EXPERIMENTS WITH GOGGLES

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Of all the senses the one most intensively studied is undoubtedly vision. Much has been learned about the physical and physiological basis of visual perception, but understanding of the process remains primitive. Vision is perhaps the most complex of the senses; nonetheless it offers the investigator a tantalizing opportunity to learn how the brain processes sensory data and constructs an effective image of the outside world. Presumably this image is the result of an unconscious learning process; the image is "better" than it should be, considering the known defects in the visual system. For example, the lens of the eye is not corrected for spherical aberration; hence straight lines should look slightly curved. By the same token, lines of a certain curvature should appear straight. It is also well known that the eye is not corrected for color; as a result different wavelengths of light—originating at a common point—do not come to a common focus on the retina. One would expect this defect, called chromatic aberration, to have a noticeable effect on vision, but it does not, except under special conditions.

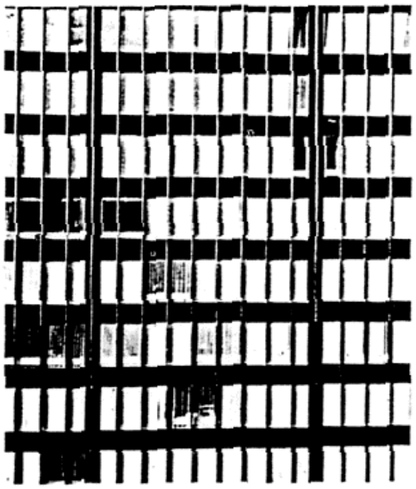
One way to explore the unconscious learning process that goes on in normal vision is to investigate how the visual system responds to images that are systematically distorted by specially constructed goggles. In this article I shall describe some of our studies, conducted at the University of Innsbruck in Austria, which show that the eye has a remarkable ability to discount or adapt to highly complex distortions involving both spatial geometry and color. But we have been surprised to discover that the eye does not adapt to certain other distortions that seem, superficially at least, less severe than those to which the eye does adapt. Some of these findings appear to be incompatible with traditional theories of vision in general and of color vision in particular.

In addition to contributing to the understanding of vision, experiments with goggles have immediate practical importance for ophthalmologists. If the ophthalmologist knows the extent to which the visual system can adapt to "wrongly" constructed experimental glasses, he will be less reluctant to prescribe strong glasses for his patients. The stronger a glass, meaning the higher its refractive power, the greater its capacity to distort images and produce a fringe of color around them. The ophthalmologist can tell a patient in need of strong glasses that the initially disagreeable distortions and rainbow fringes will disappear if he wears the glasses faithfully for several weeks. Or, to give another example, an operation to repair a detached retina sometimes leaves a fold in the retina that causes a bulge in the patient's visual world. On the basis of goggle experiments, the physician can assure the patient that the bulge will become less noticeable with time and will probably disappear altogether. The fold in the retina will remain, but the patient's vision will gradually adapt to discount its presence. What this implies, of course, is that an individual born with a fold or similar imperfection in his retina may never be aware of it.

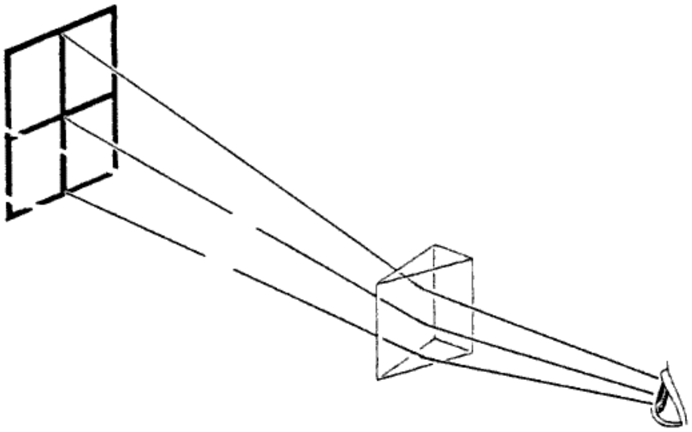
We conclude, therefore, that sense organs are not rigid machines but living and variable systems, the functioning of which is itself subject to variation. If a sensory system is exposed to a new and prolonged stimulus situation that departs from the one normally experienced, the system can be expected to undergo a fundamental change in its normal mode of operation.

The use of distorting goggles seems to be the simplest way of producing novel and prolonged visual-stimulus situations. The volunteer subject can be said to be wearing the laboratory on his nose; he cannot leave the laboratory unless he closes his eyes or removes the goggles. The entire visual system, including the manifold projection regions in the brain of which we still know so little, is subjected in a certain way to a completely novel and disturbing situation. Finally it "breaks down"; established habits are abandoned and the visual system begins to respond in a new manner.

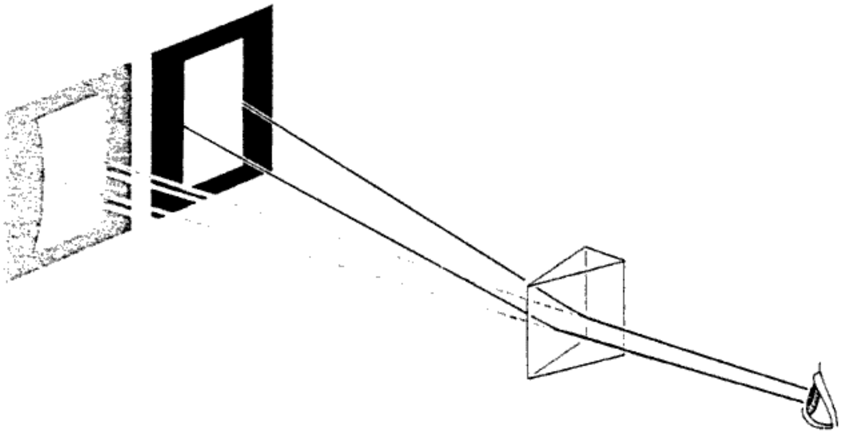
When we make the system break down and learn a new way of functioning, we do not believe we are forcing the system to function artificially or abnormally. We assume, rather, that a single mechanism is at work at all times. The mechanism that removes or minimizes an artificially created disturbance is the same one that brings about a normal



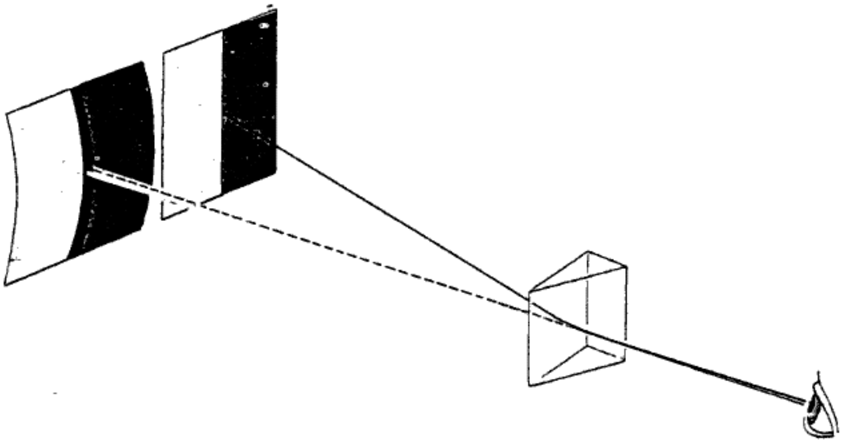
UNDISTORTED VIEW of the Union Carbide Building in New York can be compared with distorted images on page 310.



