1955 55

Reprinted from THE JOURNAL OF COMPARATIVE AND PHYSIOLOGICAL PSYCHOLOGY
Vol. 48, No. 6, December, 1955 *Printed in U.S.A.*

# PATTERN PERCEPTION FOLLOWING INSERTION OF MICA PLATES INTO VISUAL CORTEX[1]

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Electrical field concepts of cerebral integration have not found support in earlier experimental tests in which functional organization has been observed to be but little disturbed by extensive radial slicing of the cortex or by short-circuiting of the cortical currents with implanted pins and wires of gold, tantalum, and stainless steel (2, 3, 4). However, it has not been unanimously agreed that either knife cuts or metallic inserts produce sufficient distortion of direct current flow in the cortex to make the findings definitive in so far as the electric field hypothesis is concerned. It seemed that a more effective test could be obtained by inserting into the cortex numerous plates of a dielectric material. With the cortical currents forced to detour around a series of dielectric barriers, gross distortion of their normal patterning would be inevitable. This latter approach was employed in the present study. Small plates of mica were implanted into the visual and surrounding cortex in cats, and the functional effects were tested subsequently on a battery of trained, visual form discriminations.

## METHOD

### *Animals*

Six cats were used, all of them cage-reared in the laboratory from an age of seven weeks or younger. At the start of the experiment they ranged in age from six to ten months, and previously had had no experience with any sort of formal learning. They were maintained in open wire cages (approximately 60 by 75 by 90 cm.).

### *Preoperative Training*

The cats were taught to perform a series of pattern or contour discriminations by methods described earlier (4). Training was carried out in a darkened discrimination box in which the translucent patterns to be discriminated were presented in two swinging doors at the end of the box which the cats pushed open with their heads. A correct choice allowed access to a morsel of food; an incorrect choice activated an electric buzzer. The cats were trained to discriminate an equilateral triangle from any of a series of imperfect triangles of similar dimensions arranged on a scale in which the critical difference was gradually reduced, as shown in Figure 1. Simultaneous paired presentation of positive and negative patterns was used with cats *Slp*, *Whs*, *Nsy*, and *Sst*. With cases *Nbr* and *Clv* individual successive presentation was employed as described below.

As a rule 30 to 50 trials were run per day, all on the same kind of negative pattern. The daily sessions were started with 1 to 5 runs on each of the simpler stages of the pattern already mastered and proceeded to more difficult stages as rapidly as learning permitted. The most difficult or "top" negative figure that could be discriminated was determined prior to operation for each type of negative pattern. The discrimination habits were stabilized by overtraining approximately 400 trials on figures of intermediate and high difficulty. The training and overtraining schedules were interrupted erratically and extended over prolonged periods totaling 5 to 18 months.

### *Surgery*

The cats were anesthetized with veterinary Nembutal (intraperitoneal injection of 38 mg. per kg. body weight). The skull was opened on both sides and across the mid-line with a dental crown saw and rongeurs until a wide bilateral exposure of the visual cortex was achieved. Small plates of mica (0.02 to 0.04 mm. thick, 2 to 4 mm. wide, 3 to 20 mm. long, and slightly pointed at one end to facilitate insertion) were then pushed into the visual region in the over-all patterns shown in Figure 2. The mica was inserted through short slits in the pia that were cut in advance with a fine steel knife. The majority of plates were individually trimmed in length and width at the time of insertion to suit the locus of implantation. An attempt was made to avoid interrupting the optic radiations as much as possible by placing the deeper insertions in a plane parallel with the radiation fibers. The larger blood vessels on the surface were avoided, but there was extensive hemorrhage in many instances from large unseen vessels running deep in the fissures. The dura was replaced over the implants and fastened with fine silk sutures. A median bridge of the skull plate 1.5 to 2.0 cm. wide was reinserted over the saggital sinus and fastened firmly with tantalum sutures. Penicillin (procaine G, 300,000 units) was injected intramuscularly at the start of the operation and on the following four days.

