

A COMPARISON OF THE EFFECTS OF MEDIAL AND LATERAL CEREBRAL RESECTIONS ON CONDITIONED AVOIDANCE BEHAVIOR OF MONKEYS¹

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In recent years considerable theoretical interest has centered on the functions of the medial and basal cortex of the cerebral hemispheres. Suggestions have been proposed that this cortex serves as the neural substrate of "affect" or "emotion" suggestions based on comparative anatomical data (3) and on the massive interrelationships of medial and basal cortex with septal and hypothalamic structures (2). As pointed out in a recent review (9), little systematic neuropsychological experimentation has been undertaken to test specific hypotheses derived from such suggestions. In part, this has been due to the lack of experimental methods suitable for such an investigation; in part, it has been due to the persuasiveness of the concepts put forward.

Specifically, there is no report in the literature which systematically compares the effects on avoidance behavior of lesions or stimulations of medial and basal cerebral structures with the effects of such manipulations of isocortex. Regardless of the theoretical interpretation of avoidance conditioning which one might favor, most investigators would agree that it may serve as an indicator of "emotional" behavior. During a previous investigation (14), a two-compartment shuttle box was adapted for use with monkeys which were taught to avoid electric shock. The procedure was found to be sufficiently sensitive to differentiate between the effects of two kinds of cerebral lesions: Bilateral lesions of the amygdaloid complex, when compared with those of inferotemporal cortex or with control sham operations, were found to accelerate the extinction of avoidance behavior learned

before the operation and to retard slightly its acquisition.

The present study was undertaken to answer the following specific questions: Do the effects on conditioned avoidance behavior follow only lesions of the amygdaloid complex or are they characteristic of damage to any of the medial and basal allo-juxtallocortical cerebral structures? Secondly, are lesions of lateral isocortical tissue, to which inferotemporal cortex belongs, uniformly *ineffective* in changing avoidance behavior?

METHOD

Subjects were 14 immature and experimentally naive rhesus monkeys approximately one to two years of age.

All were trained to avoid electric shock in a two-compartment shuttle box. The conditioned stimulus was the dimming of illumination over one of the two compartments. If present in the darkened compartment S was shocked, 4 sec. after the change in illumination. Trials were separated by 30 sec. The barrier between the two compartments consisted of an elevation over which the animal had to jump. (No door impeded the jumping since, in a previous experiment [14], difficulties were encountered in using the conventional closed barrier shuttle box with monkeys; many monkeys jumped across the barrier as soon as the closed door was opened prior to receiving any shock.) In the present experiment, animals were always shocked for retracing. The delivery of shock to the grill bars was rapidly "scrambled" by a commutation device to prevent shock avoidance by straddling. Shock strength averaged about 1 ma. (60 cycles alternating current). Fifty trials were given daily until a criterion of five or fewer shocks on a given day was achieved. After reaching criterion, all animals were given a one-stage bilateral surgical operation. Brain tissue was removed by subpial suction.

Six animals received lesions of the medial and basal allo-juxtallocortical structures, two animals each receiving lesions in the following three categories: (a) the medial frontal and cingulate cortex, corresponding essentially to the medial frontal region as delineated in neuronographic studies (10); (b) the posterior orbital gyrus, anterior and limen insular cortex, the temporal polar cortex, and the amygdaloid complex, corresponding essentially to the frontotemporal region as delineated neuronographically; and (c) Ammon's formation and adjacent structures: this lesion included the hippocampus, subicular complex, and entorhinal cortex.

