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ELECTRICAL STIMULATION OF FRONTAL CORTEX IN MONKEYS DURING LEARNING OF AN ALTERNATION TASK¹

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ESTABLISHMENT of focal epileptoid discharges from isocortical areas results in learning deficit, but does not impair memory of previously learned tasks. The deficit is restricted to those tasks which, as found by ablation studies (4), are correlated with the cortical structures from which discharges are recorded. In experiments with monkeys made epileptoid by the technique of implanting aluminum hydroxide paste, specific learning deficits were obtained on delayed alternation with the focus from lateral frontal cortex (6), on visual discriminations with foci from occipital or from inferotemporal cortex (2, 7), and on somesthetic discriminations with posterior parietal cortical focus (8). However, monkeys which were trained on these tasks before implantation of the alumina cream showed no retention deficits when tested over extended periods after the onset of focal epileptoid discharges.

The evidence obtained from these experiments suggests that the behavioral dissociation of learning and memory is a function of the neuronal mechanisms which initiate epileptoid discharges. However, this hypothesis has not been clearly substantiated because of several limitations inherent in the methodology employed. On the physiological side placement of the irritative material results in small damage to cortical structures, in the formation of scar tissue, and in alterations of size and distribution of underlying nerve cells (1, 6). Behaviorally, comparisons can only be made of performance scores between groups of monkeys made epileptoid before the start and after the completion of training on a task. Consequently, a technique is required which permits the disruption of the ongoing cortical electrical activity during certain predetermined periods in the learning process. Electrical stimulation which can be controlled by the experimenter may satisfy these requirements.

Rosvold and Delgado (5) and Weiskrantz *et al.* (9) investigated the effects of electrical stimulation of frontal lobe structures in monkeys which had been trained to a high criterion on alternation tasks before application of the stimulus. The former authors, using implanted needle electrodes, found no effects on alternation performance from stimulation, whereas Weiskrantz *et al.*, employing surface electrodes, reported complete disruption of alterna-

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tion behavior during stimulation. This discrepancy in results may be related to the placement of electrodes and to the mode of stimulus application, since in both of these experiments electrodes were placed over only small portions of frontal cortex with different locations in each investigation. For the present experiment surface electrodes were designed so that an electric field could be established within the limits of the lateral cortical surface but without direct excitation of cortical or subcortical neurons. This was accomplished by construction of an electrode assembly with multiple stimulation points which, when placed over lateral frontal cortex, permitted excitation of neural structures along the banks of the principal sulcus. This area has been found by ablation studies (3) to be essential to the performance of alternation tasks.

In preliminary experiments, when electrode assemblies were placed over both frontal lobes, it was found that seizure thresholds sometimes differed for the two hemispheres and that excitation spread from the stimulated to the contralateral frontal lobe by commissural pathways. Consequently, in order to obtain more precise control in excitation of cortical neurons monkeys in the main experimental group had one lateral frontal cortex ablated and an electrode assembly placed over the intact hemisphere. Electrical stimulation could then be applied while the experimental subjects were trained on an alternation task. Since prolonged training is required for the acquisition of this task, with gradual improvement seen in performance scores, we could stimulate during some of the training sessions and then assess the effects of stimulation on performance as a function of the degree of prior learning.

Based on the findings with epileptoid monkeys, the hypothesis is suggested that electrical stimulation of frontal cortex affects the rate of acquisition of the alternation task, but does not disturb correct performance after the task has been learned. By applying stimulation after incomplete learning on this task further improvement might be retarded, whereas performance patterns which had already been consolidated would not be affected. Thus, the present hypothesis, which distinguishes between neuronal processes implicated in the acquisition and in the retention of complex tasks, may be extended to include partially learned behavior.

METHOD

Subject. Ten immature, experimentally untrained rhesus monkeys were used. Electrodes for stimulation and recording were implanted chronically over frontal or over occipital cortex. Each electrode assembly consisted of a thin polyethylene sheet which supported eight stainless steel points arranged in two rows with a distance of 8 mm. between adjacent points (Fig. 1). Each electrode point was a sphere of approximately 0.5 mm. in diameter. Wires from the stimulating points were brought together in a cable and soldered to a small female transistor plug.