CURVATURE OF LINES is observed when looking through a prism because light rays entering the prism obliquely are bent more than those entering at right angles. A prism that has its base to the right displaces images to the left and bends the top and bottom of vertical lines still farther to the left. As a result vertical lines seem to bow to the right.



FRINGE OF COLOR borders light-colored objects because a prism bends short wavelengths of light more than long wavelengths. If the prism base is to the right, blue rays, being bent the most, are seen as a blue fringe along the left-hand border. Similarly, a yellow-red fringe of color (*shown here in gray*) appears along the right-hand border of the object.



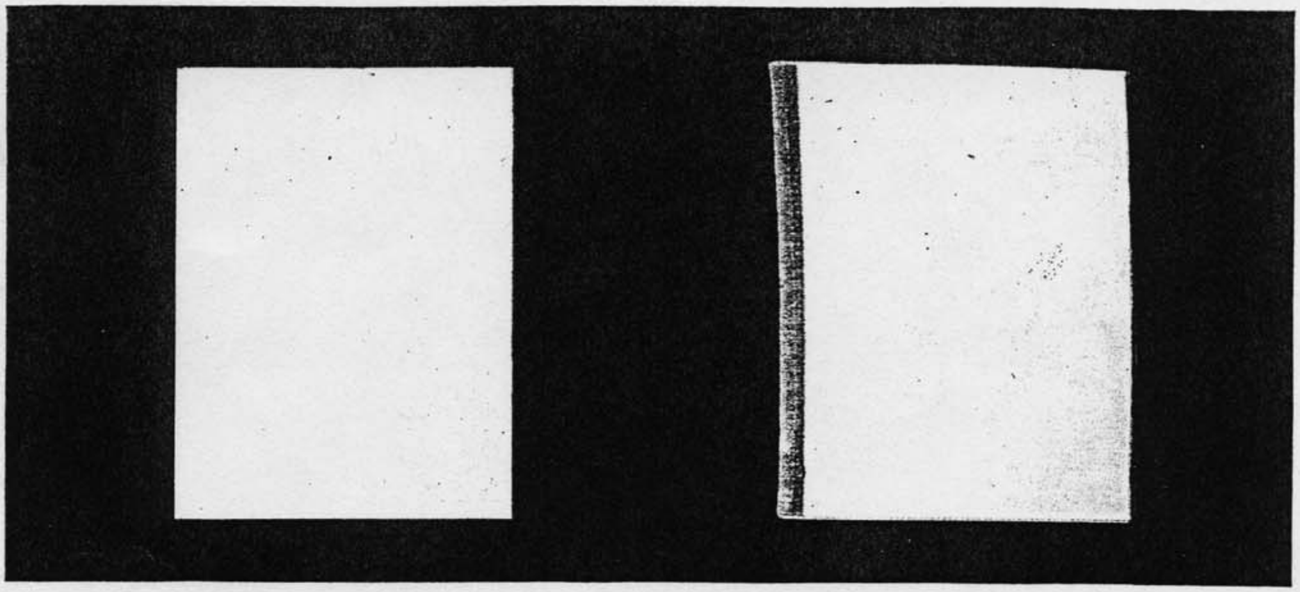
COLOR DISPLACEMENT is another consequence of the differential bending of light rays having different wavelengths. The diagram shows what happens if the green-red figure on the opposite page is viewed through a prism, base to right. The green area (*gray here*) is displaced to the left more than the red area, leaving an empty dark space between the two.

functioning of the sensory system under normal conditions. If this assumption is correct, the development of the normal visual system—in so far as its development depends on the environment—can be explored by the goggle method.

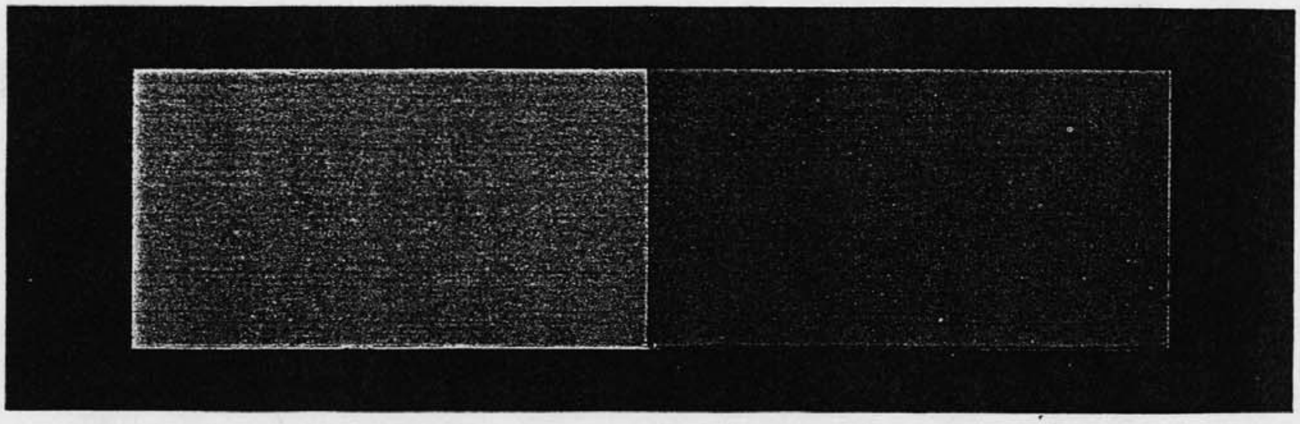
The application of distorting goggles to the study of visual adaptation dates back to the work of G. M. Stratton of the University of California, who used himself as a subject. Primarily because of the difficulty of finding subjects willing to wear goggles for days, weeks or even months, the method was little employed until about 1928. Then, independently and simultaneously, goggle experiments were undertaken by Theodor Erismann at the University of Innsbruck and by James J. Gibson at Smith College. Gibson's subjects wore goggles that placed a glass wedge, or prism, in front of each eye. Erismann experimented not only with prism goggles but also with more elaborate devices that transposed the visual field from right to left or from top to bottom. Another device allowed the subject to see only directly to the rear, as if he had eyes in the back of his head. After several weeks of wearing goggles that transposed right and left, one of Erismann's subjects became so at home in his reversed world that he was able to drive a motorcycle through Innsbruck while wearing the goggles.

Although Gibson's subjects wore goggles for only a few days at a time, they were the first to discover adaptation to the color fringes and line curvature that a prism produces. Depending on the extent to which the front and rear faces of a prism depart from the parallel, light rays passing through the glass are bent to a greater or lesser degree. This property is called the deviation of the prism. The deviation angle is approximately half the angle between the two faces. Deviations between five and 15 degrees are most useful for goggle experiments. Color fringes arise because light of short wavelength, such as blue light, is bent more than light of longer wavelength. As a result the line marking the edge of an object is spread out into a small spectrum, which becomes more noticeable the greater the contrast between the brightness of the object and that of its background [*see top illustration on opposite page*].