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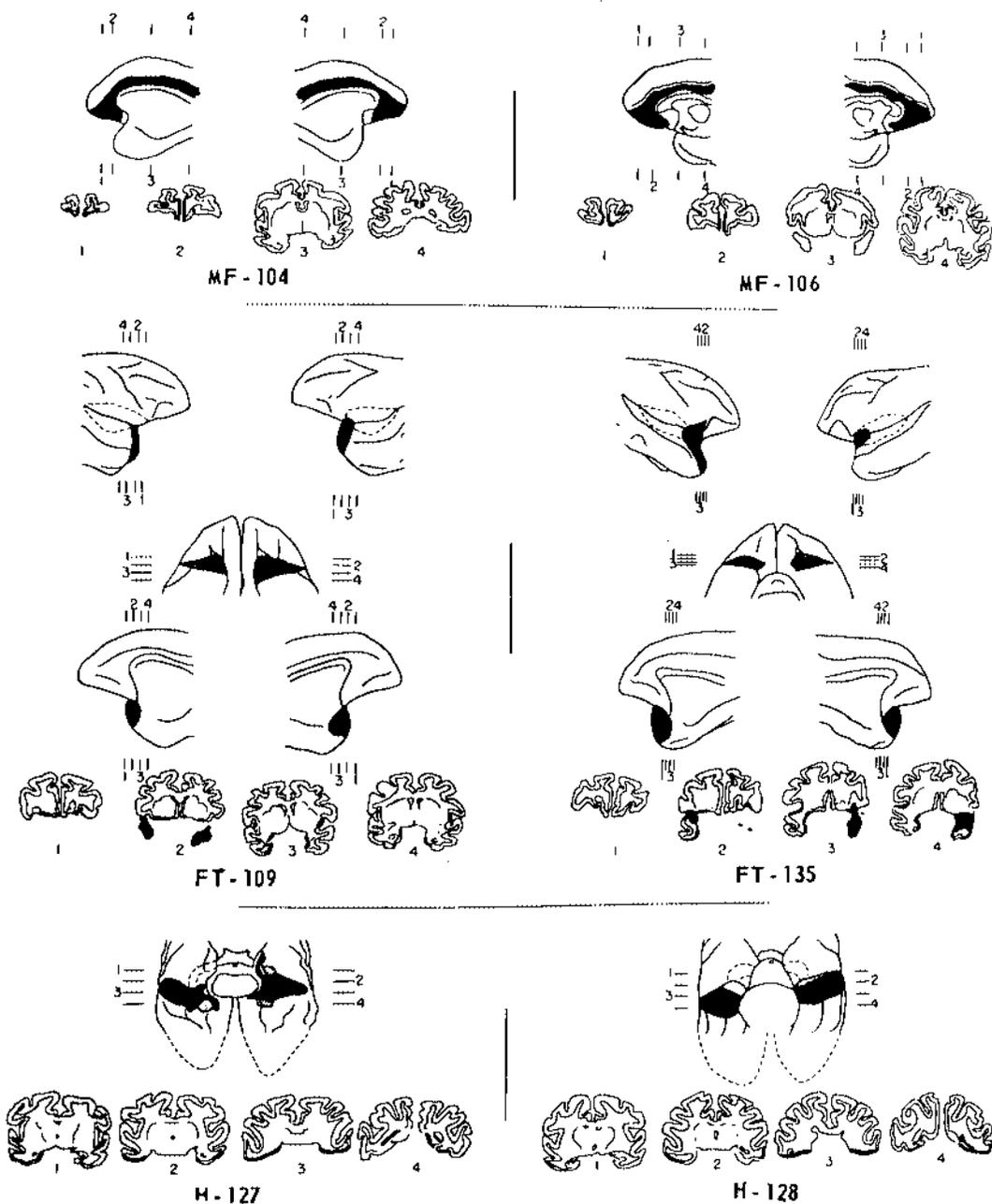


FIG. 1. Diagrams showing, by means of reconstructions and representative cross sections, the extent and depth of lesions of the animals with resections of the medial and basal allo-juxtallocortical cerebral structures. *MF* indicates resections of the medial-frontal-cingulate regions; *FT*, of the frontotemporal region; *H*, of Ammon's Formation. The large numbers refer to the animals used, the small numbers, to cross sections.