Surgery for electrode implantation was performed aseptically under Nembutal anesthesia. The skull was opened by drill and rongeur, the dura was cut and the polyethylene sheet placed on the pial surface. For frontal placement the two rows of electrode points straddled the principal sulcus and the posterior pair was over the arcuate sulcus (Fig. 1). For occipital placement the assembly was reversed so the electrode points contacted cortex from approximately the lunate sulcus to the tentorium. The dura was then

sutured over the assembly and the skull opening was covered by stainless steel screen. The cable was brought over the intact skull and the plug was tied with stainless steel wire over the occipital (for frontal electrodes) or the frontal (for occipital electrodes) bone. The skin was sutured in layers so that only the surface of the plug protruded. When frontal cortex was ablated, resection was by subpial suction from the frontal pole to the arcuate sulcus, laterally to the orbital and medially to the medial surface.

Three groups of subjects were tested. In the *Frontal Learning Group* surgery was performed before the start of formal training. Four monkeys had electrode assemblies placed over left frontal cortex and the right frontal cortex ablated during one-stage surgery. Two other subjects in this group had electrode assemblies placed over intact right and left frontal cortex. Two monkeys in the *Frontal Retention Group* had electrode assemblies placed over left frontal cortex and right frontal cortex ablated after they had attained criterion on the alternation task. Two monkeys in the *Occipital Learning Group* had electrodes placed over left and right occipital cortex before the start of formal testing.

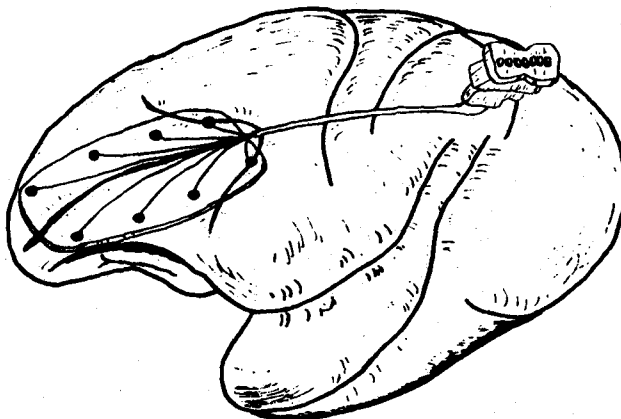


FIG. 1. Sketch showing placement of electrode assembly over left frontal cortex. Polyethylene sheet is placed subdurally and transistor plug is tied to occipital skull.

Testing apparatus. During experimental testing the monkey was seated in a restraining chair which was arranged so that the animal could not reach the electrode plug on its skull or the cable connecting this plug to a terminal board. The monkey's left wrist was attached by a chain to the chair. On the alternation task the monkey faced a vertical panel with two levers placed 6 inches apart horizontally and protruding 0.5 inch in front of the panel. A food cup was directly under each lever. When the monkey pressed either lever with its free hand, both levers retracted for a period of 8 sec. The first press during each testing session was rewarded with a 50 mg. sugar pellet. On subsequent trials the monkey was rewarded when it pressed on the lever opposite to the one last rewarded. For testing of visual pattern discriminations the monkey faced a vertical opaque panel on which two hinged transparent doors were mounted flush with the front of the board. Each door could be pushed slightly open so the monkey could retrieve a peanut reward. Plaques made of diffuse lucite were inserted in grooves on the reverse sides of the doors. On each plaque was pasted a black cloth in which a pattern, consisting of symmetrical straight lines, was cut. The apparatus was operated manually.

Stimulation apparatus. The electrical connections from a terminal board were arranged so that the implanted electrode points could be switched either to the stimulus pulse or to the electroencephalograph. The stimulator generated a square wave pulse of 1 msec. duration and 22 pulses per sec. were generally used. During some stimulations frequencies of 50 pulses per sec. were used, but since the behavioral consequences with this frequency were the same as those obtained with the lower frequency, the 22 pulse per sec. stimulation was employed in order to minimize effects of neuronal damage. The output of the stimulator was connected to the primary coil of an isolation transformer. The

secondary coil was connected to the terminal board. Bipolar stimulation was applied by connecting adjacent points on the electrode assembly (Fig. 1) to opposite poles. (The wire which tied the plug to the skull was grounded.) When monkeys with two electrode assemblies were tested, symmetrical electrode points on the left and the right assembly were connected together. The stimulus pulse was also monitored by a cathode ray oscilloscope. Electrocorticograms were taken with an Offner six-channel Dynograph Recorder.

