from the eye. A slope value was calculated for each subject at each test age. Median slope values and their ranges were then calculated from the group data for each month starting at birth and ending at 4 months of age. The group performance for each month is shown in Fig. 1.

Perfect adjustment to changing target distance would be represented by a slope of 0.00, whereas the complete absence of accommodative change would be indicated by a value of + 1.00. Prior to 1 month of age, the infant's accommodative response did not adjust to changes in target distances. The system appeared to be locked at one focal distance whose median value for the group was 19 cm. This is indicated by a slope value for the group of + 1.00. Occasionally, infants of this age did not remain alert long enough to allow complete calibration of their responses. In these few instances, the magnitude of error was estimated (see Fig. 1). Flexibility of response began at about the middle of the 2nd month and performance comparable to that of the normal adult was attained by the 4th month, as shown by a median slope value of 0.03.

For infants less than 1 month of age it might be assumed that the accommodative system is incapable of any change whatever. We therefore tested 11 sleeping infants, opening their lids in order to take readings. In every case, the lenticular system was relaxed and measured on the average 5 diopters less than when the infant was awake and alert.

During the 2nd month of infancy, the accommodative system began to respond adaptively to change in target distance. By 3 months of age, the median magnitude of hyperopia for targets at 20 cm was 0.75 diopter, a degree of accuracy comparable to the emmetropic (normal) adult. By the time the infants began to look at their own hands and make swiping motions at nearby objects (*6*) their eyes were able to focus sharply on such targets.

Knowledge of the developmental state of the accommodative system is a prerequisite for measuring the limits of visual discrimination in infants, because resolution is limited by the sharpness of the retinal image. Although accurate accommodation is a first step in achieving clear vision, there is not a simple relation between the capacity to focus an image on the retina and the ability to see clearly (visual acuity). Even when the image is optically focused on the retina, visual acuity in the infant is unlikely to be equivalent to that of the adult until the visual receptor mechanisms and neural pathways are sufficiently mature. The results of this study provide a basis for the design of studies of the vision of human infants.

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### References and Notes

1. J. J. Gorman, D. G. Cogan, S. S. Gellis, *Pediatrics* **19**, 1088 (1957); R. L. Fantz, *Science* **140**, 296 (1963); G. Stechler, *ibid.* **144**, 315 (1964); M. Hershenson, *J. Comp. Physiol. Psychol.* **58**, 270 (1964); G. O. Dayton, Jr., M. H. Jones, P. Iau, R. A. Rawson, B. Steele, M. Rose, *Arch. Ophthalmol.* **71**, 865 (1964).
2. F. J. Slataper, *Arch. Ophthalmol.* **43**, 466 (1950); W. S. Duke-Elder, *Textbook of Ophthalmology* (Mosby, St. Louis, 1949), vol. 4.
3. Cited in W. M. Feldman, *Principles of Antenatal and Post-natal Child Physiology, Pure and Applied* (Longmans Green, New York, 1920).
4. J. I. Pascal, *Modern Retinoscopy* (Hatton, London, 1930); H. M. Haynes, *Optom. Wkly.* **51**, 43 (1960).
5. M. B. McGraw, *Neuromuscular Maturation of the Human Infant* (Columbia Univ. Press, New York, 1943); B. C. Ling, *J. Genet. Psychol.* **61**, 277 (1942).
6. B. L. White, P. W. Castle, R. Held, *Child Develop.* **35**, 349 (1964).
7. Supported by grant M-3657 from the National Institute of Mental Health, grant 61-234 from the Foundations' Fund for Research in Psychiatry, and a stipend from the Optometric Extension Program.

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## Adaptation to Prismatically Rotated Visual Fields

Abstract. *The aftereffects of viewing a tilted field of lines differ from the effects of viewing a tilted field of objects. The difference is attributed to the fact that unlike isolated lines, objects have specifiable normal orientations.*

Viewing a field of tilted lines results in a change in the apparent orientation of a field of vertical lines subsequently viewed. Gibson (*1*) showed that the magnitude and direction of this aftereffect is contingent upon the angle of tilt of the inspection lines. When the lines are tilted less than 45° from true vertical, the position of apparent vertical shifts in the direction of tilt of the lines. When the lines are tilted more than 45°, the position of apparent vertical shifts counter to the direction of tilt of the lines. Gibson attributes this change in direction to a change in the axis toward which the tilted lines adapt. When the lines are tilted less than 45° from vertical, adaptation is toward the vertical axis; when more than 45° from vertical, adaptation is toward the horizontal axis. The general rule is that tilted lines adapt toward the axis to which they are closest (*2*).