The resection of Ammon's formation was accomplished by first making an incision in the ventral surface of the temporal lobe, exposing the temporal horn of the lateral ventricle through which the excision was then performed in a ventral and medial direction (5).

(Precise description of the surgical procedures used in making the other two lesions may be found in references 7 and 8.)

Six other animals were given lateral isocortical resections, two in each of the following categories: (a)

the anterofrontal region, (b) the occipitoparietal region, and (c) the inferotemporal region. (The description of the surgical procedures used to accomplish these lesions can be found in references 5, 6, 11.) Finally, two animals were given sham operations which consisted of posterior retraction of the temporal lobe through open

dura to visualize the region of the optic chiasm without removal of neural tissue.

After surgery all Ss were given a rest period of one week. Extinction training was then started, during which, though shock was no longer applied, all other variables were maintained in the test situation as pre

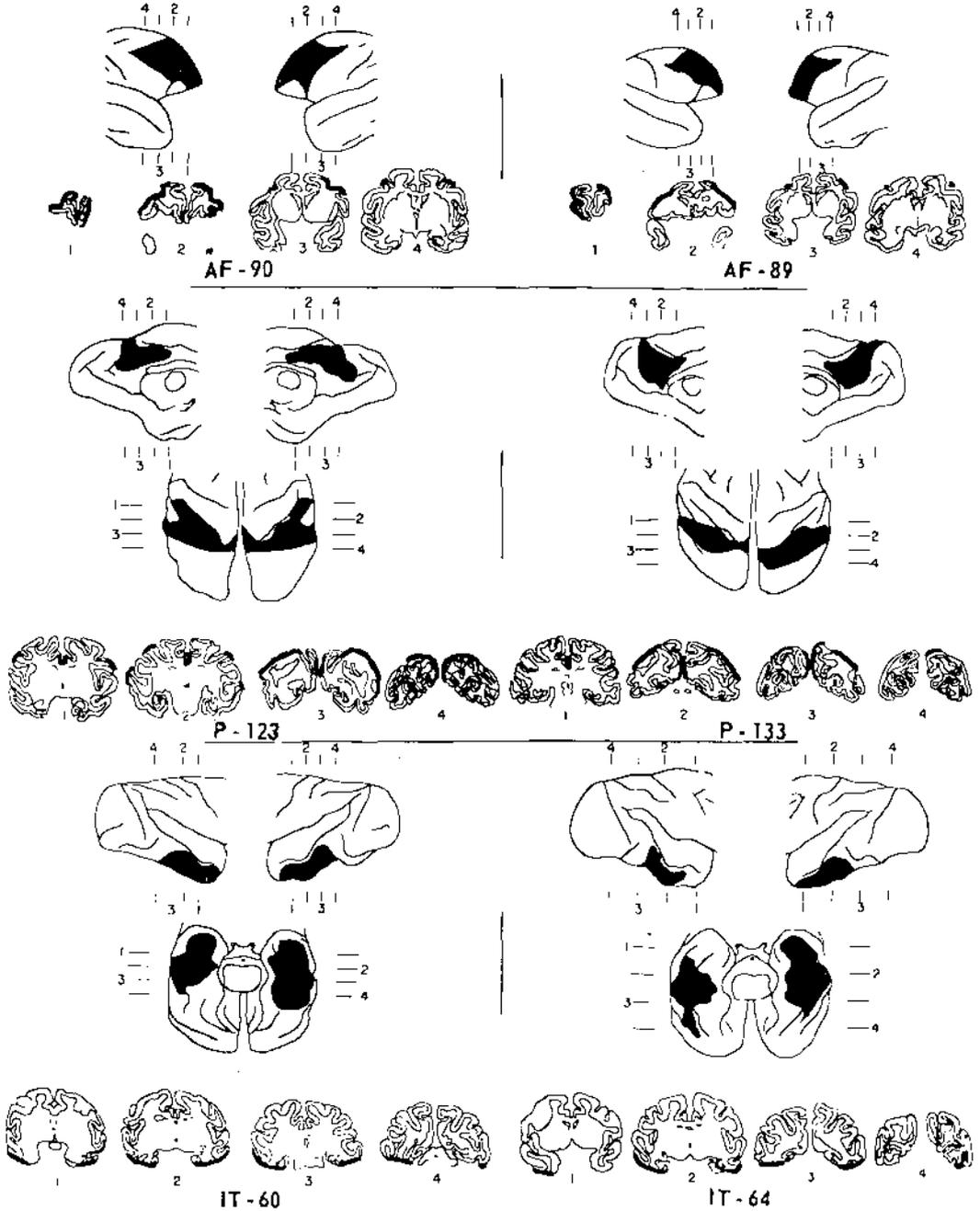


FIG. 2. Diagrams showing the extent and depth of lesions of the animals with lateral isocortical resections. *AF* indicates resection of the anterofrontal region; *P*, of the parieto-occipital region; *IT*, of the inferotemporal region. The numbers refer to animals and cross sections, as in Fig. 1.

operatively. This procedure was continued at 50 trials a day for ten days. Next, the animals were reconditioned with the identical procedure used preoperatively, until they met the original acquisition criterion. Finally, the avoidance was re-extinguished for a ten day period. After completion of the behavioral portion of the experiment, all animals were sacrificed, their brains perfused with saline and formalin, the brains removed, fixed, dehydrated in alcohols, and imbedded in celloidin. Serial sections were made, stained with aniline thionine, and from these the lesions reconstructed by orthogonal projection onto graph paper. Figure 1 shows these reconstructions and representative cross sections through the lesions of the brains of the animals that were given medial and basal allo-juxtallocortical resections; Figure 2 shows the reconstructions and representative cross sections of the brains of the animals that were given resections of the lateral isocortical cerebral structures.