PROCEDURE

During preliminary training, before implantation of electrodes, the monkeys were gradually adapted to sitting in the restraining chair, picking pellets from the cups, and pressing on a single lever for food reward. Surgery was then performed on the animals in the *Learning Groups* and approximately one week was allowed for recovery from the operation.

Threshold determinations. Convulsive thresholds for all monkeys were then determined by gradually increasing the stimulus strength in steps of 0.7 V. until motor signs indicative of seizure activity were observed. Several threshold determinations were taken, one each day, with reversed polarities on successive days. The thresholds, which differed among subjects, were in the neighborhood of a 12 V. peak of the square wave.

Learning Group. After completion of the determinations for convulsive threshold, training on the alternation task began. Monkeys were tested six days per week, generally 100 trials per session. In agreement with scoring procedures usually employed on alternation tasks in manually operated apparatus, the first response during each session was not scored and each subsequent rewarded response was considered one trial. When the subject pressed on the same lever two or more times successively, it obtained an error score; whereas when it shifted to the opposite lever after a rewarded press, a correct score was given. A *response score* was also computed for each session, as the ratio of correct responses to number of trials, expressed as a percentage.

The subjects were first given from one to four sessions of testing without stimulation. During each stimulation session the stimulus voltage was set at zero for the first 20 trials. The voltage was then set at 60% of convulsive threshold and gradually increased by groupings of 10 trials to 90% of threshold value. When motor signs of seizure activity appeared, testing was terminated. Seizure signs were generally rhythmic shaking of the arm which made it difficult or impossible for the subject to operate the apparatus. Only a few times were generalized seizures observed. Stimulation, applied continuously, usually lasted from 15 to 20 minutes. Electrocorticograms were taken immediately before and after stimulation. On days following stimulation 100 trials were given without stimulation. After a rise in the learning curve of approximately 10% from the last prestimulation level, stimulation was usually applied again. This procedure was followed for the *Frontal* and the *Occipital Learning* groups until the animals attained the criterion of 85 correct alternations in 100 successive trials.

Retention Group. The two monkeys were first trained to criterion on the

alternation task and then had electrodes implanted. One of the subjects from the *Frontal Learning Group* was added to the *Retention Group* for further testing. These three animals were then given a minimum of 500 overtraining trials each before cortical stimulation was applied. Additional overtraining sessions were given, interspersed with periods of stimulation, to a maximum of 1,500 overtraining trials. Because of the behavioral findings, the stimulus voltage was increased until clear motor signs indicative of seizure activity were observed.

Visual discriminations. After they had learned the alternation task the two monkeys with occipital electrodes and one of the frontal subjects were trained on visual pattern discriminations. They were given 50 trials per day with the rewarded pattern placed at the left or the right position on successive trials according to a chance sequence. The initial problem (a discrimination between a dark, *rewarded*, and an illuminated square) was learned without cortical stimulation. The monkeys were then trained to criterion on discriminating a vertical from a horizontal bar and a cross from an outlined square. While they were learning these discriminations, cortical stimulation was applied according to the same procedure as used on the alternation task.

RESULTS

Frontal stimulation during alternation training. Figure 2 presents the learning curve on the alternation task for one subject with ablated right frontal cortex and an implanted electrode assembly over left frontal cortex. During stimulation it was often not possible to give the subjects 100 trials within the 20-minute testing period or before the onset of seizure signs. This was the case especially during the early stimulation sessions when the subject responded with unusually high rates of repetitive errors. Consequently, in Fig. 2 the number of trials represented during stimulation sessions are less than 100. During each of the stimulation sessions, as seen in Fig. 2, the score of correct responses dropped from its prestimulation level. Similar results were obtained from the other subjects in the *Frontal Learning Group*. All subjects with implanted electrodes attained criterion performance on the alternation task after approximately the same number of trials required by monkeys which had not been stimulated. This finding may be attributed to the relatively small proportion of stimulation sessions during the training period and the great variability among normal monkeys in number of trials (1,300–2,500) to criterion.