If the inspection field is composed of tilted objects rather than lines, a different condition prevails. Unlike isolated lines, objects may have "normal" orientations toward one or the other axis (trees and walls are "normally" vertical; streets and floors "normally" horizontal). For our purposes, we consider visual stimuli to be "objects" by virtue of these specifiable orientations or past histories of experienced positions.

This distinction gains significance in the light of a second group of experiments in which the visual world is reversed, displaced, or tilted by means of prisms worn over the eye (*3*). After such prisms are worn, the initially displaced or tilted scene appears more normal. If, for example, tilting prisms are worn, the position of apparent vertical shifts in the direction of tilt of the prism. These studies, then, are similar to those of Gibson's in that for small angles of tilt (the only angles tested), similar directional aftereffects are obtained. They differ from Gibson's in the following ways. In the prism studies, aftereffects are much larger and require, according to some (*4*), active movement of the subject in order to be established. As noted above, they also differ in the kind of visual field used.

In view of these considerations we attempted to determine systematically, with but one method of presenting a tilted field (optically rather than directly), the role of the following: (i) type of inspection field (lines or objects); (ii) degree of inspection tilt (15° or 75° clockwise from vertical); (iii) activity during inspection (walking or sitting). For our object field we chose the corridors and classrooms of a school building. To generate the line field, we mounted luminescent strips of cardboard vertically in an otherwise dark room. Eight university students were tested in each of eight experimental conditions. The order of presentation of the conditions was randomized among the subjects.

We hypothesized that the shifts in the positions of apparent vertical obtained would be congruent with the following assumptions (*5*). With tilted lines, adaptation would take place toward verticality in the 15° condition; toward horizontality in the 75° condition. With tilted objects, adaptation would always take place so as to right the field—that is, no difference in direction would be obtained between the 15° and 75° conditions.

A large circular protractor with degree markings lighted from behind was suspended in an otherwise dark room. Subjects wearing prisms were given the task of determining the marking line on the protractor which appeared vertical just prior and subsequent to each inspection condition. Inspection periods were 15 minutes long. Monocular vision was used throughout. Two 2.5-cm right-angle prisms were mounted over the right eye. The left eye was occluded.

The results, presented in Fig. 1 (*6*), are in accord with our hypotheses. Each point represents the mean change in the position in space considered vertical after exposure, from that considered vertical before exposure. When lines were presented, inspection of the 15° and 75° tilts yielded aftereffects in opposite directions (*1, 2, 7*). When objects were presented, inspection of the 15° and 75° tilts yielded aftereffects in the same direction. Analysis of variance indicates that walking while viewing significantly enhanced the aftereffects when object fields were viewed, but not when line fields were viewed.

We conclude that with object fields, the field gradually rights itself. The greater the tilt, the greater the aftereffect. But with line fields, lines tilted off the horizontal appear to become more nearly horizontal and lines tilted off the vertical appear to become more nearly vertical. Critical to this argument are the results obtained after exposure to fields tilted 45°.

According to Gibson, aftereffects should not be obtained after exposure to a visual field tilted 45°, since the tilt of such a field is equidistant from the vertical and horizontal norms. In general, we agree concerning line fields but disagree concerning object fields.

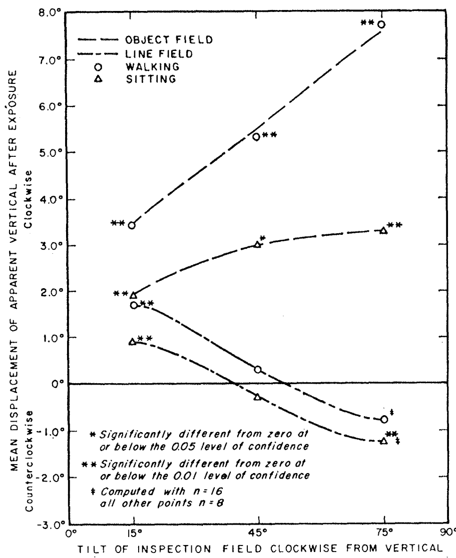


Fig. 1. Mean displacements of apparent vertical after exposure of subjects to clockwise tilts of the exposure field.