To summarize, monkeys were trained to criterion performance in the conditioned avoidance procedure, then subjected to surgical operation. One week after surgery an extinction procedure was instituted. The animals were then reconditioned and, for a second time, the extinction procedure was administered. Following this, the animals were sacrificed and their brains histologically analyzed.

RESULTS

Figure 3 shows the results obtained during *postoperative* extinction of the *preoperatively* acquired conditioned avoidance. Shown is the percentage of total time spent in the dark compartment, i.e., the compartment which, during the training procedure, contained the noxious stimulus.

As can be seen, the posterior isocortical groups (that is, the occipitoparietal operates and inferotemporal operates) did not differ from the sham operates in the amount of time spent in the dark compartment. Complete extinction for these groups did not take place until the third testing day. Practically immediate extinction was, however, shown by all other groups, comprising those with allo-juxtallocortical lesions as well as the group with the anterofrontal isocortical lesion.

A similar separation among groups by lesions occurred for the results of the reconditioning procedure. The number of shocks required to re-establish the conditioned avoidance for posterior isocortical groups (occipitoparietal and inferotemporal) did not differ from that for the sham operates. The medial-frontal-cingulate and the Ammon's formation groups required over three times as many shocks to reach criterion as did the

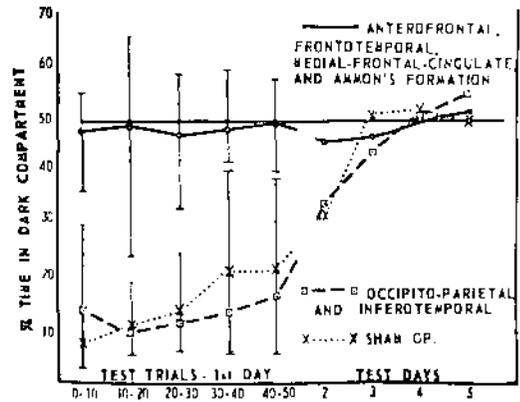


FIG. 3. Graph of the percentage of time spent by various groups of animals in the dark (previously shocked) compartment of a shuttle box during postoperative extinction of a preoperatively acquired conditioned avoidance. The scores for the first extinction day are recorded in 10-trial blocks; subsequent extinction trials are plotted in 50-trial blocks (one test day). Vertical bars indicate range of performance.