The six monkeys in the *Frontal Learning Group* were given a total of 25 sessions under stimulation. In order to combine the data from these subjects, learning scores were grouped according to response levels on the prestimulation sessions and medians were computed for groups of scores before and during stimulation. Figure 3 represents the data for four groupings of scores during the learning period and for overtraining. The scores for overtraining are medians for eight stimulations of three subjects, taken after a minimum of 500 overtraining trials. These scores of 89% and 88.5% correct

responses for the sessions immediately before and during stimulation, respectively, indicate that cortical stimulation did *not* affect the monkeys' ability to respond correctly on the task after it had been learned.

Throughout the period of learning cortical stimulation appears to depress consistently the level of correct responses attained before stimulation, as seen in Fig. 3. Of the 25 stimulation sessions during learning, responses dropped 22 times from the prestimulation score, increased twice, and remained constant once. In comparing these data with learning scores for normal monkeys account must be taken of the procedure, in that stimulation

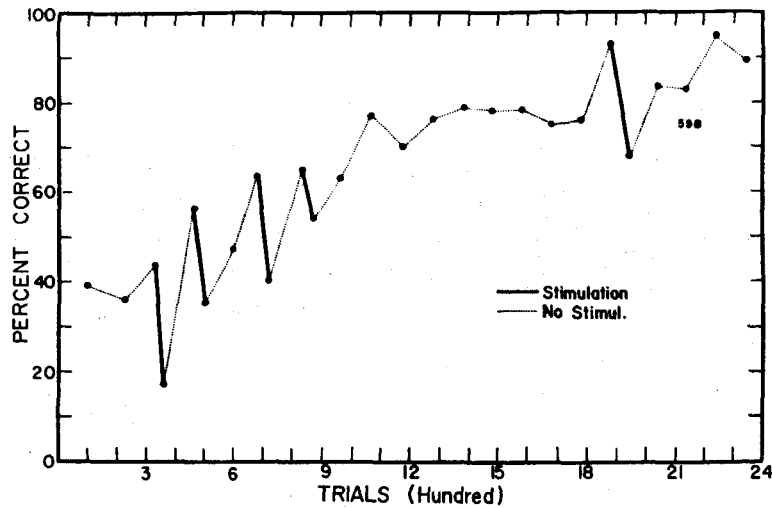


FIG. 2. Learning curve for subject with implanted electrodes over left and with ablated right frontal cortex. Test scores during stimulation indicated by heavy line; without stimulation, by dotted line.

was applied after a prestimulation session which had yielded a rise in the learning curve. The data for six normal monkeys showed that after 54 increases in learning scores the learning curve on the subsequent session rose 33 times, dropped 18 times, and remained constant three times. An analysis of these two sets of data yielded a *Chi Square* coefficient of 19.9 ($p < .01$), indicating that the depression in learning scores under stimulation could most probably not be attributed to normal fluctuations in the learning curves.

Stimulation after partial learning. Figure 3 also shows that scores of correct responses under stimulation are dependent upon the degree of learning of the task, with median scores increasing systematically for the successive groupings of data. The effect of stimulation as a function of prior learning may be evaluated statistically by means of the Mann-Whitney *U*-test. The following statistics are obtained: The subjects' stimulation scores for the fourth grouping (75-89%) are significantly higher than the prestimulation

scores for Groupings I (40-49%) and II (50-59%) at the 0.001 probability level and for Grouping III (60-74%) at 0.09 probability level. Furthermore, the stimulation scores for Grouping III are above the prestimulation scores for Grouping I at the 0.017 probability level. These analyses show that stimulation does not completely disrupt the monkeys' ability on a partially learned task but lowers his scores only to a level previously attained. Consequently, the effect of cortical stimulation on level of correct responses is a function of the degree of prior learning of the task.

Repetitive errors. It was observed that under stimulation subjects frequently pressed repeatedly on a non-rewarded lever. This increase in repeti-

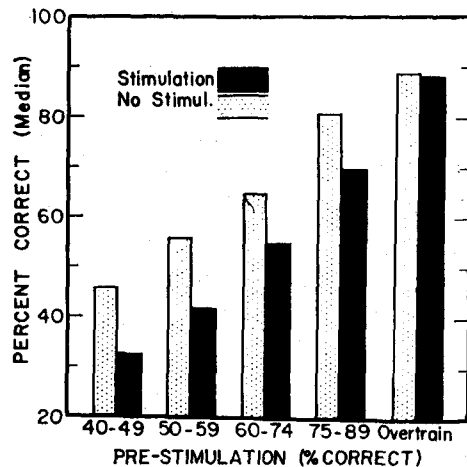


FIG. 3. Effect of stimulation on response scores (ratio of correct responses to number of trials) as function of pre-stimulation performance. Groupings of scores, indicated on abscissa, are according to response scores on day before stimulation. Bars show median response scores for pre-stimulation session and under stimulation, respectively. Data are for total of 33 pairs of sessions.