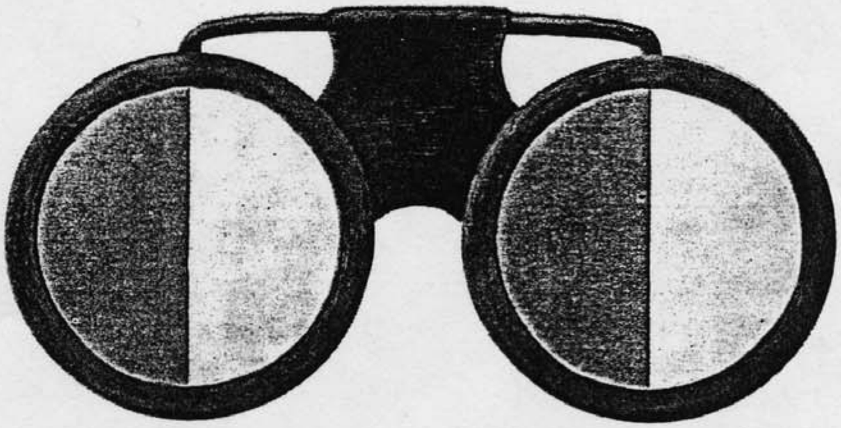
The curvature of lines is part of a more general prism effect that produces a variable change in the curvature, angle and distance of observed objects. The effect arises because the angle of deviation varies with the direction of the light reaching the front face of the prism.



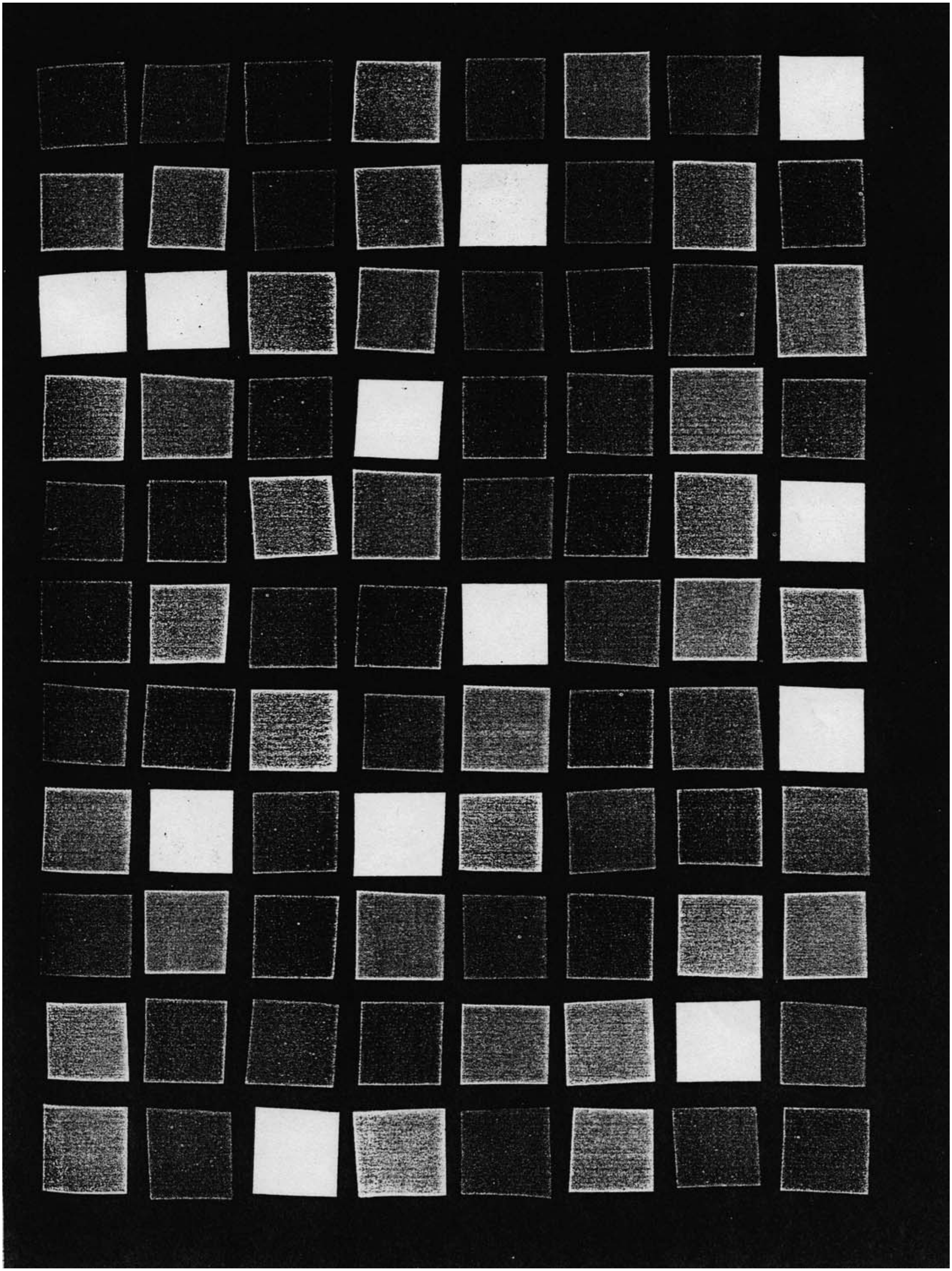
COLOR FRINGES appear (*right*) when a simple white-on-black figure is viewed through a prism having its base to the right. The prism also bends vertical lines. The undistorted figure is shown at the left. These prismatic distortions are explained in the upper two illustrations on the opposite page. After a subject has worn prism goggles for a few days the color fringes and line curvature largely disappear. When he removes the goggles, he sees fringes of a complementary color and lines having a reverse curvature.



TEST FIGURE shows how colors are differentially shifted by a prism. When viewed through a prism with base to the right, the greater shift of the green image leaves a thin black void at the color boundary (*see bottom illustration on opposite page*). When the prism is turned around, green overlaps red, producing a thin white border. An eye with prismatic defects will see similar effects.



COLORED GOGGLES devised by the author create a blue-tinted world when the wearer looks to the left and a yellow-tinted world when he looks to the right. If the goggles are worn for several weeks, the eye adapts and the color distortions tend to disappear. Somehow the visual system learns to introduce the proper correction according to whether the eyes are turned to the left or right.



Rays entering at an oblique angle are bent more than rays entering at a right angle. Consequently straight lines appear curved, right angles seem to be acute or obtuse and distances seem to be expanded or foreshortened [*see illustrations on page 300*].

To a subject wearing prism goggles these assorted distortions produce a visual world whose appearance changes drastically as he turns his head. One of our subjects reported that it is "as if the world were made of rubber." When the head is turned to right or left, objects become broader or narrower, producing a "concertina" effect. When the head is moved up or down, objects seem to slant first one way, then the other. We have called this the rocking-chair effect.

Although the distortions arising from prism movement are severe, they might present the eye with a straightforward adaptation problem if the prism were held in rigid alignment with the central axis of the eye. In this case the rays reaching any particular area of the retina would always be deflected by the same amount and would therefore maintain a fixed angular relationship to rays striking adjacent retinal areas. Such a rigid relationship between prism and eye could be achieved if the prism could be worn as a contact lens resting directly on the cornea.

In the Erismann and Gibson experiments, however, as well as in our more recent ones, there is a small distance between the eye and the prism. As a result the eye can, and frequently does, move with respect to the glasses. Two kinds of relative motion arise. In one case the eye can be fixed on a given object while the head and goggles move. In the second case the head and goggles remain fixed while the eye moves. If one analyzes the geometry of the rays striking the retina, one finds that the adaptation problem is much more severe than if the prism and the eye could be held in rigid relationship. Let us consider a single retinal area, for example the important small region called the fovea, near the center of the retina, where the eye has its maximum acuity. The images reaching the fovea will be distorted more when the eye is looking obliquely through the prism than they will be when it is looking straight ahead. In fact, the distortion changes with every change in the angle that the axis of the eye makes in relation to the prism.

