out to a diameter of 5 mm or more. A stimulus of large area and low intensity, such as an annulus, was found to be much more effective in eliciting a response from the outer part than a stimulus of small area and high intensity, such as a spot. These investigators generally used spots as stimuli; hence it is not surprising that they did not discover the outer part of the receptive field.

Wagner, MacNichol, and Wolbarsht showed that the response to red light was obtained from a smaller area than the response to green light in what I have called the inner part of the receptive field, and my results confirmed this. Consequently, they referred to a center and a periphery. In this report I suggest a new terminology—namely, red center, red periphery and green center, green periphery, the green center always being as large, or larger, than the red center. In this new terminology, the periphery of Wagner, MacNichol, and Wolbarsht is an area that is in the center for green, but in the periphery for red.

The fact that the center for green is larger than the center for red explains in part why the response to a green surround contained a weak "on" component, as shown on line 7 of Fig. 1. Scattered light was also a factor here, as it was in the response to a red surround, shown on line 3 of Fig. 1 (*8*). Thus the cells are not quite the simultaneous color-contrast detectors that theory would suggest. Nevertheless, they are appropriately organized to mediate the behavioral response that fish have been shown to give when faced with a contrast of colors.

Recent work has shown that cells with a similar organization are found in the monkey cortex (*12*). Other comments suggest that such cells may also exist in the monkey lateral geniculate (*13*) and the carp retina (*14*). Hence, the type of organization of the receptive field described in this report for ganglion cells of the goldfish retina may be much more common than had previously been thought.

NIGEL W. DAW*
Thomas C. Jenkins Department of Biophysics, Johns Hopkins University, Baltimore, Maryland 21218

References and Notes

1. C. H. Graham, N. R. Bartlett, J. L. Brown, Y. Hsia, C. G. Mueller, L. A. Riggs, *Vision and Visual Perception* (Wiley, New York, 1965).
2. K. Herter, *Biol. Zentr.* **69**, 283 (1950); G. L. Walls, *The Vertebrate Eye* (Hafner, New York, 1963); G. Revesz, *Z. Psychol. Physiol. Sinnesorgane I* **87**, 130 (1921).
3. H. G. Wagner, E. F. MacNichol, Jr., M. L. Wolbarsht, *J. Opt. Soc. Amer.* **53**, 66 (1963).
4. T. N. Wiesel and D. H. Hubel, *J. Neurophysiol.* **29**, 1115 (1966).
5. C. Michael, *Science* **152**, 1094 (1966).
6. E. F. MacNichol, Jr., and G. Svaetichin, *Amer. J. Ophthalmol.* **46**, 26 (1958).
7. M. L. Wolbarsht, E. F. MacNichol, Jr., H. G. Wagner, *Science* **132**, 1309 (1960).
8. N. W. Daw, thesis, Johns Hopkins Univ., Baltimore, Md. (1967).
9. F. Ratliff, *Mach Bands: Quantitative Studies on Neural Networks in the Retina* (Holden-Day, San Francisco, 1965).
10. N. W. Daw, *Nature* **203**, 215 (1964).
11. M. L. Wolbarsht, H. G. Wagner, E. F. MacNichol, Jr., in *The Visual System: Neurophysiology and Psychophysics*, R. Jung and H. Kornhuber, Eds. (Springer, Berlin, 1961), p. 170; H. G. Wagner, E. F. MacNichol, Jr., M. L. Wolbarsht, *J. Opt. Soc. Amer.* **53**, 66 (1963).
12. D. H. Hubel and T. N. Wiesel, in preparation.
13. R. L. De Valois, *Vision Research Reports* (Nat. Acad. Sci.–Nat. Res. Counc., Washington, D.C., Publ. No. 835, 1960).
14. K. Motokawa, E. Yamashita, T. Ogawa, *Tohoku J. Exp. Med.* **71**, 261 (1960).

15. Supported by NIH grants NB 03582 and 5-T1-GM-716, NSF grant GB 2705, and NIH predoctoral fellowship 5-T1-GM-29, 827. I thank Dr. Edward F. MacNichol, Jr., for use of his equipment and for support and encouragement during the work.

