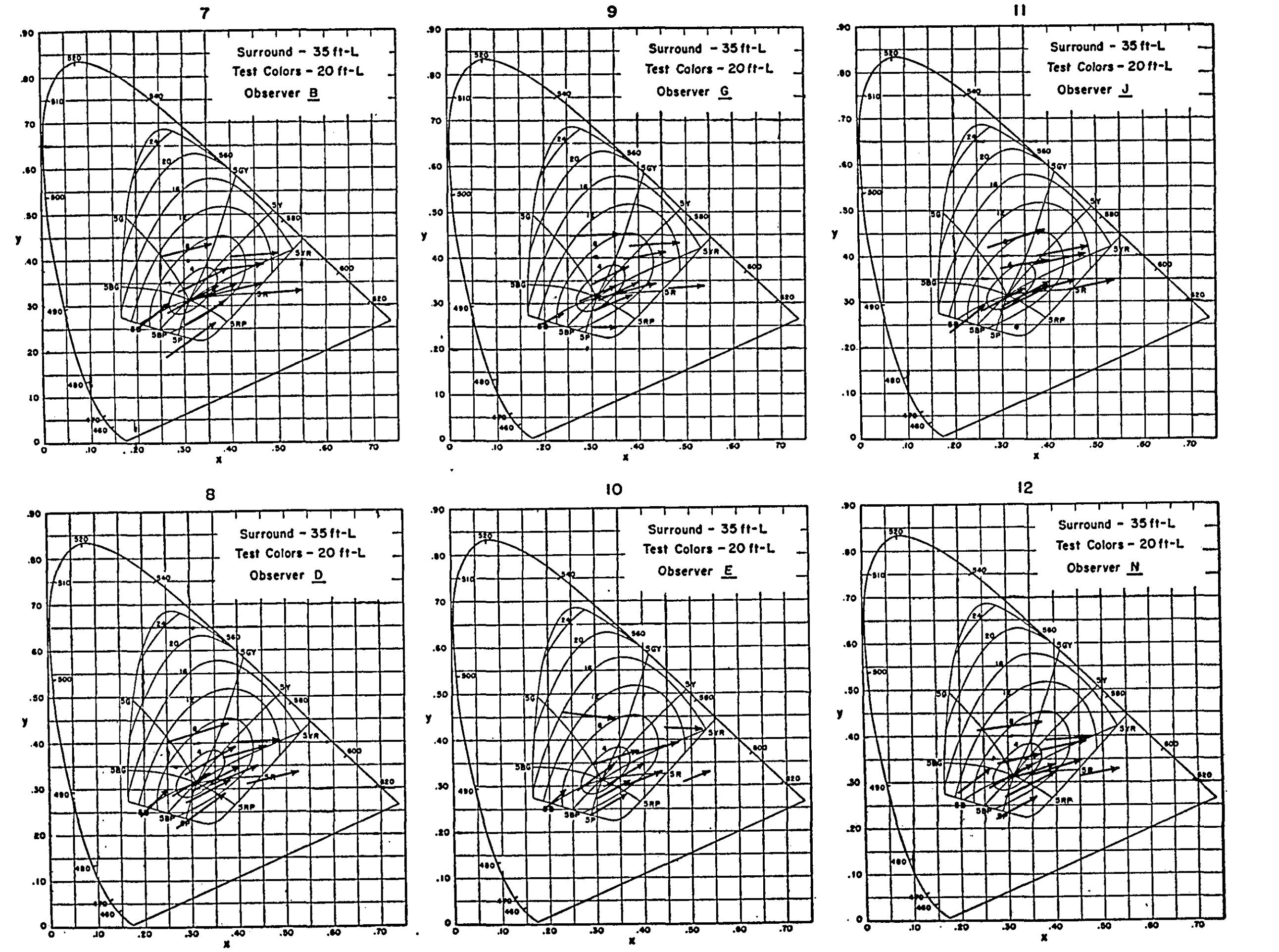

FIG. 4. Changes in perceived color ascribable to changes in adaptation illumination. Individual results of 6 observers.

comparison of Charts 1, 3, and 5 shows that at lower luminance values of the left surround the vectors move farther apart. In other words, with greater dark adaptation of the left eye, more purity was required in the left color patch to match the right color patch which was viewed always with the fully light-adapted right eye. The introduction of more purity inevitably results in greater movement of the plotted vectors away from neutral in the chromaticity diagrams. This result of reduced saturation by dark adaptation confirms Hunt's previous finding.[9]

The desaturating effect of dark adaptation accounts for the extension of certain color-shift vectors beyond the spectrum locus when the left surround was operated at the lower luminances (Fig. 3). In these cases, the left colorimeter could not supply pure enough colors to the relatively dark-adapted left eye to evoke saturation matches with the test colors as viewed by the light-adapted right eye. The light-adapted eye was stimulated with some colors so close to maximum purity that the dark-adapted eye naturally required supramaximum or impossibly high purity to afford a saturation match. Consequently, the observer could only attempt a match for hue and lightness and estimate verbally what saturation would have sufficed to complete the matches. Then, on the basis of such a report, the experimenter extended the vector to provide an approximate indication of the required (unreal) chromaticity.