COLOR-STEREO EFFECT refers to a visual phenomenon in which colors appear to be located at different depths, according to wavelength. It is a special case of color displacement. The reader should be able to obtain the effect by looking at the opposite page with the outer half of each eye shielded with a card, as shown in the drawing on the next page. Blue and green squares should appear to float above those of other colors; red should seem farthest away.

In the accounts of his experiments Gibson neglected the free mobility of the eyes with respect to the glasses. Since his experiments were of short duration it is not clear how much adaptation took place among his subjects. He refers specifically only to adaptation to color fringes and to the curvature of lines. The latter is often called the Gibson effect.

In our much longer experiments, which extended the investigations begun by Erismann, a finely differentiated adaptation can be observed. Like Gibson's subjects, ours adapt rather quickly to color fringes and line curvature. We refer to these as constant distortions because they are essentially independent of head and eye movement. After wearing prism goggles for several weeks, however, our subjects also adapt to the more complex variable distortions, which are generated partly by movement of the head and goggles and partly by movement of the eyes behind the goggles.

I should like to stress the distinction between constant and variable distortions. Adaptation to the latter category apparently involves a process more complex than all previously known processes of visual adaptation. Let us suppose that the subject is provided with goggles that have prisms whose bases point to the right. When, at the start of the experiment, the subject turns his head to the left and glances to the right, he sees an image that contracts in its horizontal dimensions. Conversely, when he turns his head to the right and glances to the left, he sees an expanding image. After several weeks, however, an adaptation occurs that counteracts both of these forms of distortion. This process of double adaptation tends ultimately to eliminate the concertina effect. What seems so remarkable is that this takes place in spite of the fact that the fovea and other retinal areas have been exposed to a random mixture of these variable images. Somehow the visual system has learned a general rule: a contracted image must be expanded and an expanded image must be contracted, depending on the respective position of head and eyes.

If, after weeks or months, the subject is allowed to remove his goggles, the adaptation continues to operate when he views the normal world. The result is an apparent squeezing of images when he glances one way and an expansion when he glances the other. It is as if he were looking for the first time through prisms that have an orientation exactly opposite to those he has been wearing for so long. Moreover, all the other distortions, such as the rocking-chair effect, to which his eyes have slowly become adapted now appear in reverse when the goggles are removed. These aftereffects in their turn diminish in strength over a period of days, and the subject finally sees the stable world he used to know.

Both adaptation and aftereffects are vividly reported by our subjects. But in addition we have built devices that provide an objective measurement of the phenomena. These devices, for example, present the subject with a variety of horizontal and vertical lines that he can adjust in orientation and curvature until they look "right." Another device allows the subject to look through prisms and select the one with the strength appropriate to cancel the aftereffects induced by wearing prism goggles.

Let us now consider the adaptation to the color fringes a prism produces. If a prism with base to the right is placed before the eye and one looks at a white card on a black background, one sees a blue border along the left vertical edge of the card and a yellow-orange border along the right edge. The explanation is that the various colors of light reflected from the card and carrying its image no longer overlap precisely after passing through the prism. The result is a whole series of slightly offset colored images: yellow to left of red, green to left of yellow and blue to left of green. Across most of the area of the white card the multiplicity of colored images is not apparent because the various colors recombine to form white light. But at the left edge, where the card meets the black background, the blue image, which is shifted farthest to the left, can be seen as a blue border. Similarly, the red image appears along the right edge. (When the prism is weak, the right border looks yellow or orange rather than red because red and yellow lie so close together in the spectrum.

If one views the world through goggles with their prism bases fixed in the same direction, the rainbow fringes diminish rather quickly in intensity and within a few days virtually disappear. Here again, as a result of adaptation, a complementary aftereffect appears when the glasses are removed. The adaptation that has canceled the blue fringe on objects produces a yellowish fringe and vice versa. This complementary aftereffect, which we call the rainbow phantom, can appear after goggles have been worn for less than a day.

At first consideration the rainbow phantom may not seem surprising. Everyone is familiar with the complementary afterimage that can be induced by staring for about 20 seconds at a brightly colored pattern. Evidently the retinal elements that have been intensively exposed to a given color change in some manner, so that when they are subsequently stimulated by a neutral light, they produce a different signal from adjacent elements that are still fresh. In accordance with the work of the German psychologist Ewald Hering, we ascribe such phenomena to a process of self-regulation. The sensory response becomes shifted in such a way as to make a persisting color stimulus appear more and more neutral. As a result a second color stimulus that had previously seemed neutral now appears shifted along the spectrum; for example, toward the blue-green if the first stimulus was red.

The puzzling aspect of the rainbow phantom is that blue and yellow are themselves complementary colors. Moreover, the small foveal area, which provides most of the eye's sensitivity to color, is randomly exposed to both yellow and blue stimuli during prism-goggle experiments. Consequently the response of the fovea should become equally modified to both colors, and since each is the complement of the other their aftereffects should cancel.

Nevertheless, the rainbow adaptation and its aftereffect, the rainbow phantom, do take place. How can they be explained? As in the case of adaptation to variable distortions of geometry, we must evidently assume a similar kind of multiple (at least double) adaptation for color vision also. The two aspects are the distortion itself and the context or situation in which the distortion occurs. I have already indicated that adaptation to the concertina effect requires the visual system to learn that images contract when one looks in one direction and expand when one looks in the other. In the case of color fringing the distortion is related to a brightness gradient. The subject looking at the world through prisms that have their bases facing to the right unconsciously learns a new rule: The boundary between a dark field on the left and a light field on the right always has a fringe of blue; when the dark field lies to the right of the light field, the fringe is always yellow. We must assume that the total adaptation process requires simultaneous adjustment to these two conditions. The rainbow phantom, which appears when the goggles are removed, can then be explained as a direct consequence of the complex adaptation process.

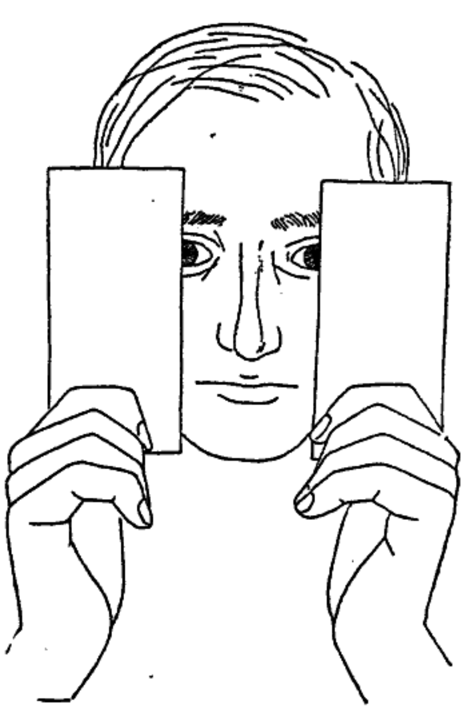
Once we had arrived at this explanatory concept, we undertook a further exploration of "situational color adaptation." For this purpose we designed goggles in which each lens was made up of two differently colored half-segments. For example, each lens might be half blue and half yellow [*see bottom illustration on page 301*]. Wearing such goggles, a subject sees a blue-tinted world when he looks to the left and a yellow-tinted world when he looks to the right. If the two colors are complementary, the situation is somewhat analogous to the rainbow effect of prism goggles. The difference is that the colors are related not to a brightness gradient but to specific positions of the head and eyes; in other words, to a "kinesthetic" gradient.