posterior isocortical and sham operate groups. Those animals which had received anterofrontal or frontotemporal resections required approximately thirteen times as many shocks as did the controls. These frontal groups actually had a decrement in terms of savings; that is, they required more shocks on the average to reach criterion than they had in their original preoperative acquisition training. However, in the case of the anterofrontal group, most of the shocks were received within the first two reconditioning sessions, while the frontotemporal group took much longer in reaching criterion.

Figure 4 shows the performance of the animals during extinction of the postoperatively acquired conditioned avoidance. In this extinction procedure, the frontal isocortical group behaved in the same manner as did the posterior isocortical groups. All the isocortically operated animals extinguished during the third day of testing; their rate of extinction did not differ from that of the sham operates. All allo-juxtallocortically operated animals, on the other hand, showed a rapid rate of extinction: within approximately 15 to 20 min., they began to play, search for food and other objects, and to jump indiscriminately with respect to the signal.

To review briefly, monkeys with medial and basal allo-juxtallocortical lesions showed

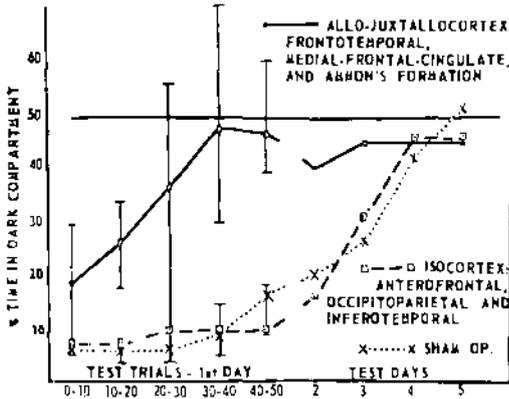


FIG. 4. Graph of the percentage of time spent by the various groups of animals in the dark (previously shocked) compartment of a shuttle box during postoperative re-extinction of postoperatively reacquired conditioned avoidance. Trial blocks divided as in Fig. 3. Bars indicate range of performance. For precise definitions of isocortex and allo-juxtallo cortex, see reference 9.

rapid extinction of both pre- and postoperatively acquired conditioned avoidance when compared with monkeys having posterior isocortical lesions or sham operations. In addition, all animals with allo-juxtallo cortical lesions took longer to acquire a conditioned avoidance in the shuttle box as used in these experiments. Monkeys with frontal isocortical lesions also took a greater number of trials to acquire the conditioned avoidance than did posterior isocortical and sham operates; furthermore the performance of these frontal operates was similar to that of the animals with allo-juxtallo cortical lesions during extinction of the preoperatively acquired conditioned avoidance. However, during extinction of the postoperatively acquired conditioned avoidance the frontal and posterior isocortical groups performed alike thus, during this procedure there was a clear separation between the performance of the isocortical and sham operates on the one hand, and that of the allo-juxtallo cortical operates on the other.

DISCUSSION

On the basis of extinction of postoperatively acquired conditioned avoidance, as tested in the shuttle box under the conditions described, the present experiments support the hypothesis that the allo-juxtallo cortical cerebral

structures on the medial and basal surfaces of the brain share a common function, a function not shared by isocortex. Caution is necessary, however, in the interpretation of these results and especially in making generalizations because antero-frontal operates differed from the other isocortical operates in their extinction of preoperatively acquired conditioned avoidance and in relearning.