* Present address: Department of Physiology, Harvard Medical School, Boston, Mass.

4 August 1967

Visual Form Discrimination after Removal of the Visual Cortex in Cats

Abstract. *Adult cats were trained to discriminate between erect and inverted triangles after simultaneous ablation of cortical areas 17, 18, and most of 19 of both hemispheres. Postoperative training proceeded through a graded series of similar triangle pairs in which the members of each pair were equated for luminous flux.*

Earlier studies investigating the function of the striate area of the cerebral cortex by Lashley (*1*), Klüver (*2*), and Smith (*3*) supported the general conclusion that this area of the brain is essential in mammals for performance of visual pattern or form discriminations. Recent work by Meyer (*4*) and by Wetzel *et al.* (*5*) has tended to confirm this conclusion with regard to the adult cat. However, evidence that some striate-decorticate animals can learn to discriminate form has appeared consistently within the studies reporting generally negative results. Data reported by Lashley (*1*, pp. 453–454), Smith (*3*, p. 262), Meyer (*4*), and Wetzel *et al.* (*5*) indicated that, from the group with lesions, one or more animals in each study had mastered the discrimination in the time allotted. Since the majority of lesioned animals did not reach the performance criterion in this period, the exceptional animals were merely described as such.

In 1961 Doty (*6*) presented evidence that adult striate-decorticate cats could discriminate triangles from circles as readily as normal controls. In his work, however, cortical ablation had been carried out on the animals as neonates. In addition, recent work on the primitive primate *Tupaia glis* indicates that removal of its striate cortex has no effect on its visually guided behavior in general or on its ability to discriminate between erect and inverted triangles (*7*).

With these indications that the striate area might not be essential for form discriminations, I reinvestigated this problem in the naive adult cat, giving special attention to three procedural variables: (i) the size of the brain lesion, (ii) the length of postoperative training, and (iii) the method of presentation of the stimuli.

The experimental handling of the first two of these variables by Smith (*3*), Meyer (*4*), and Wetzel *et al.* (*5*) imposes qualifications on specific conclusions which can be drawn from these investigations concerning the functional role of the striate cortex. First, all of these studies involved lesions of the neocortex which extended well beyond the striate area (area 17) and, in fact, well beyond the visual cortex [areas 17, 18, and 19 as defined histologically for the cat by Otsuka and Hassler (*8*)]. Second, arbitrary limits were set for the length of postoperative training. Therefore, the present study was designed to determine whether adult cats (i) with lesions limited to the anatomically defined visual cortex, and (ii) given extended postoperative training, could reach a high level of performance on a visual form discrimination.

The third and perhaps most important aspect of the procedure was the stimuli to be used. The choice of stimuli and method of their presentation during training were influenced by the desirability of working with stimuli and training apparatus comparable to those used in previous investigations of form discrimination. Accordingly, animals were trained to discriminate conventionally used visual forms, in this case triangles, through experience with a graded series of related stimuli, as illustrated in Fig. 1. The triangles in each discrimination pair were of equal area and they were equally transilluminated so that the total luminous flux (intensity of light × area) of the positive stimulus was always the same as that of the negative stimulus.

The subjects reported here were five adult female cats. Lesions were made with routine sterile surgical procedures in animals anesthetized with sodium pentobarbital administered intraperitoneally. The lateral and posterolateral gyri were removed in one stage by subpial aspiration, and the animals were allowed a 4-week recovery period before postoperative training was initiated.

Four of the five animals had received preoperative training, either on the same series of stimuli used postoperatively (animals S-8, S-11, and S-12), or on a related series of stimuli (animal R-1). One cat (S-6) had no preoperative training of any kind.

Animals were trained 40 trials per day, 5 or 6 days a week, in an apparatus similar to that used by Sperry for pattern discrimination training (*9*, Fig. 3). The apparatus used in this study differed from Sperry's primarily in that a 30-inch (76-cm) alleyway separated the start box from the stimulus goal doors, and the food compartments were enclosed. The cat learned to push open with its head the door bearing the "correct" stimulus in order to retrieve a piece of raw beef spleen. Immediate correction of an incorrect choice was allowed and no punishment was administered. On days of training, the meat obtained in the course of these discrimination trials constituted the animal's entire food ration.