### *Postoperative Testing*

Fifteen to 27 days were allowed for recovery from the surgery. The tests were started with figures that

[1] This investigation was aided by the F. P. Hixon Fund of the California Institute of Technology and by a grant from the Southern California Society for Mental Hygiene.

was made to confine the mica implants to the gray matter, avoiding damage to the underlying white matter as much as possible, particularly in the critical area of central vision.

*Slp* was nearly blind on the third day after operation, but vision returned rapidly during the following week until on day 12 it seemed nearly normal to casual observation. Postoperative testing was started on the fifteenth day after operation. In the first 20 trials on each figure, *Slp* discriminated all its most difficult test figures except A4 and E4. In a second 20 trials on these latter patterns, *S* succeeded with A3 and E3.

*Implants Invading White Matter*

After observing the high-level postoperative performance of the first case, we proceeded to make the implantations more drastic. The over-all pattern of inserts was much the same, but larger numbers of mica plates were implanted, and they were inserted deeper. The resultant invasion of the white matter along with the additional cortical damage in the remaining four experimental cases produced a moderate to severe impairment of vision that persisted beyond the early ten-day period of edema and inflammation. Improvement in vision was fairly rapid during the first weeks after operation, tending to taper off gradually thereafter to a final level that varied with the severity of cerebral insult. All the remaining cases were trained and tested in an improved discrimination box with the battery of test figures illustrated in Figure 1. The postoperative performances tabulated below include the

