Reports

Binocular Combination of Projected Images

Abstract. Two color-separation positive transparencies of a scene, one projected with "red" light and the other with tungsten lamp light, were superimposed on a screen. The light was polarized so that an observer wearing an appropriate viewer could either see both images in each eye or the "red" image in one eye and the "white" image in the other. These two situations gave different results, not the same results, as some previous investigators have claimed. Land's major results cannot be "obtained stereoscopically." We conclude that the process by which color is formed could possibly be a process of the retina or the lateral geniculate body, and does not necessarily have to be a process of the cerebral cortex as implied by the binocular experiments which purported to give the fuller gamut of color.

It has been suggested that the experiments recently described by Land (*1*) can be modified by presenting some of the wavelengths to one eye and some to the other, without changing the resulting sensations. Land's experiments, on which the binocular experiments are based, are those in which two photographs are made of a scene, one through a Kodak Wratten No. 24 "red" filter (referred to here as the long record), and one through a Kodak Wratten No. 58 "green" filter (referred to here as the short record). The long record is projected with "red" light (a Wratten No. 26 filter is placed over the projector) and the short record is projected with "white" light (a neutral density filter of about 0.4 is usually placed over the projector). The records are superimposed on the screen. If the scene contains textured objects of various wavelength compositions in a random arrangement, one sees a surprising gamut of color, including red, blue-green, blue, white, yellow, gray, brown, orange, and pink (*2*).

Geschwind and Segal made their photographs essentially the same way that Land did, but they altered the experiments. They used a Kodak stereoscopic viewer instead of projectors and a screen to view the records (*3*). One eye saw the long record and the other eye saw the short record instead of each eye seeing both records. Pastore (*4*) performed the same experiment independently of Geschwind and Segal. These authors all came to the conclusion that the colors they saw were much the same as those seen in the experiment performed by Land in which both records are presented to each eye simultaneously. This is important, if true, for it suggests that the colors which are seen, other than those of the projection lights, are the result of a central process, as opposed to a peripheral or retinal process.

However, the method which Geschwind and Segal and Pastore used does not allow a direct comparison to be made between the two methods of viewing. In this study, we set up two experiments designed to eliminate this source of error. In the first experiment we used Polariod stereo viewers, a non-depolarizing screen, and polarizers over the projectors so that the long record was in one eye and the short record in the other when the observer's head was horizontal, and both records were in each eye when the observer's head was tilted 45 degrees to the horizontal. Thus, the direct comparison could be made simply by tilting one's head through a 45 degree arc. (The observer could determine the position of his head by first covering one eye and then the other. When his head was not quite horizontal he saw a variety of color in each eye which disappeared when he straightened his head. When his head was tilted at a 45 degree angle, the picture in one eye was identical with the picture in the other eye.) In the second experiment we used a technique described previously by Land and Hunt (*5*). The observer wore a polarizing viewer in which the axes were orthogonal to each other. He then looked at two "red and white" projections which were placed side by side, one with its wavelength components polarized orthogonal to each other, and the other unpolarized. Looking to the left, the observer saw the long record with one eye and the short record with the other. By turning his eyes or his head to the right without tilting his head, he saw both records superimposed in each eye (see Fig. 1).

In the first experiment six observers were asked (i) to look at the scene without the viewers and describe the colors of the objects; (ii) to look at the scene with the viewers on, with their head horizontal, and describe the colors of the objects; (iii) to continue looking at the scene for several minutes (either 5 minutes or 10 minutes) with the viewers on, and, with their head horizontal, to describe the colors of the objects; (iv) to turn their head through a 45 degree arc and describe the colors of the objects; (v) to hold their head horizontal with the viewers on, while the experimenter put various neutral density filters over one projector or the other, and to choose the filter which produced the greatest variety of color for them (Geschwind and Segal had noted that the balancing of brightness in the two images is of critical importance); and (vi) with this filter, to compare the colors, first with their head horizontal and then with it tilted at a 45 degree angle to the horizontal.

Each observer performed the experiments by himself so that he could not be influenced by the report of any other observer. Without exception, the reports were as follows: (i) without the viewers a variety of colors was seen, including red, brown, turquoise, pink, blue, orange, gray, black, and white; (ii) when the viewers were put on the scene became essentially gray and red; (iii) after 5 minutes of looking at the

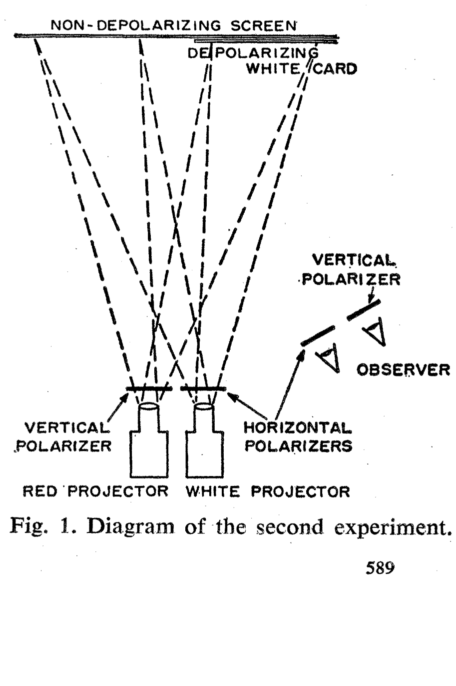

Fig. 1. Diagram of the second experiment.

scene with the viewers on there was a little, but not much, more color; (iv) when the head was tilted through a 45 degree arc the colors became much more saturated [A typical remark at this stage was: "The colors have come back again".]; (v) all observers, when looking at the "red" image in one eye and the "white" image in the other, chose to have a neutral density filter, varying from 0.7 to 1.1, put over the short record projector in addition to the 0.4 neutral density filter which was already there. The 0.4 neutral density filter was the one which produced the best variety of color without the viewers; (vi) this additional neutral density filter reduced the range of color seen without the viewers. In spite of this the colors were still much more evident with the head held at a 45 degree angle than with the head held horizontal.