tive errors, which was seen particularly during the early phases of training, is not necessarily reflected by the response scores, because one error score is given for two or more successive presses on the same lever. In order to assess repetitive errors and permit further computations, *pressing scores* were determined for each session. A pressing score is the ratio of the number of total presses to the number of correct responses per session. Medians of pressing scores, arranged according to the four groupings of learning scores and for overtraining, are represented in Fig. 4. This figure shows increases in pressing scores during stimulation from the prestimulation level throughout the learning period but not during overtraining. Moreover, the magnitude of the increase in pressing scores becomes systematically smaller during the course of learning. The increase in pressing scores during stimulation was computed for every stimulation session for each subject, and medians for the increase were obtained according to the grouping of scores. The median increases were 6.3, 2.2, 0.7, and 0.5 presses per correct response, respectively, for the four groupings during the learning phase and 0.01 for the overtraining sessions. Statistical evaluation of these data by means of the Mann-Whitney *U*-test showed that the increase for Grouping I was significantly higher than

that for Grouping II at the 0.066 probability level and for Groupings III and IV at the 0.004 level. The increase for Grouping II was above those for Groupings III and IV at the 0.117 and 0.066 probability levels, respectively. The increase in scores for Grouping III differed from the change in pressing scores obtained during overtraining at the 0.057 probability level. These analyses substantiate the finding that stimulation becomes increasingly less effective in disrupting learned responses as a function of degree of learning.

Stimulation of occipital cortex. The two subjects with electrode assemblies over occipital cortex learned the alternation task at approximately the same rate as did other subjects with two intact frontal lobes. Under stimulation

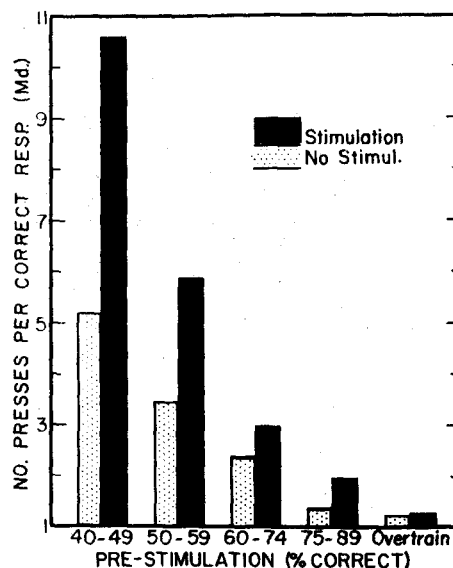


FIG. 4. Effect of stimulation on pressing scores (ratio of number of lever presses to number of correct responses, indicated on ordinate) as function of pre-stimulation performance. For explanation of abscissa, see legend of Fig. 3.

the response scores for these subjects increased from the prestimulation scores five times and decreased four times, thus showing no consistent effect of stimulation on behavior. Median scores for all stimulation sessions were 60% and 68% correct responses before and during stimulation, respectively.

Learning of visual discriminations. Stimulation of frontal cortex was applied during training on five different pattern and color discriminations by one subject in the present group and three additional monkeys used in another investigation. For 23 stimulation sessions learning scores were above the prestimulation levels 16 times and dropped slightly or did not change seven times. Thus, electrical stimulation, which had several times been raised to convulsive threshold, did not interfere with the normal learning rates on visual discriminations.

Stimulation of occipital cortex, however, retarded the learning of visual discriminations with consistent drops in scores from the prestimulation levels. A median drop of 9.5 percentage points from the prestimulus response

level was obtained for eight stimulations by the two subjects in this group. The parameters of the stimulus during these sessions were the same as those used in testing on the alternation task.