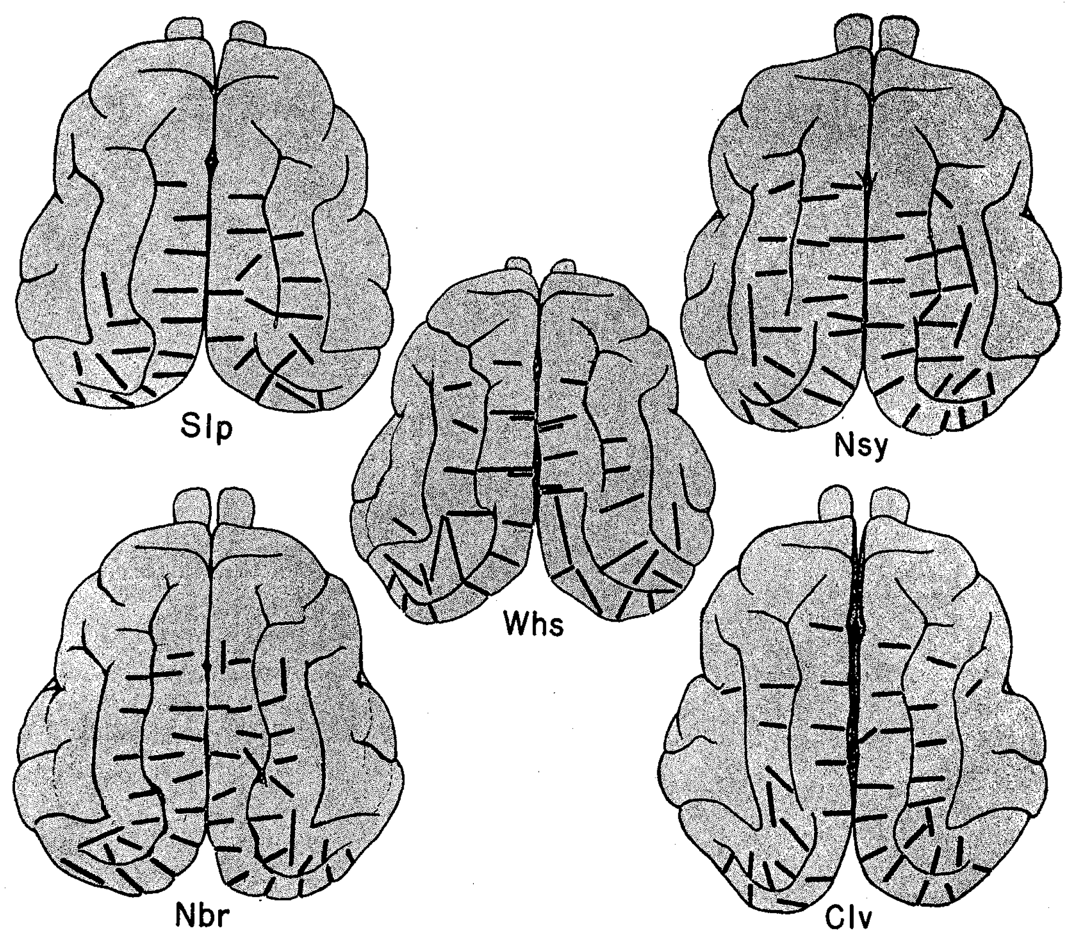


FIG. 2. Distribution of mica implants traced from photographs of fixed brains. Plates along median and posterior border of marginal gyrus go deepest (cf. Fig. 3).

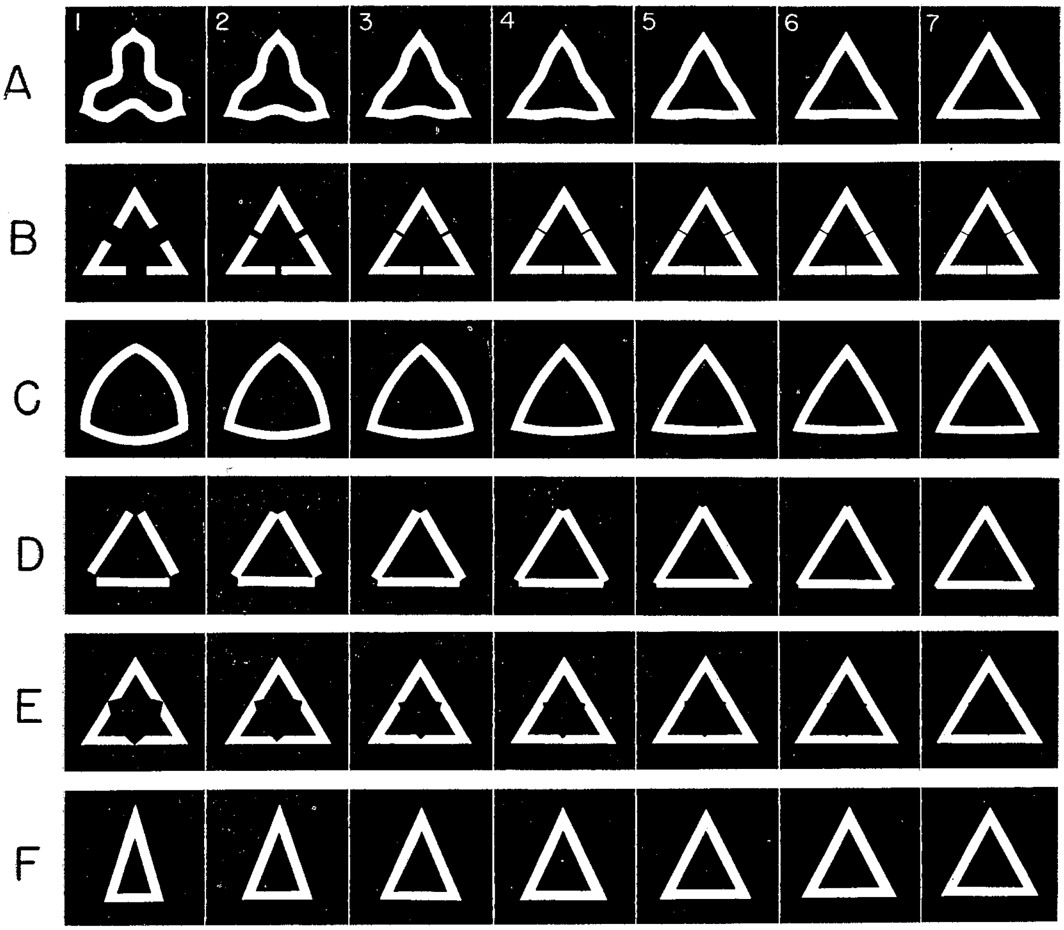


FIG. 1. Test scale of the negative figures reproduced from photostats of original stimulus cards. Positive figure was always an equilateral triangle like B7 without the crosslines.