In the second experiment four transparencies were used, two identical transparencies being placed side by side in each projector (see Fig. 1). Both transparencies in the long record "red" projector were polarized vertically, while those in the short record "white" projector were polarized horizontally. Both pairs of records were registered on the nondepolarizing screen, but where the right-hand picture appeared the screen was covered with a white card to depolarize the light. The observer's viewer contained two polarizers, one oriented vertically before one eye and the other oriented horizontally before the other eye. As long as the observer held his head horizontal both eyes saw both records in the picture on the white card; and each eye saw only one record in the light which was registered on the nondepolarizing screen.

Six observers were asked to look at the two doubly lighted screen areas and compare them, being careful to keep their heads horizontal. The observers were placed so that the two pictures appeared to be the same in brightness to the naked eye. To start with, the neutral density filter over the "white" projector was 0.4, the one most commonly used to give the best variety of color. All six observers found the left-hand picture to be colorless compared with the right-hand picture. Objects which were green, pink, yellow, and blue on the right were gray on the left; objects which were red on the right were black or reddish on the left. In fact, the left-hand picture was almost completely red and gray, whereas the right-hand picture had quite a variety of color in it.

The neutral density filter over the "white" projector was then varied, and the observer was asked to pick the one that made the two images look most nearly alike. Three of the observers chose a density of 1.0; one, 0.7; one, 1.1; and one, 1.3. At this stage the two images still looked different. Some of the cool objects looked green in the left-hand picture, but the green was unsaturated compared with that in the right-hand picture. Some pink objects looked the same in both pictures. Two objects which looked respectively orange and red in the right-hand picture could not be distinguished from each other in the left-hand picture.

Throughout the experiment there was lustre in the left-hand picture; it was never seen in the right-hand picture. Accompanying the lustre in three objects which had different densities in the two component light patterns was an alternation of color which was a form of binocular rivalry. For example, an object in the left-hand picture which was light and red for one eye, and black for the other, would appear red at one moment and black the next. The colors in these objects on the left half of the screen obviously could not match the colors on the right side permanently, since two separate colors were seen at different times in the left-hand picture of the objects, and only one color was seen in the right-hand counterpart. The most impressive part of the demonstration was that the colors in the left-hand picture which did not show rivalry (that is, those colors which did "fuse") were not a very close match either. It is well known that one does not obtain identical colors from a binocular combination of monocular stimuli and from physical mixture of the same two stimuli on one retina when uniform fields of the two stimuli are used.

From the results reported here, we are forced to disagree with Geschwind and Segal, and with Pastore, and to say that the results obtained when a "red" image is presented to one eye and a "white" image is presented to the other are not the same as those obtained when both images are combined on the same retina, either in one eye or in both (*6*). We have not performed enough experiments to know whether a "red" image presented to one eye and a "white" image presented to the other, at one particular relative brightness value, can be made to look like both images presented to both eyes at another particular relative brightness value. Even if this should occur, we could not agree with Pastore's statement that "Land's major results can be obtained stereoscopically" (*7*). Our experience suggests that one would have to have a remarkably colorless subject in the case where both wavelength components are presented to both eyes, if this were to match the case where one wavelength component is presented to one eye and the other wavelength component to the other eye. Nor can we agree that these experiments provide any support for the claim that the colors are formed after cerebral fusion of information from the two eyes. It is entirely possible that they are formed instead in the retina or in the lateral geniculate body.

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References and Notes

1. E. H. Land, *Proc. Nat. Acad. Sci. U.S.* **45**, 115, 636 (1959).
2. Color names can be used in two senses—to describe a sensation or to describe a correlate of bands of wavelengths. In this paper, to avoid confusion, quotation marks have been used whenever a color name is used in the latter sense.
3. N. Geschwind and J. R. Segal, *Science* **131**, 608 (1960).
4. N. Pastore, *ibid.* **131**, 1400 (1960).
5. E. H. Land and W. A. Hunt, *ibid.* **83**, 309 (1936).
6. In a recent letter, Hayward appears to have come to the same conclusion as Geschwind, Segal, and Pastore: see R. Hayward *J. Opt. Soc. Amer.* **52**, 226 (1962).
7. When these experiments are performed with "red" light and "green" light, and with other light combinations, the results seem to be slightly different.

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A Theory of Middle Ear Muscle Function at Moderate Sound Levels

Abstract. The minor amplitude modulations of auditory input, which are introduced by the middle ear muscle acoustic reflex at moderate and low sound intensities in the cat, may contribute significantly to signal analysis or attention mechanisms of the auditory system.

To anyone who has pursed his lips and emitted a high-pitched squeak in the vicinity of a cat, whether somnolescent or ambling along in cat-like pursuits, the participation of the peripheral auditory system in the animal's orientating response is immediately evident—the outward twitch of the pinna, the abrupt halt in ongoing activity . . . the pause . . . then relaxation and resumption of whatever came before, unless the stimulus be repeated. In addition to the reaction of the pinna, the muscles