Levels of Adaptation and Brightness Changes During Color Adaptation

Dorothea Jameson and Leo M. Hurvich

Color Control Department, Eastman Kodak Company

In an article which appeared recently in *Science* (*3*), Jozef Cohen has restated the major generalizations which summarize his data on color adaptation (*2*). Intensity, according to these generalizations, increases during color adaptation.[1] The increase, while independent of the hue of the stimulus, is dependent on its saturation and intensity. The general conclusion concerning the change in intensity stands in direct contradiction to the findings of a number of earlier investigators, who usually concluded that brightness (intensity) decreased rather than increased during the course of color adaptation (*1*, *6*, *7*, *8*).

Cohen is well aware of this major discrepancy. He is also aware of the lack of complete agreement among previous investigators concerning other aspects of color adaptation, and he reports (*3*) an experiment designed to determine the source of the discrepancies. Most investigators have described their stimuli only in terms of color appearance. Cohen, therefore, tested the hypothesis that color adaptation of the eye is a function of the spectral composition of the stimulus and not of its tristimulus values (or appearance). Although the stimuli used by different earlier investigators may be comparable as regards tristimulus values, unrecognized differences in the physical compositions of various stimuli might have led to different adaptive effects. Cohen's experimental results were, however, negative. Stimuli of different spectral distributions but of the same tristimulus values produced no appreciable differences in color adaptation. Although this finding is not without its own intrinsic interest, the discrepant results concerning brightness changes during color adaptation still remain unexplained.

An analysis of the experimental methods and procedures used by most investigators, including Cohen, suggests an alternative explanation in terms of differential adaptation effects. The specific aim in color adaptation studies of this sort is to determine the manner in which a visual sensory effect, produced by a test stimulus of fixed intensity (luminance) and spectral distribution, varies with continued exposure. The variation in brightness, for example, is measured by equating to the test field after various times of exposure a comparison stimulus of variable intensity which stimulates a spatially separate retinal area in either the same or the other eye. Changes in the matching intensity of the comparison field are then taken as measures of the adaptive effect in the test area.

Unfortunately, however, in studies of this sort the responses evoked in the comparison area are, like those of the test area, also conditioned by initial and subsequent states of adaptation. Even if one were to assume, as Cohen does in his experiments, that a static or equilibrium state can be maintained in the comparison area during the course of the measurements, the initial level of adaptation of the comparison area still exerts a decisive influence upon the result. Visual comparisons between two discretely stimulated retinal areas depend not only on physical stimuli but upon the respective adaptation levels of both areas. Craik, in an extensive study of the effects of adaptation on brightness, has given a striking experimental demonstration of the extent of this dependence: ". . . an illumination of 3 e.f.c. presented to the dark-adapted left eye is judged subjectively equal to the adapted brightness of 15,000 or 75,000 e.f.c. presented to the right eye" (*5*, p. 239).

Since brightness equations made during the course of color adaptation depend on the relative adaptation levels of the visual test area whose adaptive changes are being measured and the visual comparison area which is used to measure these changes, the conflicting results which have been reported may very probably be due to different relations between these two levels in different experiments.

An examination of experiments in which a decrease in brightness of the test area during color adaptation is reported shows that the retinal comparison area is adapted to a lower illuminance level than the test area. Except for flash exposures necessary to make a color match to the test field, the comparison area is unstimulated during adaptation to the test color. The comparison area is in effect dark-adapting. Since its sensitivity, relative to that of the test area, is increasing with time, it is therefore to be expected that less and less light will be required for an equation to the test brightness.

It follows directly that opposite effects should occur if the adaptive levels and consequently the relative sensitivities of the two areas are reversed. With the adapting illuminance of the comparison area higher than that of the test patch, the intensity required for a match would be expected to increase during adaptation, as it did in Cohen's experiments. Were this one of his experimental conditions, the unexpected direction which his results took might readily be explained. In his experiments, in contrast to other investigations, the retinal comparison area was continuously stimulated during the adapting period by what he calls a neutral "gray of medium brightness" (*2*, p. 100). Unfortunately, the intensity level is not specified. It is asserted simply that "the patch upon which the match was made underwent little,

[1] Cohen uses the word *intensity* to specify both the psychological and physical dimensions. His conclusions, however, refer specifically to measured physical variations in a matching stimulus during color adaptation. Given certain known psychophysical relations between stimulus intensity and sensation, such measurements are frequently interpreted as indicative of changes in the psychological dimension, and to describe them the word *brightness*, rather than intensity, is more commonly used. For specifying the stimulus, *luminance* is preferable to *intensity*. Intensity is restricted to the specification of point sources, while luminance, measured in lamberts or foot lamberts, specifies the intensity per unit of projected area of source. (See Colorimetry Report, Reference *4*.) Since the older work with which the present paper is concerned has been reported and discussed in terms of "stimulus intensity," this usage is retained in the present discussion to avoid confusion.

if any, change, i.e., the retinal processes were in equilibrium'' (*2*, p. 109). In the absence of precise specification of the adaptation levels of the test and comparison areas, the proposed explanation lacks experimental confirmation. The following experiments are intended to provide such confirmation.