were arbitrarily selected in each case according to the apparent degree of recovery as judged on the basis of generalized visual behavior. The test figures were then adjusted immediately upward or downward on the scale depending on the performance until the most difficult figure that could be discriminated was determined for each pattern. Only one type of negative pattern was tested on a given day. A performance level of 16 or more correct out of 20 consecutive trials was used as the criterion of discrimination. In all but one case, *Slp*, the postoperative testing extended over periods of three to six and one half months. Tests were carried out at arbitrary intervals during this time with lay-offs not longer than six weeks, an effort being made to keep the tests frequent enough to avoid regressions from loss of memory.

### *Follow-up Examination*

After the brains had been fixed by perfusion with 10 per cent formalin, they were removed, photographed, and X-rayed to record the pattern of mica inserts. The mica pieces were then pulled out and measured. The brains were dissected carefully to assess better the extent of the damage and degeneration, particularly that in the white matter. The lateral geniculate nuclei were excised, sectioned transversely at 25 mu, and stained with cresyl violet to determine the amount of retrograde degeneration caused by interruption of the optic radiation fibers.

## OBSERVATIONS AND RESULTS

### *Mica Implants Limited Mainly to Cortical Gray, Case Slp*

This first cat was trained on our earlier test scale (4) to the highest level on A through F with approximately 475 overtraining trials on each top figure. Mica plates were then inserted bilaterally, as shown in Figure 2. An attempt best achievements of the first several days of postoperative testing for each pattern and also the most difficult (top) figures mastered later after recovery had reached a stable level.

*Simultaneous Presentation, Cases Whs and Nsy*

As shown in Tables 1 and 2, *Whs* eventually attained a high level of recovery, mastering most of its top preoperative patterns, whereas *Nsy* did less well. The difference was partly reflected in the amount of brain damage in the two cases, but other factors were involved. *Nsy* had never performed as well as *Whs* even before operation. During surgery, widespread yellowish granulations were noted in the pia-arachnoid of *Nsy*, suggestive of an earlier meningitis. Two weeks after surgery the scalp had to be reopened to drain a suppurative infection which gradually subsided under penicillin treatment. At nine weeks another ulceration broke through the scalp. When the brain was removed 15 weeks after operation, widespread infection was evident under the skin extending into the brain at several points around the mica. Because of the complications in *Nsy*, the performance of *Whs* was regarded as the more informative of the two cases.

TABLE 1
Summary of Case *Whs*

| Preoperative | | | Postoperative | | | |
|---|---|---|---|---|---|---|
| Overtrained | | | Initial Discrimination | | Top Figure Achieved | |
| No. of trials | Fig. | Top fig. achieved | Fig. | Days postop. | Fig. | Days postop. |
| 446 | A4 | A7 | A3 | 27 | A7 | 114 |
| 426 | B6 | B7 | B4 | 35 | B6 | 74 |
| 420 | C6 | C7 | C5 | 32 | C7 | 61 |
| 400 | D6 | D7 | D6 | 42 | D7 | 73 |
| 800 | E6 | E7 | E5 | 47 | E6 | 61 |
| 424 | F6 | F7 | F5 | 34 | F7 | 52 |

TABLE 2
Summary of Case *Nsy*

| Preoperative | | | Postoperative | | | |
|---|---|---|---|---|---|---|
| Overtrained | | | Initial Discrimination | | Top Figure Achieved | |
| No. of trials | Fig. | Top fig. achieved | Fig. | Days postop. | Fig. | Days postop. |
| 410 | A4 | A6 | A1 | 29 | A3 | 64 |
| 190 | B6 | B6 | B1 | 27 | B3 | 80 |
| 205 | C4 | C5 | C2 | 35 | C4 | 72 |
| 420 | D4 | D5 | D1 | 45 | D1 | 45 |
| 325 | E4 | E5 | failed E1 | 48 | E1 | 83 |
| 240 | F4 | F5 | failed F1 | 37 | F2 | 77 |