Comparison of the 6.8 ft-L and 20 ft-L (5/ and 8/ value) plots with each surround luminance also shows a difference in departure of the vectors from neutral (Fig. 3). In each of the three comparisons, as the test color luminance decreased with constant surround luminance, there is a decrease in saturation relative to purity which is similar to that found with relative dark adaptation.

Lowering the adaptation luminance has been seen to influence markedly the chromaticness evoked by the color stimuli. As might be expected, lowering the adaptation luminance also influenced the lightness evoked by the color stimuli (Fig. 5). The plot shows for three conditions of surround luminance of the left field the average luminance of the left field patch

[9] R. W. G. Hunt, Proc. Phys. Soc. (London) (Series B) 62, 203 (1949).

required to match the right field patch fixed at 6.8 or 20 ft-L and a constant surround luminance of 35 ft-L. At the lower surround luminances, the matching color luminances are seen to run far below 6.8 ft-L and 20 ft-L. These matching luminances decrease more gradually than the surround luminance, presumably leveling off around zero surround luminance.

APPLICABILITY OF RESULTS

Since we are especially interested in the color-rendering properties of illuminants as widely used in homes, offices, stores, and industry, it is desirable to attempt some evaluation of our results in terms of applicability to such viewing situations of everyday life. Because the experimental viewing conditions were so obviously different from the viewing conditions of everyday life, the results are probably not completely applicable. Most of these differences in viewing situation are considered in the following sections.

Binocular Septum Technique

Color matching is commonly carried out with natural binocular vision in which both eyes view both color patches; but in the present study and a few others, a septum was used to permit each eye to view only one of the colors. Since the current expression "binocular matching" fails to distinguish this method, the expression "binocular septum matching" is here used instead.[10]

Binocular septum matching differs from normal binocular matching in various respects. (1) The adaptation illumination frequently differs for the two eyes in the septum situation but rarely differs noticeably in the normal situation. Of course, a difference in adaptation illumination was expected to yield some difference in the color perceived by the left eye, and did so. But we must question whether the difference in adaptation of the two eyes may produce disturbing inter-eye effects which change the color perceived by the right eye, *viz.*, change the reference standard. The answer is not wholly satisfactory at present. All that can be said is that users of the binocular septum method are inclined to admit some inter-eye adaptation effect but not to regard it as disturbingly large.[11]

(2) Simultaneous contrast enhancement in the septum situation probably differs from the normal situation. When one observes in the septum situation with the left surround illuminated by A and the right by C, the fused field presents an apparent surround which differs in appearance from the surround in the normal binocular situation. Moreover, in the septum situation, the simultaneous contrast is different when both C illuminations are used from what it is when A is used on the one side and C on the other. Thus, the effect of simultaneous contrast may not only differ from the normal situation but also may have some influence on our reference standard. What these contrast differences amount to is unknown, though they may be small relative to the effect of adaptation.

(3) Noncorresponding areas of the two retinas are stimulated by the two color patches in the septum situation while corresponding areas would be stimulated in the normal situation. This means that each perceived color in the septum situation might depend on a sort of cerebral mixture of color and black as compared with color and color in the normal situation. Rivalry of color and black, it will be recalled, was an initial experience of all observers. If the color is not wholly dominant over the corresponding dark area, it should appear darker than in normal viewing. Apparently the color is largely preponderant as it does look nearly the same as in normal viewing. Still, there were possibilities of changes in hue and saturation as well as lightness, and so an experimental control seemed indicated.

Comparative observations were made with and without color stimuli falling on the corresponding areas, using test colors 5R 5/4, 5R 5/12, 5Y 7/6, and 5B 7/6 only. The observed changes in hue and saturation turned out to be small and of doubtful significance; but the changes in lightness were moderate and significant, running in equivalent magnitude up to a full Munsell value step or about 10 ft-L at value 7/ (Fig. 6). In other words, when color and darkness (nearly zero stimulation) fell on corresponding retinal areas, the