The apparatus was housed in a darkened testing room and stimuli appeared as simultaneously presented translucent isosceles triangles, diffusely illuminated from the rear. As noted above, the luminous flux of the correct stimulus equaled that of the incorrect stimulus at all times. Auditory, olfactory, and individual stimulus-panel cues were also controlled.

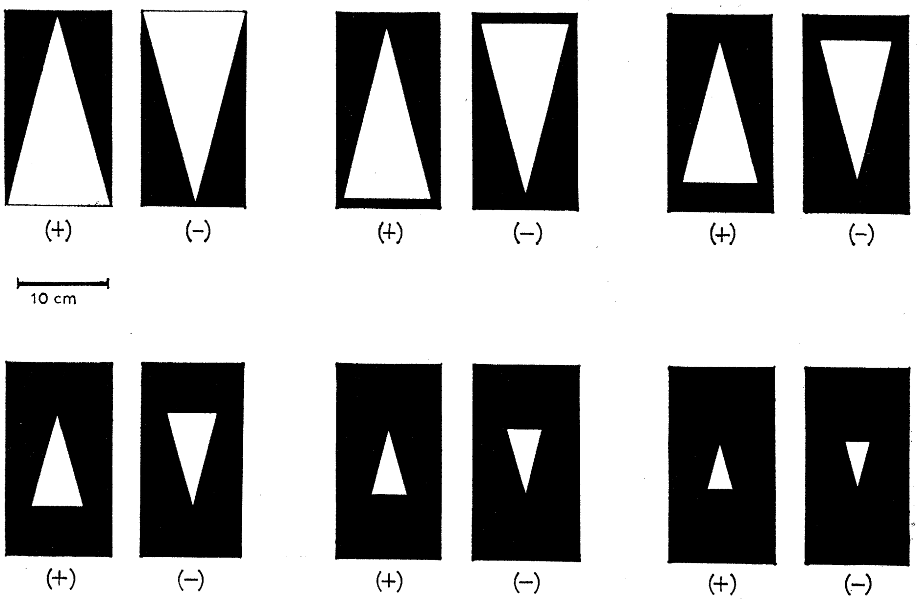

Fig. 1. Stimuli to scale. Each of the six pairs of stimuli was mastered to criterion sequentially (in the order largest to smallest) by the lesioned cats.

Training was begun with the largest pair of triangles in the stimulus series. The stimuli were randomly alternated from right to left. When the cat's performance reached a criterion of 90 percent correct responses for each of three consecutive daily sessions on this large pair of triangles, the next smaller size was introduced. This procedure was repeated for each stimulus pair until the entire series had been mastered to the required criterion. Figure 2 shows the numbers of trials necessary for the animals to learn each step of this series of discrimination problems to the established criterion. Generalization of learning along the stimulus size continuum illustrated here will not be considered in this report, in which mastery of the smaller triangles in the series is the principal interest.

None of the animals with which I have worked has been unable to learn this discrimination, with the partial exception of cat S-11. This cat achieved criterion on the first five triangle pairs