The experimental results were in accord with those obtained with prism goggles. As before, we found that the visual system adapts to complementary color stimuli so long as the colors are invariably associated with a particular situation—in this case, particular head-and-eye positions. The illustrations on pages 306 and 307 show the results of measuring color adaptation on the first day and on the 60th day of an experiment with blue-yellow glasses. The measurements are obtained through the use of an illuminated window whose color can be varied by turning a dial. The subject first looks at the window through the yellow half of his glasses and turns the dial until the window appears white or neutral in color. To achieve this condition the window must actually be made somewhat blue. The amount of blue light required is automatically recorded. The subject then readjusts the color of the window while looking through the blue half of his glasses. Finally he views the window without glasses, with his eyes turned first to the right and then to the left.

When the subject eventually removes his two-color goggles after wearing them continuously for 60 days, there is no doubt that his visual world is tinged distinctly yellow when he looks in the direction that his goggles had been blue and blue in the direction that his goggles had been yellow. The movement of the eyes, either to right or left, seems to act as a signal for the foveal area to switch over in its color response, compensating for a yellow image in one case and a blue image in the other.

At this point in our investigations everything seemed reasonably clear, but suddenly a new and mystifying phenomenon appeared, the implications of which have not yet been fully explored. During our prism experiments we had also constructed glasses in which the prisms in front of each eye were mounted with their bases pointed in opposite directions. Similar glasses are regularly prescribed by ophthalmologists to correct strabismus, also known as squinting. People with strabismus are unable to focus both eyes on the same object because the eyes turn either inward or outward; crossed eyes are an example. Ophthalmologists are often reluctant to prescribe corrective prism glasses for strabismus because of their concern that the patient may be disturbed by the distortions and color fringes that such glasses produce.

It was partly this prejudice that prompted our experiments. Because our subjects did not have strabismus they



COLORS ACQUIRE DEPTH if viewed with the eyes partially covered by two cards *(left)*, which exploit the chromatic aber-

found the wearing of "squint glasses" difficult until they learned to squint; that is, to turn their eyes either inward or outward, depending on the orientation of the prisms. We found, nevertheless, that adaptation is possible and that it occurs just as rapidly as it does with our usual prismatic goggles.

Our interest, however, was soon drawn to some special effects produced by squint glasses. Because the prism bases face in opposite directions, the glasses create novel stereoscopic effects in addition to those normally seen in binocular vision. The stereoscopic effects involve geometric figures and, more important, colors. If one looks at a vertical rod with prism glasses of the type described earlier, the rod will seem to bend either to the left or to the right, depending on which way the prism bases face. If the same rod is viewed with squint glasses equipped with prism bases facing outward, the rod will appear to be bent away from the observer. Similarly, plane surfaces will look concave.

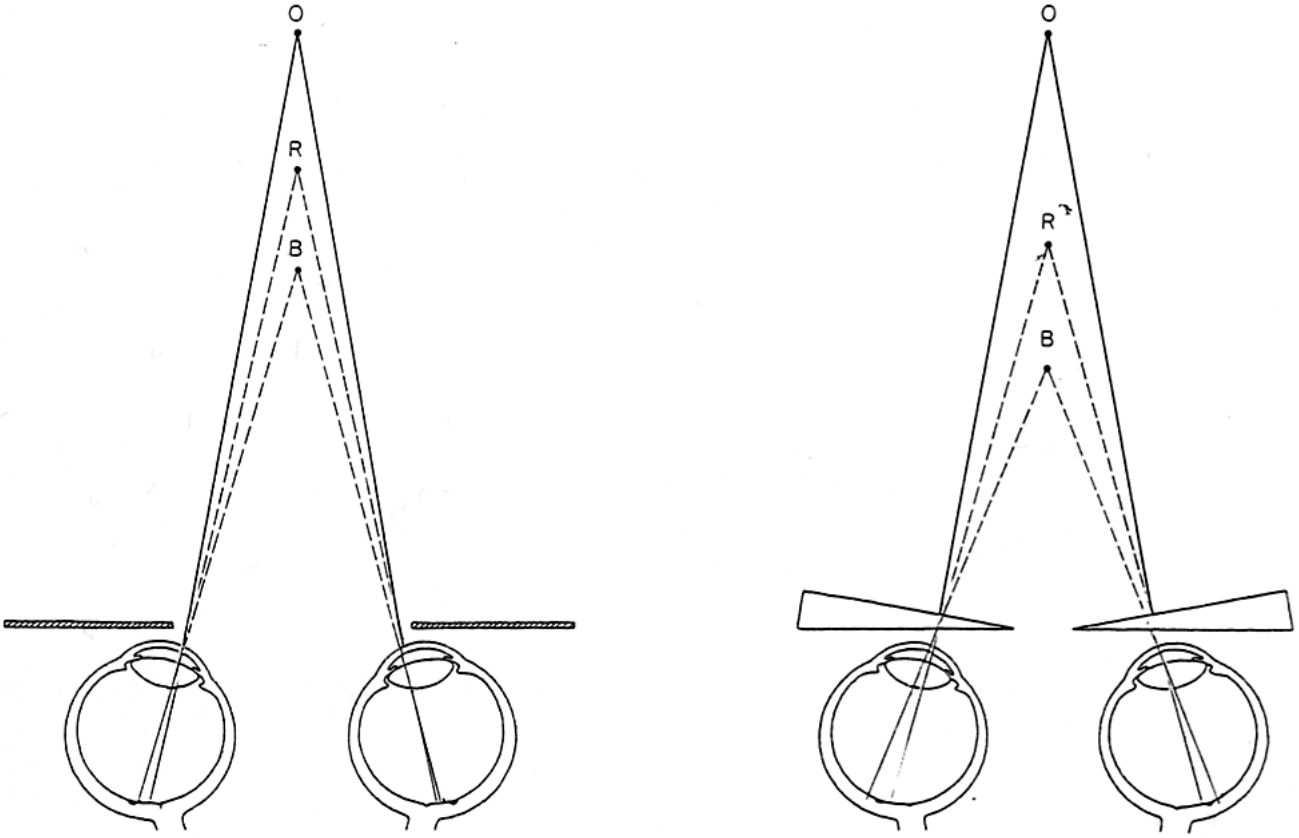
But it was the stereoscopic effects involving color that took us most by surprise. On September 10, 1952, the first day of an extended experiment with squint glasses, one of our subjects described his discovery as follows.

"In the course of a trip through town, I made the following peculiar observations: multicolored posters, traffic signs, people wearing multicolored clothes, and so on, did not appear as before to lie in one plane, but blue seemed to protrude far beyond the object plane, whereas red seemed to recede, depending on whether the background was bright or dark. A woman carrying a red bag slung over her back seemed to be transparent, and the bag to be inside her, somewhere near her stomach.... Most peculiar was a woman wearing a red blouse. She had no upper body, and the red blouse seemed to be following her about a pace behind, moving its empty sleeves in rhythm with the movement of her arms."

After explaining to ourselves this "color-stereo" effect, we were impatient to learn whether or not the subject's eyes would ultimately adapt and restore colored objects to their proper place. The explanation is not difficult. Each prism deflects colors differentially according to wavelength but in opposite directions since the prism bases are in opposition. When the bases face outward, the blues are deflected outward more than other colors and the eyes must actually converge more to bring blue images into focus than to focus red images, which are deflected less by the two prisms. As a result, blue images seem closer to the observer than red images, and images in other colors seem to lie somewhere between the two, according to wavelength [*see illustration below*].