Effects of stimulation on the electrocorticogram. The effects of stimulation on cortical discharges were evaluated by the following procedure. Stimulation periods of 1 minute were alternated with 5-minute recording periods. The stimulus was applied only to the anterior three pairs of electrode points

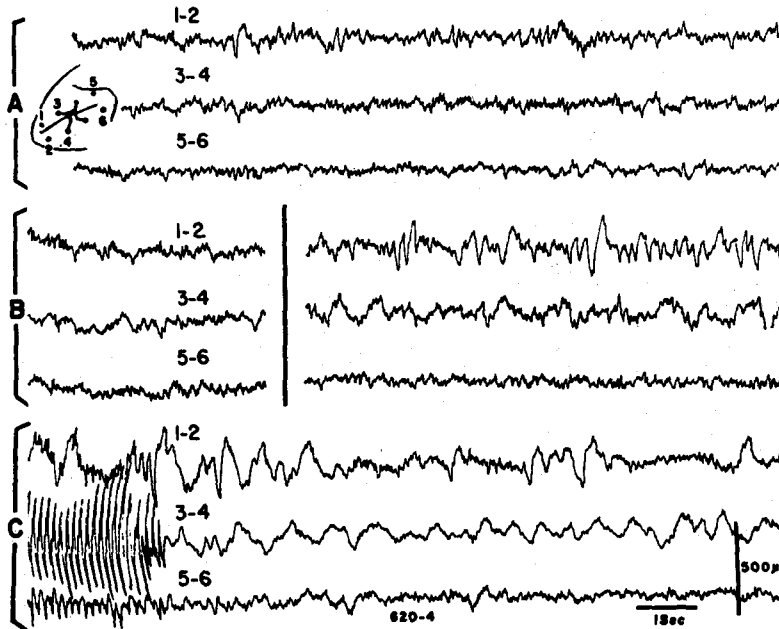


FIG. 5. Traces of electrocorticograms from one monkey. Bipolar recordings between electrode points indicated on insert: A—before cortical stimulation; B—after 1-minute stimulation at 60% of seizure threshold: first section taken 3 sec., second section taken 3 minutes after stimulation; C—after 1 minute stimulation at 75% of threshold, starting 3 sec. after stimulation. Calibration as indicated.

for bipolar stimulations, while bipolar electrocorticograms were taken from the four pairs of electrode points. The stimulus voltage was first set at 50% of seizure threshold and then raised in steps of approximately 0.7 V. during the succeeding stimulation periods. This procedure was terminated when marked after-discharges appeared in the electrocorticogram.

Samples of electrocorticograms obtained by this procedure are shown in Fig. 5. Because the plug on the monkey's skull had only six sockets, cortical electrode points were interconnected for the points labelled 3 and 4 in Fig. 5 (see insert). Traces of the prestimulation corticogram are shown in Part A. Since the seizure threshold, as obtained in prior determinations, was 11.0 V., the initial setting of 5 V. was used. Traces B were recorded after the third voltage setting (60% of threshold). The first section, taken 3 sec. after the

end of stimulation, shows essentially normal patterns in all three channels with a few slow waves (1.5-5 per sec.) from the middle electrodes. Several minutes after stimulation, as seen in the second section of Fig. 5B, trains of high-voltage slow waves were recorded from the electrodes which had been used for stimulation, but not from the posterior pair. Slow wave activity persisted for several minutes and was generally seen after stimulation for voltage settings above 60% of threshold value. After further increases in stimulus strength to 8.5 V. (77% of threshold), all traces show after-discharges lasting for several seconds. Trains of slow waves were then recorded from the areas under the stimulating electrodes but with only minimal spread to the posterior recording points. This slow wave activity persisted for as long as 20 minutes after the end of stimulation. Evoked motor activity was not observed in the monkey while the stimulus was being applied. In recordings taken from the experimental monkeys after termination of cortical stimulation the traces were generally like those shown in Fig. 5B. Similar patterns were also obtained after stimulation through electrodes placed over occipital cortex.

The finding that slow wave activity did not spread markedly to the posterior electrode points (placed 8 mm. from the stimulating points) would indicate a restricted focus of neuronal excitation. These observations, together with the absence of evoked motor activity in the subjects, support the hypothesis that stimulation as applied in the present experiment was restricted to the cortical area around the electrode points and did not spread widely to surrounding structures.