At 45°, with a line field there should be little or no aftereffect; with an object field, there should be a large aftereffect in the direction of the imposed tilt. To test these predictions, we repeated the experiment using 45° tilts. Because variability had been somewhat high in the 75° condition in experiment 1, this condition was retested. There were thus six conditions in experiment 2. A new group of eight university students were tested according to the same general procedures used in experiment 1. There was one difference in the apparatus. Partially masked Lumiline bulbs rather than luminescent strips were used to generate the line field.

The results, shown in Fig. 1, are again in accord with our hypotheses. There were no significant aftereffects when 45° lines were presented. The aftereffect of viewing objects at 45° angles were significantly different from zero and were in the predicted direction.

In their monograph on "Figural After-Effects," Köhler and Wallach tried to reinterpret Gibson's adaptation studies within satiation theory (*8*). One of Gibson's findings—that as the angle between the inspection line and a vertical test line increases, the direction of the aftereffect reverses—could not be so interpreted. According to satiation theory, as the angle increases, the aftereffect should first increase and then slowly decrease (the "distance paradox") but not reverse direction. Köhler and Wallach noted, however, that in order to obtain this reversed direction effect, Gibson had used a reduction-like situation in which the inspection and test lines were the only contours visible. They hypothesized, therefore, that the effect might belong to the category of what they termed "normalization effects." By this term they referred to the change in the apparent orientation of rich visual fields which have been tilted or turned by mirrors or prisms (*9*). Our results indicate that for small angles of tilt the direction (if not magnitude) of aftereffects subsequent to the inspection of tilted lines is indeed similar to that subsequent to the inspection of a visually rich field. The results indicate further, however, that the similarity breaks down when greater angles are used, since the effects after viewing line fields reverse direction, while the effects after viewing object fields do not. Our findings then are not congruent with the Köhler-Wallach analysis.

Thus, we tentatively maintain that the difference between line and object fields, which determines such divergent effects, is that objects have meaning—a history of preferred positions—which is lacking in lines.


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**References and Notes**


1. J. J. Gibson, *J. Exptl. Psychol.* **20**, 553 (1937).
2. The angle at which the shift of direction occurs is actually slightly more or less than 45°, depending upon whether testing is done at the vertical or horizontal axis. For discussion of this point, see R. B. Morant and J. R. Harris, *Am. J. Psychol.*, in press.
3. Reviews of these experiments can be found in K. U. Smith and W. M. Smith, *Perception and Motion* (Saunders, Philadelphia, 1962); J. G. Taylor, *The Behavioral Basis of Perception* (Yale Univ. Press, New Haven, Conn., 1962); S. Ohwaki, *Am. J. Psychol.* **64**, 3 (1961); H. Mikaelian and R. Held, *ibid.* **77**, 257 (1964).
4. R. Held, *Percept. Motor Skills* **16**, 764 (1963).
5. The role of movement in adaptation is particularly complex and cannot be discussed here. See C. E. Harris, *Science* **140**, 812 (1963); H. Wallach, J. H. Kravits, J. Lindauer, *Am. J. Psychol.* **76**, 568 (1963).
6. Results are also presented for 45° tilts; *N* for the 75° line field tilts is 16 rather than 8 (see experiment 2).
7. These results are comparable with those reported by Gibson (*1*) and Morant and Harris (*2*) after exposure to non-optically tilted line fields.
8. W. Köhler and H. Wallach, *Proc. Am. Phil. Soc.* **88**, 269 (1944).
9. M. Wertheimer, *Z. Psychol.* **61**, 161 (1912); G. G. Brown, *Brit. J. Psychol.* **19**, 117 (1928); H. Kleint, *Z. Psychol.* **138**, 1 (1936).


10. This investigation was supported by research grant M-3658 from the National Institute of Mental Health.

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