Again we were surprised by the outcome of the experiment. We have discovered that there is not the slightest adaptation to the color-stereo effect. This was true even in our longest test, in which a subject wore squint glasses for 52 days.

The reader can see the color-stereo effect for himself by viewing the illustration on page 302. Although the effect is more vivid with two prisms, or even one, it can be observed by making use of the chromatic aberration present in the normal eye. The procedure was described almost a century ago by the German physicist Hermann von Helmholtz. One covers the outer half of each

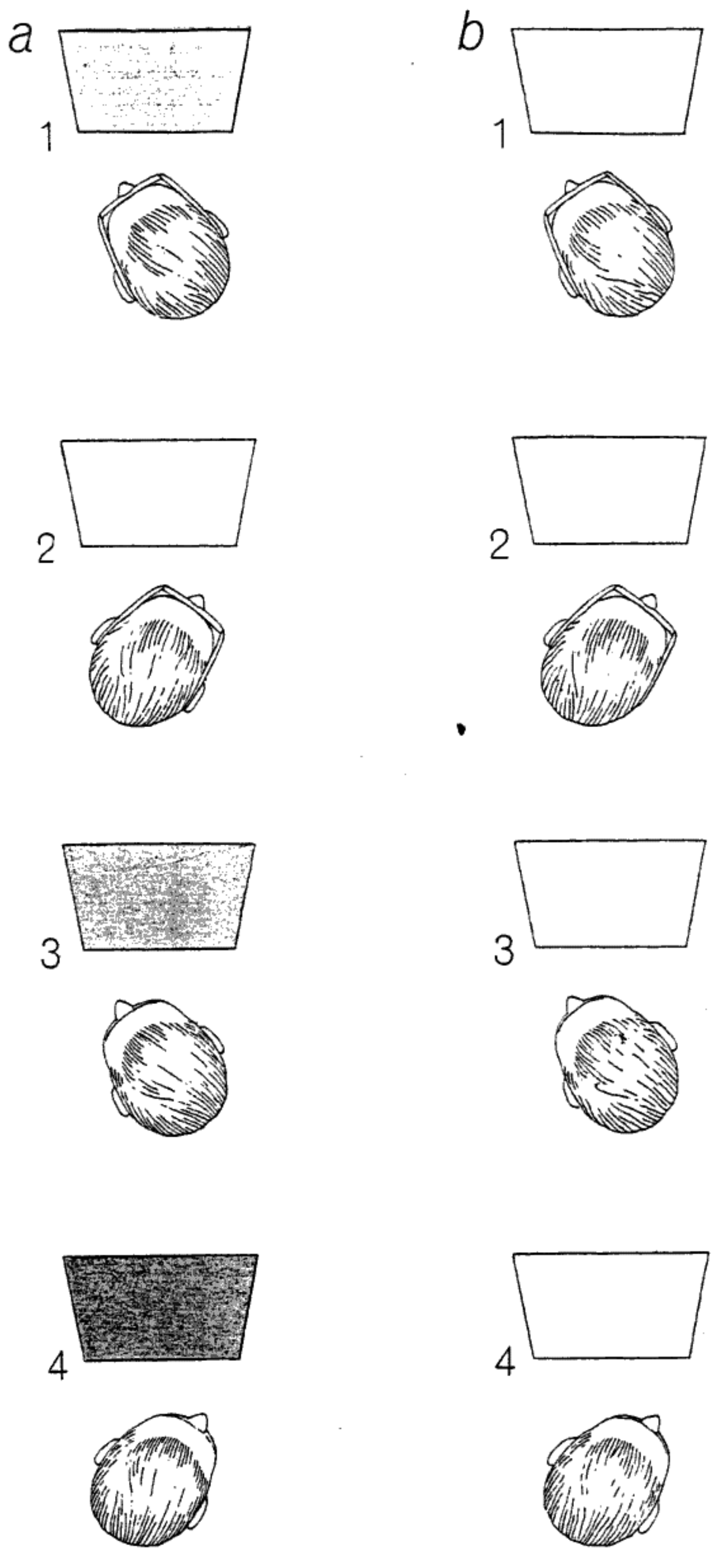


ration of the eye and simulate the effect of looking through prisms whose bases are opposed. The stereo effect works best when strong colors appear against a black background, as on page 302. If light originating at *O* is blue (B), it is bent more than red light (R) in passing through the shielded eye *(center)* or a prism *(right)*. The displacement makes the colors appear to be at different depths.

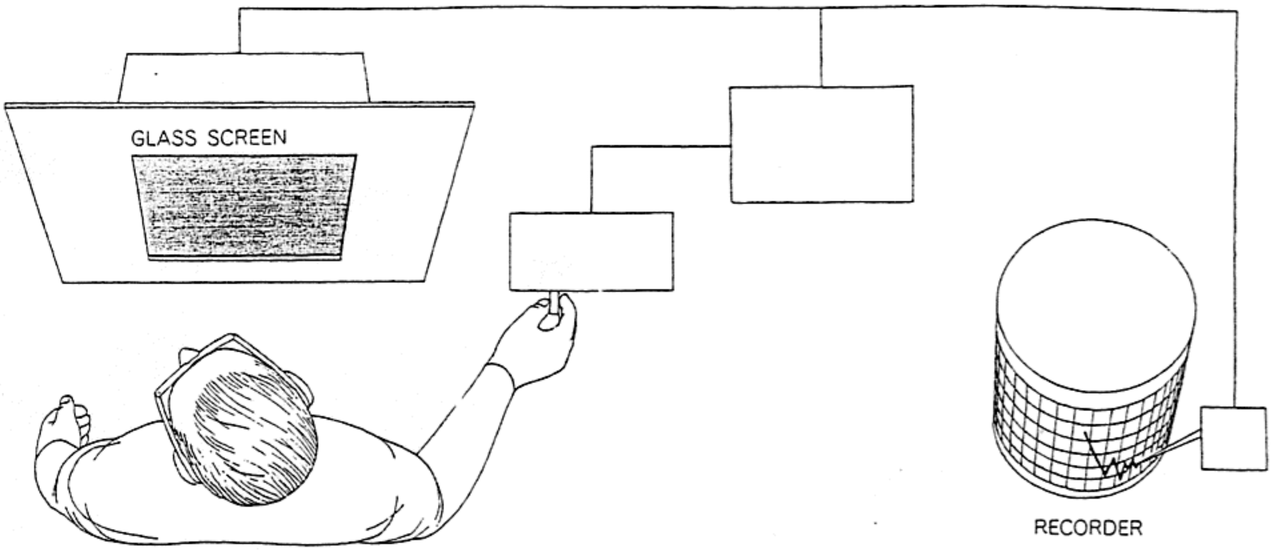
pupil, using two fingers or two pieces of paper. With the outer half of each lens covered, light passes only through the inner halves, which act as if they were prisms with bases facing outward. If the inner halves of the two lenses are covered, a reverse stereo effect takes place and red objects look closer than blue ones. (The reverse effect is difficult to obtain with prisms because it is hard to force the eyes to diverge enough when the bases of the prisms face inward.)

In a small percentage of people the prismatic defects of the eye are large enough so that they can obtain a color-stereo effect even without prisms or the use of Helmholtz' procedure. A sensitive check for such defects can be made with the help of the green-red figure in the middle of page 301. The figure is to be viewed with each eye separately. To a normal eye the green and red halves of the figure meet cleanly, without any noticeable peculiarity. A defective eye, however, will see either a thin black line or a thin white line where the two colors meet. A black line indicates that the green area is being displaced slightly farther to the left than the red, as it would be by a prism having its base to the right. A white line indicates that the green is being deflected to the right as by a prism with base to the left. When the green shifts to the right, it overlaps the red image, and the combination of green and red reflected light creates a white boundary. People with prismatic defects of the eye have a certain advantage over people with normal eyes, for they can differentiate colors not only by hue but also by the color-stereo effect.