DISCUSSION

In evaluating the results from the present experiment and comparing them with findings reported by other investigators, consideration must be given to the method and parameters of stimulation and to the physiological and behavioral consequences of stimulation.

Method of stimulus application. The present results are contingent upon voltage settings of 60-90% of seizure threshold. Stimulation below 60% of threshold did not depress the level of correct responses, whereas voltages close to threshold value interfered with the monkey's coordination of motor responses required for performance on the apparatus.

Behavioral effects obtained with multiple pairs of stimulating electrodes may be compared with the results from experiments employing only one electrode pair. During several testing sessions we applied stimulation only through the frontal pair of electrode points. For low settings of stimulus voltage, when no marked patterns of slow wave activity were seen in the post-stimulus EEG, the level of correct responses remained unaffected by the stimulation. When the stimulus voltage was considerably increased until the post-stimulus EEG showed high-voltage slow wave patterns from all recording points, the subjects responded at chance level during stimulation, even when they had previously attained the criterion score. The stimulation

condition with low-voltage settings may be similar to that employed by Rosvold and Delgado (5), who found no impairment in alternation performance when frontal cortex was stimulated through needle electrodes. The effect obtained with high-voltage stimulation may parallel the results of Weiskrantz *et al.* (9), who reported that stimulation through a cortical electrode pair placed near the principal sulcus disrupted correct performance on an alternation task during the period of stimulation.

Consequences of cortical stimulation. Stimulation of frontal cortex as applied in the present experiment affects response scores on the alternation task, with the degree of prior learning on the task as an important variable. The present results may be influenced by concomitant consequences of the experimental procedure, such as (a) behavioral effects of stimulation regardless of stimulus locus, (b) neuronal and behavioral adaptation of the monkey to repeated stimulation, or (c) the subject's adaptation to the testing procedure during the course of training.

(a) Stimulation applied through electrodes placed over occipital cortex did not affect learning rates on the alternation task but did depress learning scores on visual discrimination. Frontal lobe stimulation did not disrupt visual discrimination learning. It is therefore unlikely that the results obtained in the present investigation are consequences of cortical stimulation regardless of locus of application. The results may rather be interpreted in terms of the unique function of the frontal lobes in the learning of certain tasks such as alternation.

(b) In all subjects additional determinations of seizure thresholds were taken after termination of testing and occasionally between successive testing sessions. The thresholds did not increase appreciably between the initial and final determinations. This would indicate that little neuronal adaptation of the stimulated structures had occurred as the consequence of repeated stimulations during the course of the experiment. Behavioral adaptation to the stimulus is contradicted by the finding that the subjects in the *Retention Group*, which were first stimulated after attainment of the learning criterion, showed no drop in response scores during stimulation. Moreover, the monkeys with occipital electrodes were affected by stimulations applied during tests on visual discriminations which they learned after they had been repeatedly stimulated during training on the alternation task.

(c) It might be argued that the decreasing effectiveness of the stimulus in depressing response scores is a function of *training* (*i.e.*, number of trials) on the alternation task rather than a function of the degree of prior *learning* (*i.e.*, percent correct responses). This question cannot be resolved unequivocally at present because training and learning are highly interrelated variables. The finding of considerable individual variability among the subjects in learning rates on the task may be pertinent to this argument. The four unilaterally ablated monkeys, which reached the learning criterion between 1,310 and 2,200 trials, yielded consistent results when their response scores were analyzed as functions of learning scores, whereas groupings of

the data according to blocks of training trials revealed no consistent relationship between training and effectiveness of the stimulus. Two other subjects (not included in the present investigation) attained criterion on the alternation task after 730 and 2,600 trials. During the first stimulation, applied after 320 and 1,170 trials, respectively, the learning scores of both monkeys were markedly depressed and during subsequent stimulations the effectiveness of the stimulus decreased gradually. According to these considerations, the level of correct responses attained before stimulation is a more relevant variable in assessing the effectiveness of stimulation than the amount of training on the task.