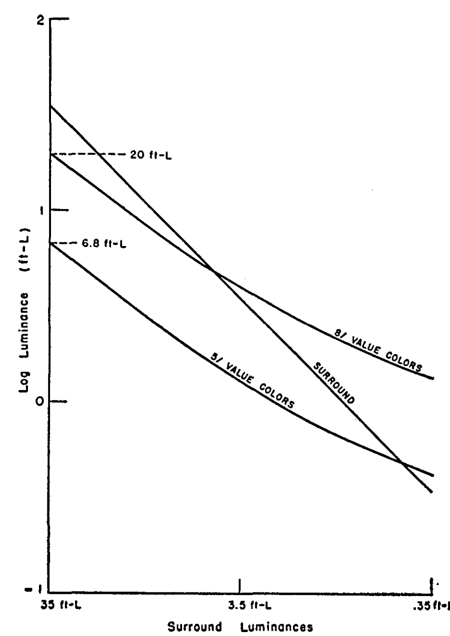

FIG. 5. Changes in lightness of perceived color ascribable to changes in surround luminance. The declines in the color curves represent the reductions in the luminances of the colors which were required to maintain constant lightness while the surround luminance was reduced as indicated.

[10] J. R. Smith, J. Gen. Psychol. 14, 318 (1936).

[11] W. D. Wright, *Researches on Normal and Defective Colour Vision* (C. V. Mosby Company, St. Louis, 1947), p. 214.

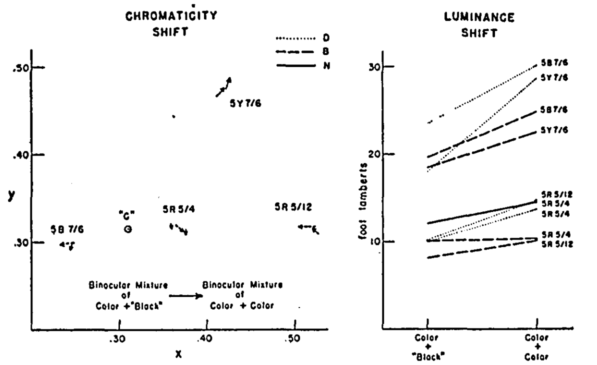

FIG. 6. Control data to indicate changes in perceived color when test colors are viewed with normal binocular vision as compared to the binocular septum viewing used in the main experiment. Each vector represents the amount of change in the appearance of the test color when binocularly mixed with itself, as compared to the test color binocularly mixed with "black" (due to zero stimulation in the corresponding retinal area of the other eye).

fused patch appeared moderately darker than in the normal case where color fell on both. In our main experiment, the darkening applied to both left and right fused patches and was in that sense a constant factor.

(4) Ocular dominance might play a different role in the septum situation than in the normal situation. Thus, in the septum situation, if the right eye is strongly dominant we might expect the right perceived color to be less dark and more steadily chromatic than the left perceived color. In normal viewing, on the other hand, both eyes view both colors so that a lack of balance makes little or no difference.

Five of the observers were nominally right dominant and the sixth left dominant, but during the course of the preliminary practice observations, all disturbing rivalry of color and darkness in the color patches seemed to disappear; and from then on ocular dominance seemed to be a negligible appearance factor.

Amount of Color Adaptation

The amount of adaptation to the illumination in the experimental situation may not have been representative of the normal situation. Since in everyday life persons commonly work or play under a given illumination long enough to become well-adapted to it, we arranged for relatively full experimental adaptation by allowing at least 5 minutes for it. Our results cannot be expected to apply directly to less common everyday situations in which personnel are moving rapidly about from one illumination quality to another.

The amount of adaptation to the color patches themselves was considered reasonably representative of the normal situation. In the septum situation, the observer looked more or less steadily at the juxtaposed color patches while making his match; and we believe that in a typical normal situation the observer also tends to look more or less steadily at an external object of attention such as a pair of color patches. Leaving the observers uninstructed regarding direction or duration of fixation was believed to afford the best approximation to the generalized normal case.

Nevertheless, it is also undoubtedly true that in everyday life we often glimpse colors momentarily, and so it was also of some interest to see what would happen under as little adaptation as feasible to the test colors. Four observers participated in two control series to test this point, each series employing the test colors 5P 8/4 and 5Y 8/6. In one series the color patches were exposed intermittently by sector disks for about 0.3 second every second, while in the other series the sequence was one 0.3-second exposure per second for 3 seconds followed by a 10-second interval, then three more 0.3-second exposures in 3 seconds, then another 10-second interval, and so on. Between exposures, the surround filled the central field so that neither test colors nor borders were visible. In comparison with the possible exposure time of 100 percent in our regular experimental procedure, the total amounts of exposure time in these control series were about 31 percent and 6 percent, respectively. Naturally, the task of making the color matches in the control series was much more difficult than in the experimental series. However, with each observer making 10 matches in each situation, a rather definite trend in the results was revealed (Fig. 7). The points in this figure indicate the individual observer determinations, while the vectors represent the averaged results. Thus, in case of either test color, the solid line vector, representing a repetition of the regular experimental procedure or 100 percent exposure, shows the least amount of color shift with change in adaptation from C to A; the dashed vector above, representing the control with 31 percent exposure, indicates noticeably greater shift; and finally the dotted vector, representing the control with the 6 percent exposure, shows much the same result as with the 31 percent exposure. It appears, therefore, that still further reduction in exposure would have negligible further effect on the perceived color.