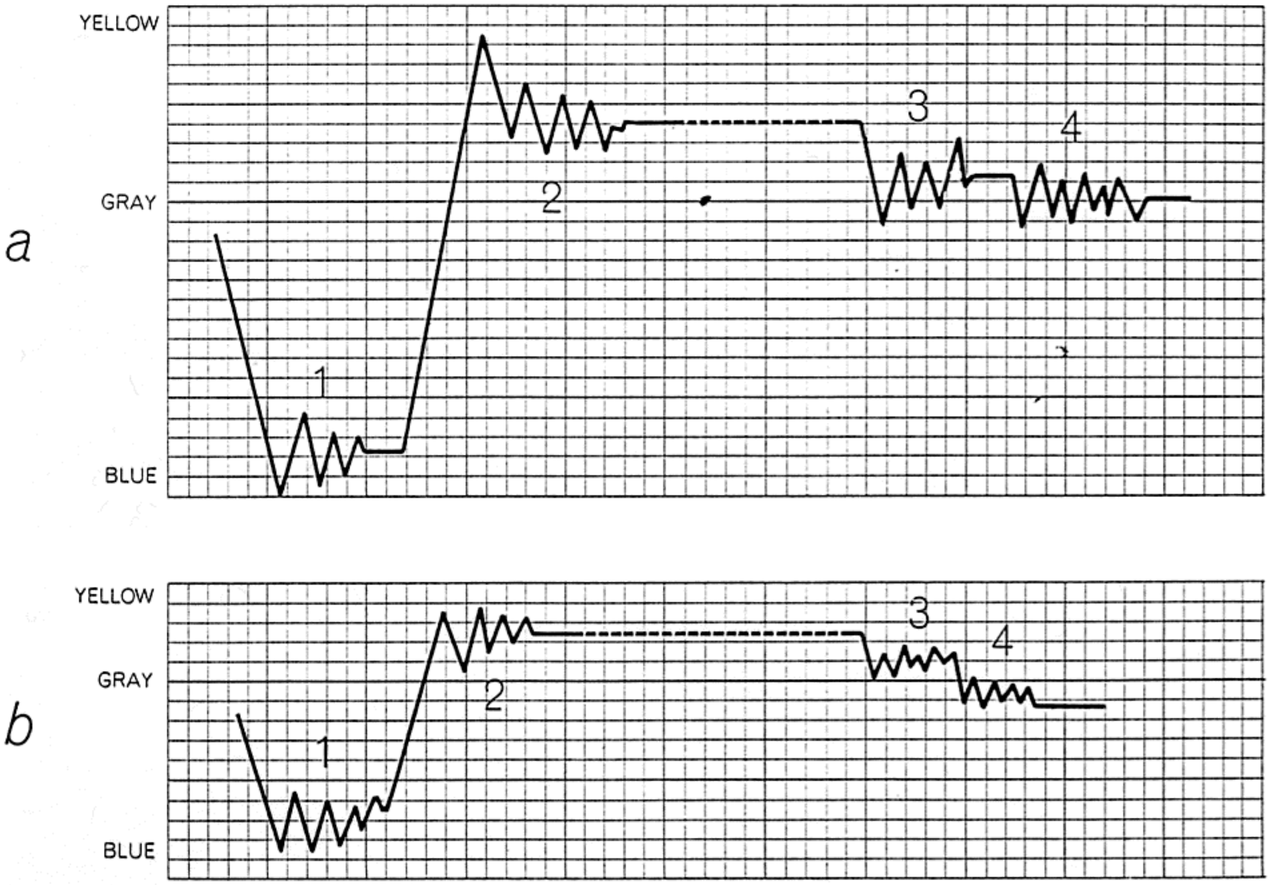
Although it may not be immediately obvious, the color-stereo effect does not depend on the ability of the eye to see color. Like a prism, the lens of the eye bends light according to wavelength regardless of the hue we have come to associate with any particular wavelength. For example, if one photographed the colored pattern on page 302 in black and white using a stereoscopic camera equipped with a suitably oriented prism in front of each lens, one would obtain two pictures that would look three-dimensional when viewed through a stereoscope. The colored squares of the pattern would appear in various shades of gray, lying at various depths according to the wavelength of the original colors. It follows from this that one could enable a color-blind person to discriminate colors by providing him with prism glasses. He could be taught, for example, that the green in a traffic light will look closer to him than



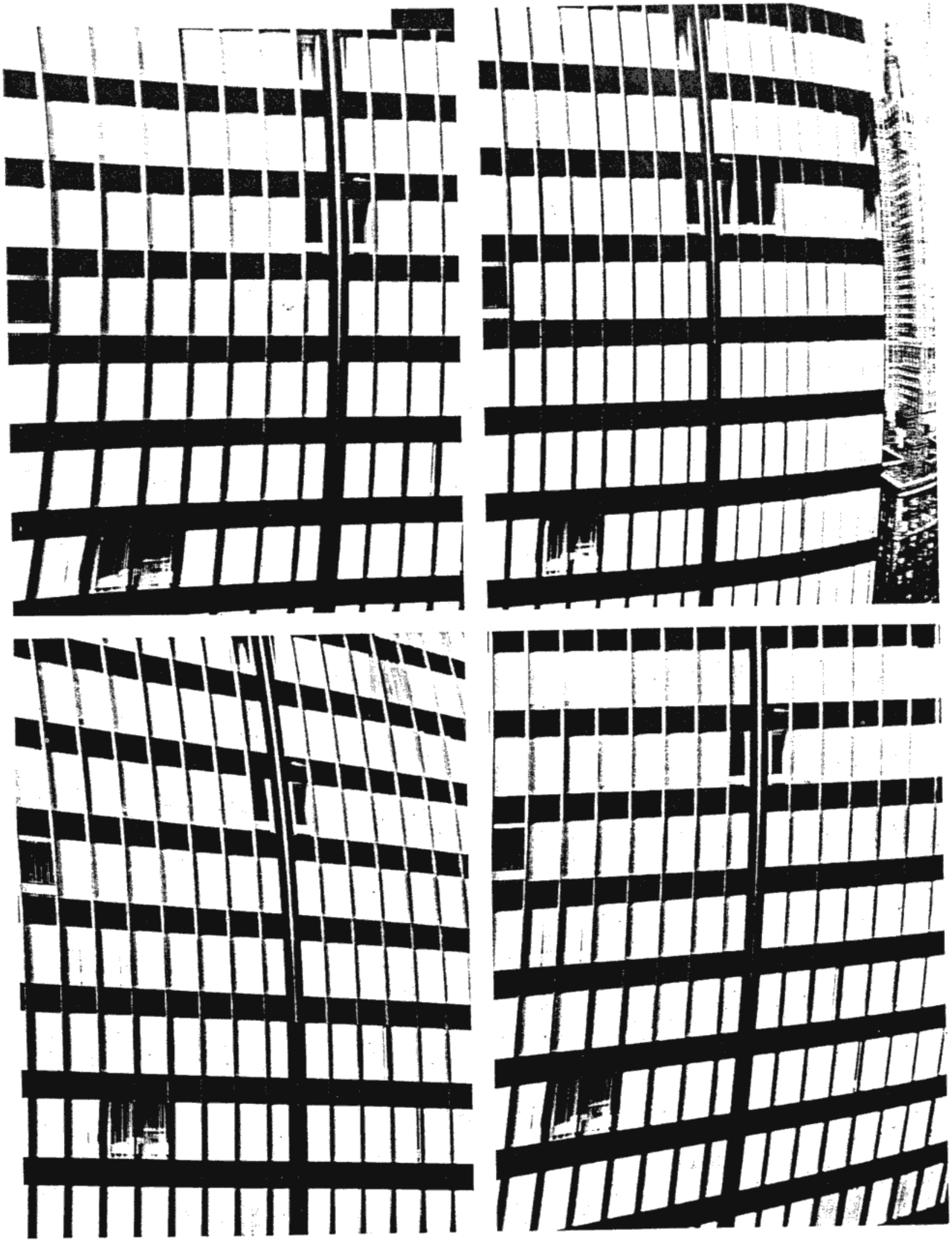
EXPERIMENTS WITH COLORED GOGGLES determine the adaptation to a split-color field, blue on the left, yellow on the right. On the first day of the experiment (*a*) the subject adjusts the color of a glass screen (*see top illustration on opposite page*) until it looks neutral through the yellow half of the goggles (*1*), the blue half (*2*) and with goggles removed (*3 and 4*). After goggles have been worn 60 days the results are different (*b*).