The ineffectiveness of stimulation in depressing performance scores *after* the task had been learned is in agreement with the findings obtained by alumina cream implants which showed that monkeys' retention scores on alternation were not affected by epileptogenic discharges from frontal cortex (6). In interpreting these findings a distinction was made between the cortical processes required for learning and those necessary for retention of acquired tasks. In the present experiments this distinction may be extended to include partially learned tasks. The finding that stimulation lowers the response score only to a level attained during prior testing sessions and not to the chance level would indicate that during the course of training the memory processes are gradually consolidated and become resistant to the disruptive influences of the stimulus. Increments in response level obtained just prior to stimulation, however, are not yet incorporated in the engram and are more readily disrupted. Thus, performance scores attained *during* stimulation reflect the formation of the engram as a relatively stable neuronal process which can be destroyed only by complete surgical ablation.

By means of the present technique the neural correlates of learning may be distinguished from those underlying the memory process. Excitation of frontal cortex, either by electrical stimulation or by epileptogenic discharges, disrupts the learning process even for partially learned tasks but does not affect the memory for behavior patterns which have been established prior to the excitation.

SUMMARY

In eight experimentally untrained monkeys electrode assemblies were chronically implanted over lateral frontal cortex, and in two monkeys over occipital cortex. Each assembly consisted of eight stimulating points embedded in a polyethylene sheet, with 8 mm. spacing between adjacent points.

All subjects were trained to criterion on an automatic alternation task. Several subjects were subsequently tested on visual discrimination problems. Electrical stimulation was applied throughout some of the training sessions. The stimulus was a square wave pulse (through an isolation transformer) which was set at a voltage of 60-90% of the subject's convulsive threshold. Adjacent points on the electrode assembly were connected to opposite poles, so that bipolar stimulation was applied through the eight electrode points.

Six monkeys with frontal and the two with occipital electrodes were stimulated during learning on the alternation task, while the two remaining monkeys were stimulated only during overtraining on this task.

The following results were obtained. (i) All monkeys reached criterion on the alternation task within the normal limits of learning trials; (ii) during stimulation of frontal cortex the scores of correct responses were depressed from their prestimulation values, but generally did not drop to chance level; (iii) furthermore, the effectiveness of stimulation in depressing scores of correct responses was a function of the degree of prior learning—stimulation was increasingly less effective as the learning curve rose; (iv) after the task had been learned stimulation had no effect on response scores; (v) stimulation applied to occipital cortex did not affect learning on the alternation task, but did depress learning scores on visual discriminations; and (vi) stimulation of frontal cortex did not interfere with learning rates on visual discrimination problems.

It is concluded that stimulation of frontal cortex, as applied in this experiment, interferes with efficient learning on the alternation task but does not impair memory for the task after it has been learned.

REFERENCES

1. BARRERA, S. E., KOPELOFF, L. M., AND KOPELOFF, N. Brain lesions associated with experimental "epileptiform" seizures in the monkey. *Amer. J. Psychiat.*, 1944, 100: 727-737.
2. KRAFT, M. S., OBRIST, W., AND PRIBRAM, K. H. The effect of irritative lesions of the striate cortex on learning of visual discriminations in monkeys. *J. comp. physiol. Psychol.*, 1960, 53: 17-22.
3. MISHKIN, M. Effects of small frontal lesions on delayed alternation in monkeys. *J. Neurophysiol.*, 1957, 20: 615-622.
4. PRIBRAM, K. H. Toward a science of neuropsychology (method and data). Pp. 115-142 in: *Current trends in psychology and the behavioral sciences*, Pittsburgh, Univ. of Pittsburgh Press, 1954.
5. ROSVOLD, H. E. AND DELGADO, J. M. R. The effect of delayed-alternation test performance of stimulating or destroying electrically structures within the frontal lobes of the monkey brain. *J. comp. physiol. Psychol.*, 1956, 49: 365-372.
6. STAMM, J. S. AND PRIBRAM, K. H. Effects of epileptogenic lesions in frontal cortex on learning and retention in monkeys. *J. Neurophysiol.*, 1960, 23: 552-563.
7. STAMM, J. S. AND PRIBRAM, K. H. Effects of epileptogenic lesions of inferotemporal cortex on learning and retention in monkeys. *J. comp. physiol. Psychol.* (in press.)
8. STAMM, J. S. AND WARREN, A. M. Learning and retention by monkeys with epileptogenic lesions in posterior parietal cortex. (In preparation.)
9. WEISKRANTZ, L., MIHAILOVIC, L. AND GROSS, C. G. Stimulation of frontal cortex and delayed alternation performance in the monkey. *Science*, 1960, 131: 1443-1444.