These control series may provide some idea of what to expect in case of attentively glimpsed colors as compared with colors which remain in the environment and are fixated at pleasure. The glimpsed colors exhibit a noticeably greater shift in appearance when the adaptation illuminations are changed than do the ever-present colors.

Color Sample Pattern

In this first investigation we chose to employ the relatively simple sample pattern above described, *viz.*, two juxtaposed color patches perceived as at the middle of an extended nearly nonselective light field. There is of course a great range of complexity in the visual fields of everyday life; some contain many competing color patches and some only a few. More complex fields are capable of greater organization, and the degree of organization is a well-recognized factor favoring color constancy. The presence of the supplementary colors is believed to contribute to the frame of reference in judging the appearance of the color sample of special interest. These supplementary colors are believed to be especially effective when they are familiar object colors as is often the case in familiar environments.

On the other hand, there is the physical fact that the greater the area of the field occupied by colors differing from the illumination, the less adaptation to the illumination itself is possible. With numerous supplementary colors present, less of the unmodified illumination can reach the observer's eyes and so there is less opportunity for thorough adaptation to that illumination. This means that an investigation with a multi-sample field is less definitely concerned with the influence of adaptation to tungsten and daylight and more concerned with the influence of adaptation to the undefined lights which happen to be reflected from the samples present.

In brief, while the simplified sample pattern was unfavorable to high color constancy so far as the factor of field organization was concerned, it did provide opportunity for a high degree of adaptation to the particular illumination qualities under investigation.

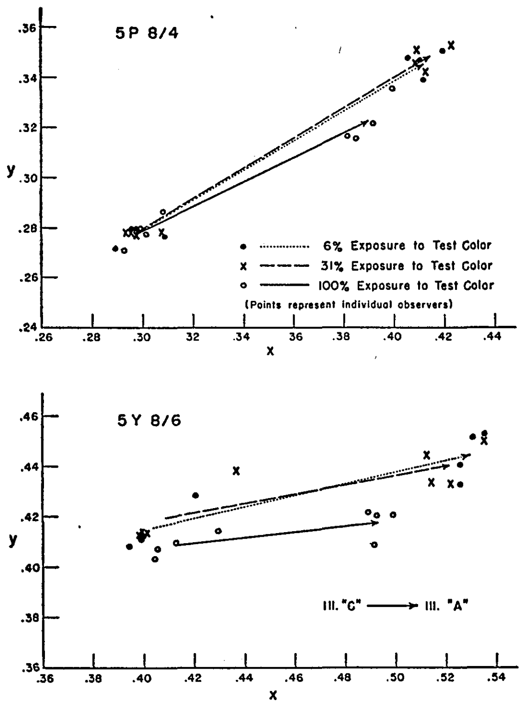

FIG. 7. Control data to indicate changes in perceived color ascribable to amount of adaptation to the test color. Each vector shows the average amount of change in the corresponding color which was required to maintain a visual match under the second illuminant with 100 percent, 31 percent, and 6 percent of the experimental exposure to the test color.

PRINCIPAL EXPERIMENTAL FINDINGS

(1) Change from adaptation to tungsten light to adaptation to daylight resulted in substantial correlative shift in perceived color toward the yellows. Similarly, change from daylight to tungsten adaptation produced similar shift toward the blues. This result is in accord with the recent findings in the binocular septum studies of Hunt and of Winch and Young.

(2) The amount of the chromaticness shift varied with the test colors and other factors, but it was of the average order of some 20 just perceptible differences.

(3) The amount of the shift in perceived color was found to vary with the amount of exposure to the color patches; but the amount of shift secured in the main body of data, at a surround luminance of 35 ft-L, seemed close to the maximum obtainable.

(4) The amount of shift in perceived color decreased systematically with decrease in level of the adaptation illumination.

(5) Perceived colors in binocular septum viewing with minimum stimulation of the corresponding retinal areas were found to be somewhat darker than in natural viewing.

(6) Strong confirmation was secured of the fact that dark adaptation significantly reduces saturation.

Work is going forward on the relation of the results to the theory of color vision and on other studies having to do with the same problem. These aspects will form the subjects of future publication.