ADAPTATION-MEASURING DEVICE consists of a glass screen or panel whose color can be adjusted by the test subject. The setting of the color-selection dial is automatically transmitted to a pen recorder *(far right)*. The subject is viewing the window through the yellow half of goggles that are half yellow and half blue, as shown at the bottom of page 302. His task is to make the window look neutral gray in color, which requires, in this case, that it be adjusted to look blue as seen by the normal eye.

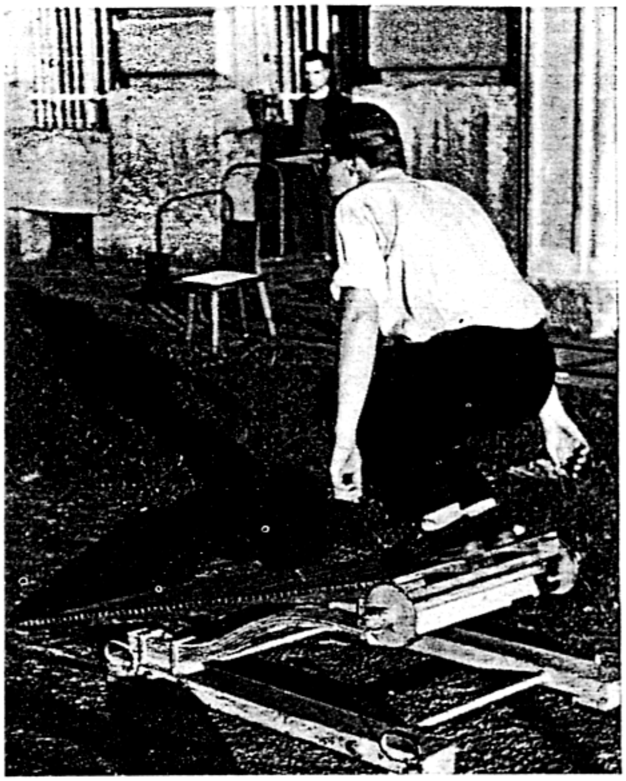


RESULTS OF COLOR-ADAPTATION TEST are shown by chart records made on the first day (*a*) and 60th day (*b*) of the experiment with blue-yellow goggles. On the first day the window of the test apparatus must be made strongly blue (*1*) to compensate for the yellow tint of the goggles and yellow (*2*) to compensate for the blue tine. When the goggles are removed after several hours, the aftereffects are negligible (*3*, *4*). By the 60th day, however, the eye has adapted significantly to the color distortions produced by the goggles (*b1*, *b2*), and when the goggles are removed the complementary aftereffects are significant (*b3*, *b4*).



"RUBBER WORLD" is created by prism goggles. These photographs show what the eye would see through a prism with its base held to the right. If the head is turned to the right while glancing to the left, the image expands toward the left *(top left)*. If head and eye movements are reversed, the image shrinks *(top right)*. If the head is moved up and down, vertical and horizontal lines tilt so as to produce a "rocking chair" effect *(two bottom pictures)*. For an undistorted view of this building see page 301.

REAR-LOOKING "GOGGLES," actually a mirror device, were used in early experiments by Theodor Erismann at the University of Innsbruck. Here Erismann is testing the responses of a subject.



INVERTING GOGGLES, which transposed up and down, were also devised by Erismann. This subject is balancing on a springboard to help relate the upside-down world to his bodily sensations.

yellow and that yellow will look closer than red.

The color-stereo effect may also have general implications for biology. It has always seemed strange that in the eyes of most animals, including man, the fovea lies to one side of the optical axis of the lens system. This lack of alignment may combine with the eye's chromatic aberration to produce prismatic effects that are opposite for the left and right eyes, thereby producing a weak color-stereo effect. When we consider that these defects—off-center fovea and chromatic aberration—have persisted through millions of generations of animals without being "corrected" by evolution, we cannot refrain from speculating that the defects may have functional utility. Perhaps in the development of the vertebrate eye the color-stereo effect provided the first form of color discrimination, the colors being associated not with hue but with subtle differences in the depth of images. As a matter of fact, cats, mice and other animals, which are known to be color-blind, sometimes puzzle psychologists by their apparent ability to distinguish a few strong colors in visual tests. Although this color sensitivity is likely to be demonstrated by only a few animals in any experimental group, the ability cannot be ignored, and the explanation may well be that the unusual animals possess a heightened sensitivity to the color-stereo effect.

My colleague Anton Hajos can be credited with showing, by rigorous measurement, that not the slightest adaptation to the color-stereo effect occurs among subjects wearing squint glasses. He also conceived the idea of intensifying the stereo effect to see if it heightened the sensation of color. To test this idea we were fortunate to find in Innsbruck a man who had lost his color vision as the result of an accident. When he put on a pair of our squint glasses, he reported that he was instantly able to see all the colors he had not seen for years. When he removed the glasses, the colors disappeared again. We are carrying on a further investigation of this and related cases.

What shall we make of the finding that the eye adapts rather readily to various intense distortions of geometry and color but fails totally to adapt to the type of distortion embodied in the color-stereo effect? One possible explanation is that in all cases where adaptation occurs the eye is provided with certain systematic clues as to the nature of the distortion. Straight lines always curve in the same direction; blue or yellow color fringes occur in fixed relation to light-dark boundaries; blue and yellow glasses present the eye with color fields that remain consistently either on the right or on the left; even the rubber world is rubbery in a consistent way. The color-stereo effect, however, presents the visual mechanism with a random and nearly unpredictable assortment of displaced images. As the focus of the eye shifts from one point to another, it is just as likely to encounter one color as another, and, depending on wavelength, brightness and background, the stereoscopic position of the colored image is shifted forward or back. Although the eye might conceivably learn to correlate color and displacement and thereby use the former as a basis for correcting the latter, the task is evidently beyond the power of the eye's adaptation mechanism. There is, however, an alternative possibility: the color-stereo effect may represent a primitive way of identifying colors. The failure of the visual system to adapt to this effect, when presented in exaggerated form by squint glasses, may be evidence that spatial displacement of colors indeed played such an evolutionary role.