TABLE 3
Summary of Case *Nbr*

| Preoperative | | | Postoperative | | | |
|---|---|---|---|---|---|---|
| Overtrained | | | Initial Discrimination | | Top Figure Achieved | |
| No. of trials | Fig. | Top fig. achieved | Fig. | Days postop. | Fig. | Days postop. |
| 360 | A3 | A4 | A3 | 22 | A4 | 87 |
| 350 | B5 | B6 | B2 | 20 | B3 | 73 |
| 500 | C4 | C6 | C4 | 23 | C4 | 23 |
| 375 | D2 | D3 | D2 | 24 | D3 | 85 |
| 400 | E3 | E5 | E1 | 27 | E2 | 61 |

TABLE 4
Summary of Case *Clv*

| Preoperative | | | Postoperative | | | |
|---|---|---|---|---|---|---|
| Overtrained | | | Initial Discrimination | | Top Figure Achieved* | |
| No. of trials | Fig. | Top fig. achieved | Fig. | Days postop. | Fig. | Days postop. |
| 445 | A3 | A4 | A1 | 27 | A2 | 125 |
| 660 | B4 | B5 | B2 | 44 | B2 | 44 |
| 675 | C3 | C5 | failed C1 | 41 | C5 | 129 |
| 550 | D2 | D5 | failed D1 | 42 | D3 | 120 |
| 420 | E3 | E5 | failed E1 | 45 | — | — |

* When retrained during the sixth month after operation, and allowed to compare negative and positive figures simultaneously like *Slp*, *Whs*, and *Nsy*, *Clv* successfully discriminated figures A3, B2, C5, D4, and E2.

*Serial Presentation, Cases Nbr and Clv*

The last two cats were trained to perform a more difficult type of discrimination in which only one test figure was presented at a time. The cat had to respond differentially depending on whether the figure shown was the positive equilateral triangle or one of the imperfect negative triangles. Both positive and negative figures were presented in the right door of the training box. When the positive figure appeared, the cat approached it and pushed open the door. When a negative figure was presented, the cat avoided it and went instead to the left door, marked only by a vertical slit of light that remained constant. It was thought that this use of a single figure constituted a somewhat more critical test of possible perceptual distortions. In part it was an answer to an earlier objection (4) that with two figures, both might be distorted and yet still be distinguishable because the positive would be less distorted than the negative.

As seen in the tables, the general level of performance, both pre- and postoperative, was lower throughout on this more difficult task. The F series was abandoned because the training proved too difficult under these conditions. The postoperative performance of *Nbr* was somewhat better than that of *Clv*, and this correlated with the degree of cerebral damage produced by the mica inserts.

*Knife Cuts Without Mica, Control Case Sst*

In a sixth cat deep knife cuts were made in the same general pattern as the mica implants. The cuts went well down into the white matter, simulating the tissue damage produced by the more drastic of the mica implantations. Nothing was inserted into the cuts, the aim being to find out to what extent the functional impairment in the experimental cases might be ascribed to the dielectric properties of the mica and how much to the tissue injury alone. The resultant impairment proved to be as great as in the most severely affected of the experimental group. Trained preoperatively to discriminate A4, B5, C4, and F4, with a minimum of 300 overtraining trials on each, the best *Sst* could do at six weeks after opera-