We must consider various behavioral effects of cerebral resection to which the results in the shuttle-box situation might be attributed. One such effect is the change in level of the animal's general activity. The shuttle-box situation itself provides an internal measure of activity in terms of the number of jumps between compartments which an animal makes during the extinction period. Activity data compiled for the first five days of initial extinction and of re-extinction show that, although there are no consistent differences in the number of jumps among the other groups, the antero-frontal operates have a considerably higher rate of jumping. As a further control measure, some of our animals were tested in an "activity" cage, and in these tests as well, the antero-frontal operates were "hyperactive," confirming a frequently repeated finding (1, 11). Thus, as in a previous study (13), it is difficult to decide whether the results obtained in the shuttle box for the antero-frontal group are due solely to this hyperactivity. Rapid retracing during the first extinction period yields a measure of 50 per cent in the dark compartment and may impede reconditioning; during reconditioning the animals altered the form of their marked activity from a rapid rate of jumping between compartments to a rapid circling within the safe compartment, a form which was maintained during the subsequent extinction procedure so that the rate fell in line with that of the other isocortical groups. What remains in doubt is whether the initial randomness of hyperactivity is secondary to a deficit in preoperatively acquired conditioned avoidance, or whether it is the primary disturbance. In other studies using the shuttle box, the former proved the correct interpretation (13); the present dilemma may be resolved by utilizing the procedure described by Sidman (12)

so that each transfer between compartments, or some other established act, delays the shock for a given temporal interval.

Among the groups with medial and basal cerebral resections, the frontotemporal operates were greatly altered in their general behavior, as has been reported previously (7). Their behavior in the experimental situation had been predicted, and presented an even more marked pattern than had occurred when resections were limited to the amygdaloid portion of this region (14). On the other hand, no gross behavioral changes were noted in the medial-frontal-cingulate operates and in those having had resections of Ammon's formation. These animals' results came, therefore, somewhat as a surprise.

These operates, which can be grouped together on the basis of a classification of rhinencephalic systems (9), are of special theoretical interest because of the considerable amount of speculation according to which these systems are the neural substrate of "emotions." As stated earlier, little experimental support for this notion had been accumulated. Although some of the results of the reported experiment tend to support these suggestions, there is additional evidence that induces caution against too ready acceptance. Recent observations, made on human patients who had received resections of the medial surfaces of the temporal lobe (4), confirm the findings of the present experiment that the duration of an "emotional" reaction after the cessation of the exciting incident is considerably shortened. However, these observations on man show that the "deficit" may be more general. In the presence of interfering or distracting events, the patients quickly forget situations and the details which occurred in these situations. All "memory" functions are *not* impaired since the patients can perform tasks demanding recall provided interfering events do not occur. No such experimental parallel has yet been devised for monkeys with medial lesions, despite the administration of many varied tests (5, 7, 14), nor has the human clinical material permitted histological verification to date. Nevertheless, such clinical material cannot be ignored in

directing future research and conceptualization.

SUMMARY AND CONCLUSION

The shuttle-box procedure, as used in the present experiment to test conditioned avoidance, differentiates the effect of damage to medial and basal (allo-juxtallocortical) cerebral structures from that produced by posterior isocortical lesions and from control procedures. In addition, some, but not all, of the procedures differentiate the effects of anterofrontal isocortical resections from those of posterior isocortical resections; other procedures differentiate the effects of anterofrontal resections from those of medial and basal cerebral resections. Thus, the effects of lesions of the anterofrontal cortex may reflect similarities of function with either of the other anatomical categories. Since considerable anatomical evidence exists (2) which relates the anterofrontal cortex to the medial and basal cerebral structures, and since both the frontal and the medial and basal structures have been repeatedly assigned functional significance in regulating "emotional" behavior, it is important to clarify this issue by further experiment. As cautioned in the discussion, such experiments cannot be undertaken with any simple notion that the function of these medial, basal, and frontal cerebral structures is reflected *solely* in "emotional" behavior. Such a notion would disregard the possibility that the effects of these lesions might alter more general processes basic to a variety of psychological functions.

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