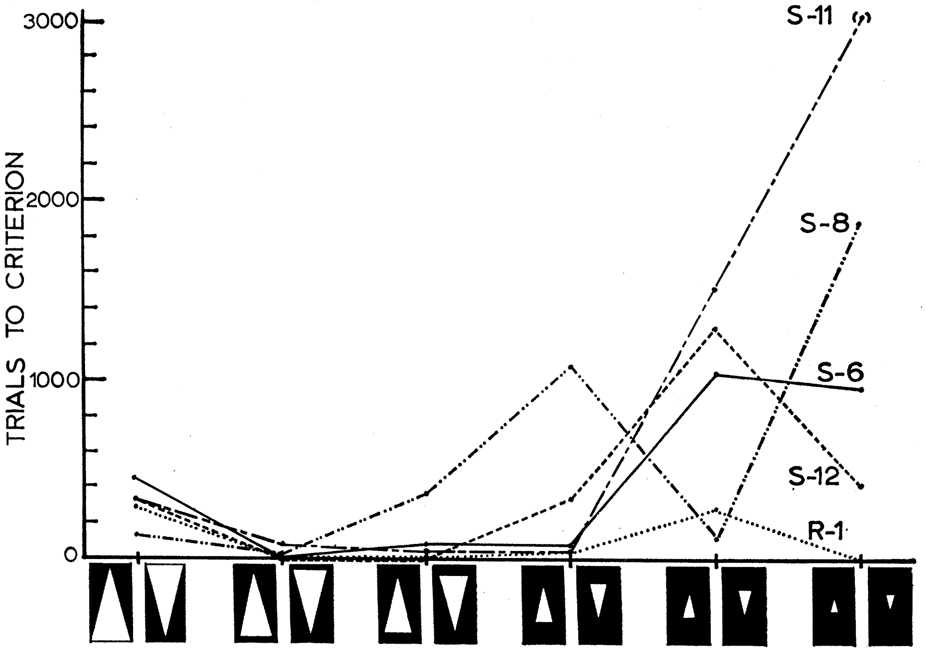

Fig. 2. Number of trials required by each lesioned animal to reach criterion (exclusive of 120 required trials constituting criterion) on each successive step of the discrimination series.

in the indicated numbers of trials. Training on the sixth (smallest) pair was terminated after 3000 trials, within which period this animal had performed at 90 percent or better on several individual days but never on three consecutive days.

To date, the lesions of animals S-6 and R-1 have been evaluated histologically. These cats had survived postoperatively for 16 and 12 months, respectively. In both animals removal of the lateral and posterolateral gyri was complete into the depths of the adjacent sulci. The dorsal lateral geniculate nuclei showed profound retrograde degeneration with gliosis in all laminae. Scattered normal-appearing neurons were seen throughout the nuclei, confirming the observations of previous investigators. The lesion of cat S-11 is complete, as revealed by gross examination. Animals S-8 and S-12 are still alive; the lesions in these animals were judged complete at the time of operation.

This study shows that adult cats can be trained in a conventional apparatus to discriminate between an erect and an inverted triangle at a high level of performance after removal of cortical areas 17, 18, and most of 19. Discrimination of figures such as these has in the past constituted evidence for the ability to discriminate visual forms. It should be noted, however, that although the total luminous flux was equated for the positive and negative stimuli, differences in the spatial distribution of flux between members of each pair were present throughout the series. This difference in the distribution of flux between erect and inverted triangles may be significant to these results since adult visual-decorticate cats can perform a discrimination based on differences in total luminous flux between two stimuli (*10*). To what extent the mastery of this discrimination represents a conceptual response to form per se (that is, triangularity of the stimulus in these studies) must therefore await further studies of the discrimination capacities of these animals.

The results presented here indicate that information about the spatial distribution of light, within areas equated for the total amount of light, can be utilized to direct purposeful behavior by areas of the brain other than cortical areas 17, 18, and most of 19. A clue as to the location of such other areas may be provided by recent evidence for "extrastriate" projections of the dorsal lateral geniculate nucleus of the cat.

As noted above, complete removal of the lateral and posterolateral gyri does not result in complete degeneration of the cells of the dorsal lateral geniculate nucleus ($\mathrm{LGN_d}$). Evidence that a portion of these remaining cells project directly to the suprasylvian and ectosylvian gyri has been presented by Glickstein *et al.* (*11*), who demonstrated Nauta-stained degenerating fibers terminating in these gyri (entirely outside visual areas 17, 18, and 19) after discrete lesions in the $\mathrm{LGN_d}$ of cats.