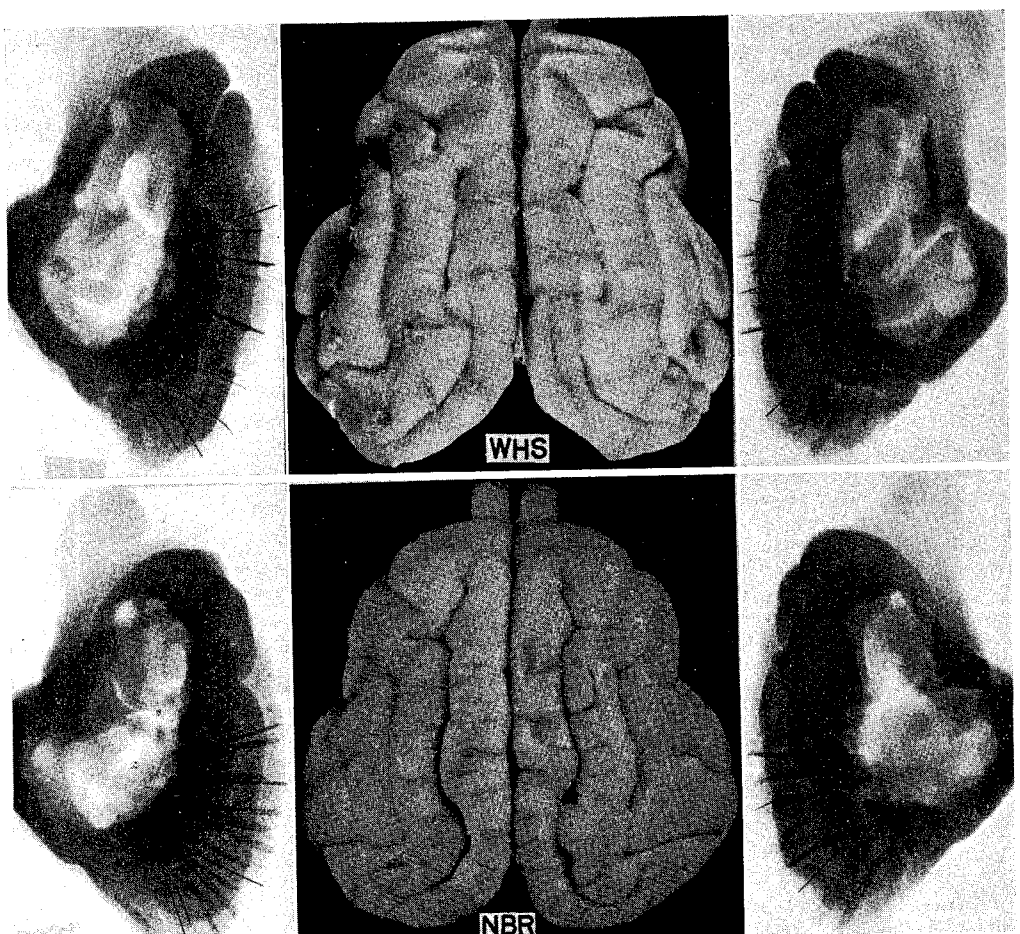


FIG. 3. Surface and X-ray views of fixed brains of *Whs* and *Nbr*. Not all inserted plates are visible at surface. X-ray views show only thicker of mica plates and/or those viewed edgewise.

tion was A1 and F1. It failed repeatedly to make criterion on B1 and C1.

### POST-MORTEM INSPECTION OF BRAINS

The mica plates were found to have survived in good condition in all cases without deterioration or crumbling. In the four cats retained for testing longer than three months after operation the mica implants had become encased in thick connective tissue sheaths that must have further enhanced their current distorting properties. The extent of damage to the cortical gray itself can be estimated roughly from Figures 2 and 3.[2] The nature and general pattern of the cortical lesions was much the same in all cases, and the amount of damage to the cortex was roughly of the same order.

Much greater variation was found in the extent to which the inserts had invaded and damaged the white matter. Invasion of the white was least in *Slp*. The medial portion of the white in the splenial, suprasplenial, and fornicate gyri was divided in *Slp*, and the plates invaded approximately the upper third of the white in the marginal and suprasylvian gyri. In the other four experimental cases, the splenial, suprasplenial, and fornicate gyri were almost completely divided by many of the inserts, and on the lateral surface most of the implants extended all the way to the base of the white in the suprasylvian and marginal gyri. In general the implants went deeper than had been intended—a result of the improvised trimming of the mica plates without close measurement during the surgery. In all cases two or more implants penetrated the lateral ventricle on each side. In *Whs* the two deepest plates on each side pierced the hippocampus. In *Nbr* seven implants had penetrated the ventricle on the left side and three on the right side. When the mica plates were extracted, the degeneration in the surrounding tissue varied from being hardly noticeable to the extent of producing large oval cavities 2 by 3 mm. Among the four cases, damage to the white was least in *Whs* and greatest in *Nsy* and *Clv*.