The apparatus used in these experiments was a form of monochromatic colorimeter. The field sizes and positions, pre-exposure times, and adaptation controls were identical with those used in the Cohen investigation (see *2* for details). Observations were binocular, with both the test and comparison fields viewed by each of the two eyes. Judgments, however, were restricted to one psychological dimension—namely, brightness. To test the effects on brightness equations of differences in the relative adaptation levels of the test and comparison areas, three separate color adaptation experiments were performed. The stimulus intensity of the test color was the same in all three experiments. The adapting intensity of the neutral comparison field, while always within a range which might be considered of medium brightness, was less than, equal to, or greater than that of the test field in the separate experiments. The general result for two observers is shown in Fig. 1.

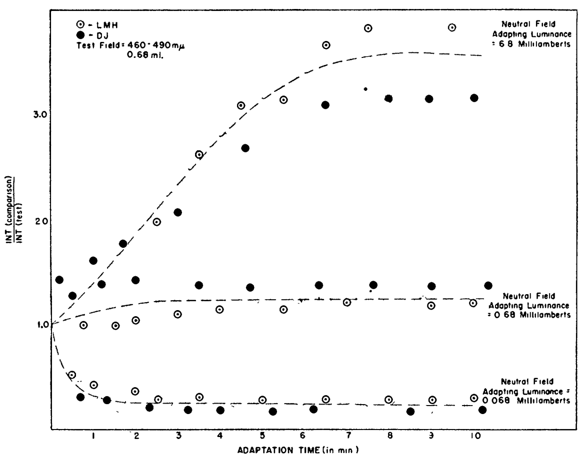

FIG. 1.

The lower curve in Fig. 1 indicates that the intensity of the comparison field necessary for a brightness equation to a test field of fixed stimulus intensity decreases with an increase in the time of adaptation. For this result, the achromatic adapting illuminance of the retinal comparison area was about one-tenth that of the colored test area. In the second experiment, on the other hand, the comparison area was adapted to approximately the same illuminance level as the test area. In this case, the curve shows that there was very little change in the matching intensity during the course of the adaptation period. Finally, the upper curve shows the matching intensity to increase with an increase in adaptation time. Here, the adapting illuminance of the comparison area was about ten times that of the colored test area. The increase in intensity under these conditions is similar to the result obtained by Cohen. The presumption seems warranted, therefore, that Cohen's experimental conditions were also comparable, and that the adapting illuminance of his retinal comparison area was, in fact, higher than that of his test area.

The results shown in Fig. 1 have been confirmed for each of two observers for two hues and two levels of test color illuminance. In all cases, the direction taken by the intensity function obtained is specific and reproducible, and depends on the relation between the adaptation levels of the retinal test and comparison areas. Fig. 1 conclusively demonstrates that the increase in intensity reported by Cohen cannot be accepted as a general law of color adaptation, any more than the decrease reported by other investigators can be so considered.

The curves presented in Fig. 1 are, in effect, equal brightness contours for different adapting levels, determined over specified periods of time and for particular experimental conditions. They reconcile the apparently discrepant results which have been interpreted as representing the manner in which brightness varies during the course of color adaptation. Actually, these curves cannot be taken to represent the manner in which the brightness attribute of a color varies with adaptation. They are functions which result from the *variations of two sensitivities,* variations in the test and comparison areas. The test sensitivity cannot be measured independently unless it is guaranteed that the comparison area is maintained at a constant level which is the same as the initial level of the test area. That a constant state of sensitivity can be maintained in the measuring area of the retina has long been doubted. To quote Almack, ''That this can be accomplished under such unusual circumstances as are imposed in an adaptation series is highly improbable . . . the choice of a method of equivalents is, we believe, an unfortunate one for rating loss of sensitivity by adaptation'' (*1*, p. 33). Further research alone will determine the validity of this point of view. It must again be emphasized, however, that even if the measuring area is demonstrated to be constant in sensitivity, results would still represent only relative changes from the specified initial sensitivity of the test area to subsequent states produced by adaptation to the retinal test illumination. Nevertheless, with complete specification of the experimental conditions, and with full awareness that results obtained in this manner represent events of a relational nature only, they, like any other measurable phenomena of color vision, provide much useful information. They require and will ultimately receive a necessary explanation in terms of underlying physiological processes.

References

1. ALMACK, M. R. *Psychol. Monog.*, 1928, **38** (2), #174, 1.
2. COHEN, J. *Amer. J. Psychol.*, 1946, **59**, 84.
3. ———. *Science*, 1948, **108**, 159.
4. Colorimetry Committee. *J. opt. Soc. Amer.*, 1944, **34**, 245.
5. CRAIK, K. J. W. *Proc. roy. Soc.*, 1940, **128**, 232.
6. KRAKOV, S. W. *J. psychol. Neurol., Lpz.*, 1928, **36**, 87.
7. SCHÖN, W. *v. Graefes Arch. Ophthal.*, 1874, **20** (2), 273.
8. VOESTE, H. *Z. Psychol.*, 1898, **18**, 257.