In light of both our behavioral evidence (following removal of the visual area) and the anatomical evidence cited supporting projections of the $\mathrm{LGN_d}$ to cortex other than the visual areas, it is reasonable to suggest that the results of earlier behavioral studies indicated a severe deficit in visual form discrimination not because the striate cortex (area 17) alone is capable of mediating such a discrimination, but because the lesions made in those studies removed all of the cortical projections of the $\mathrm{LGN_d}$, to both striate and widely distributed extrastriate areas. In the present study, confinement of the lesioned area, the unlimited length of training, and training through a graded series of stimuli may all be significant determinants of the results, which show that the histologically defined striate cortex is not essential in the cat for mastery of a visual discrimination based on the spatial organization of light.

SARAH S. WINANS

Department of Anatomy,
Cornell University Medical College,
New York 10021

References and Notes

1. K. S. Lashley, *J. Comp. Neurol.* **53**, 419 (1931).
2. H. Klüver, *J. Psychol.* **11**, 23 (1941).
3. K. U. Smith, *J. Genet. Psychol.* **53**, 251 (1938).
4. P. M. Mever, *J. Comp. Physiol. Psychol.* **56**, 397 (1963).
5. A. B. Wetzel, V. E. Thompson, J. A. Horel, P. M. Meyer, *Psychonomic Sci.* **3**, 381 (1965).
6. R. W. Doty, *Neurophysiologie und Psychophysik des Visuellen Systems* (Springer-Verlag, Berlin, 1961), pp. 228–246.
7. M. Snyder, W. C. Hall, I. T. Diamond, *Psychonomic Sci.* **6**, 243 (1966).
8. R. Otsuka and R. Hassler, *Arch. Psychiat. Nervenkrankh.* **203**, 212 (1962).
9. R. W. Sperry, *Science* **133**, 1749 (1961).
10. M. W. Fischman and T. H. Meikle, Jr., *J. Comp. Physiol. Psychol.* **59**, 193 (1965); P. Schilder, *J. Neurophysiol.* **29**, 888 (1966).
11. M. Glickstein, R. A. King, J. Miller, M. Berkley, *J. Comp. Neurol.* **130**, 55 (1967).
12. I thank T. H. Meikle, Jr., for his guidance in this research and in preparation of the manuscript. This investigation was supported by PHS grants 5-F1-GM-25,037-03 and NB-04974 from NIH.

15 August 1967

Sky-Hook: Old Idea

I would like to make a few more observations on the "sky-hook" (*1*). In 1895, the Russian pioneer of astronautics Konstantin Tsiolkovski first considered the possibility of an object's withdrawing from the earth with the aid of a rigid structure ("tower") that would extend upward at right angles to the earth's surface (*2*).

Tsiolkovski wrote: "On the tower, as one ascends it, gravity decreases gradually, and if . . . erected on the equator, then gravity will decrease not only due to removal from the planet's center but also due to the proportionally increasing centrifugal force . . . On climbing such a tower to a height of 34,000 versts [1 verst = 1.07 km], gravity will disappear, while still higher there will again appear a force that will increase proportionally to removal from the critical point, but acting in the opposite direction . . ." Thus Tsiolkovski outlined the basic scheme for the cosmic lift.

A height of 36,000 km is that required for a stationary satellite; the force of gravity is equal to the centrifugal force and the orbital time is equal to the period of axial rotation of the earth. In 1960, the Leningrad engineer Y. N. Artsutanov presented an idea similar to that of "Tsiolkovski's tower," giving it a different design and mechanical embodiment (*3*).

Artsutanov began with a 36,000-km stationary satellite. Extending straight up and down from the satellite are lengths of cable. The lower end of the cable is secured to the earth's surface. The whole system—stationary satellite and upper and lower cables—forms an integral unit and rotates at the same angular speed as the earth. The system is constantly taut, for at any point above 36,000 km, the centrifugal force exceeds the force of gravity. The upper end does not need to be anchored. It would be hung, as it were, on a "sky-hook."

Artsutanov's paper also deals with the strength of the cable. Obviously, the tension experienced by the cable is extremely great. More importantly, the tension of the cable would be greater at points closer to the stationary satellite. This means that a cable of variable diameter could be used, thin at the earth's surface, and gradually thicker toward the satellite. Further upward it could again be thinner. Artsutanov calculated that a cable weighing 1 g/meter and