The geniculate bodies of all cases but *Slp* were sectioned and examined microscopically. They showed varying degrees of degeneration scattered irregularly through the nucleus. Rough estimates of the total percentage of reduction of principal cells in the dorsal nucleus on the side least impaired ranged from around 10 per cent in *Whs* to 20 per cent in *Nbr*, 50 per cent in *Clv*, and 75 per cent in *Nsy*. Fibers to the critical area of central vision appeared to have suffered greatest in cases *Nsy* and *Clv* and were best preserved in *Whs*.

In the control case the invasion of the white matter approached that found in *Nsy* and *Clv*. In particular, the optic radiations on both sides were invaded by cuts in the region for central vision. Correlated with this, extensive degeneration was evident in the lateral geniculate nucleus amounting to roughly 80 to 85 per cent.

### DISCUSSION

The functional effects of mica implantation appeared to reflect throughout the amount of tissue damage incurred rather than the degree or quality of electric current disturbance. The distorting influence on the mass "figural" currents within the cortical gray itself should have been roughly of the same order in all five experimental cases. According to the electric field hypothesis (1), the distortion of relational effects mediated by mass current flow should have been sufficient to cause drastic disruptions of pattern perception. The high-level postoperative performances of *Slp*, *Whs*, and *Nbr* speak strongly against electric field theory as currently conceived.

Although the cortical destruction was roughly similar in the different cases, that to the underlying white matter varied over a considerable range and was correlated with the degree of functional impairment. As in the sensorimotor cortex of the monkey (3), knife cuts entering the white matter tended to have much more severe effects on function than cuts confined to the gray. The poor scores of the control case taken in conjunction with the earlier results on subpial slicing (4) support further the inference that the functional deficits were produced by the tissue lesions per se, particularly those to the white, and not by the dielectric properties of the mica inserts.

Relearning may have been partly responsible for the gradual improvement that followed the initial postoperative performance in the four cases that were tested over a long recovery period. Probably a more important factor was the spontaneous recovery from a state of cerebral depression or shock (diaschisis) produced by the surgical trauma. This is suggested in the observation that improvements continued to take place during lay-off periods when the cats were not being run, particularly during the first six weeks after operation.

The presence of relearning would not in itself invalidate the above conclusions unless the cats had learned to recognize and discriminate illusory distortions produced by the mica. If the distortion of cortical currents had in fact caused corresponding distortions in the perceptual appearance of the stimulus figures as conceived in electric field theory (1), the distortion patterns should have differed markedly for each fixation point of the eyes in looking at the figures. Any single figure would have assumed a different and grossly distorted shape for each new fixation point. Furthermore,

[2] The X-ray pictures were taken by Dr. R. S. Harrison, Huntington Memorial Hospital, Pasadena.

eye and head movements made while viewing the figures should have resulted in a violent writhing, splintering, and shimmering of the test figures. It is difficult to believe that the high-level postoperative discriminations of *Whs* and *Nbr* in particular could have been achieved under such conditions. Moreover, in the case of *Slp* there was no opportunity for relearning.

The results seem best accounted for on the assumption that the mica implants produced (*a*) scotomata of varying size and shape correlated with the location, size, and shape of the lesions, plus (*b*) a generalized and partly reversible traumatic depression of the remaining structures with which the destroyed cells and fibers were associated, and possibly (*c*) certain perceptual disturbances (like micropsia, macropsia, displacements, polyopia) as described by human patients with occipital lobe injuries (5). The cats, like human patients, may have remained largely or entirely unaware of the widely scattered scotomata, and their postoperative perception may have been aided by a tendency for perceived figures to be completed across the blind areas. If the implants produced disturbances that reached awareness as listed under (*c*), these latter were not sufficiently marked to prevent pattern recognition at fairly high levels.

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*Received November 22, 1954.*