The "manipulative response memory system" in the white rat*

PETER H. SPILIOTIS and ROBERT THOMPSON

Louisiana State University, Baton Rouge, Louisiana 70803

Adult albino rats, previously trained on a series of three latch box problems, sustained bilateral cortical or subcortical lesions and were subsequently tested for retention. Those animals showing defective retention of all three problems suffered damage to either the sensorimotor cortex, corpus striatum, posterior thalamus, subthalamus, red nucleus, or brainstem reticular formation. Excellent retention of at least two of the three problems was found in animals suffering extensive occipital, cingulate, pyriform, hippocampal, septal, amygdaloid, pretectal, or tectal damage. These findings provide additional evidence for a localized cortico-subcortical system mediating learned responses in the rodent.

As discussed earlier (Thompson & Thorne, 1973), the lesion method is ideally suited for the purpose of identifying those parts of the brain that are essential for the "memory" (expression) of previously learned responses. By canvassing many different cortical and subcortical areas with small lesions, it becomes possible to map the "memory system" of the brain for any given learned response. In our laboratory, the "visual" memory system has been thoroughly mapped in the white rat (Thompson, 1969; Thompson & Thorne, 1973). The "kinesthetic" memory system (Thompson, Lukaszewska, Schweigerdt, & McNew, 1967; Thompson, Malin, & Hawkins, 1961; Thompson & Thorne, 1973) and the "conditioned avoidance response" memory system (Rich & Thompson, 1965; Thompson, 1964; Thompson, Rich, & Langer, 1964) have also been mapped in this animal, but to a lesser extent. The purpose of the current study was to map the "manipulative response" memory system by identifying those cortical and subcortical structures which are necessary for the expression of responses previously learned in a latch box situation.

In recent years, the latch box problem (a task which involves the execution of one or more specific acts, usually manipulative in nature) has not been investigated to any large extent. Undoubtedly, one of the main reasons for its lack of popularity lies in the use of time as a measure of performance. This measure cannot readily be adjusted to make allowances for either irrelevant activity or periods of inactivity within the latch box situation and, as a consequence, is comparatively unreliable (Lashley, 1935). Another difficulty inherent in the study of latch box performance has to do with the imprecision in specifying what the animal actually learned (e.g., did the animal, in fact, learn a discrete manipulative act or simply learn to increase his vigor in attacking the object to be manipulated).

Those neuropsychological studies which have examined latch box performance in animals have largely dealt with neocortical contributions and, in particular,

the contributions of the motor cortex. As might be expected, frontal lesions tend to impair latch box performance (Jacobsen, 1932; Lashley, 1924, 1935; Pribram, Kruger, Robinson, & Berman, 1955), although exceptions have been documented (Jacobsen, 1932; Lashley, 1924).

The most extensive study examining latch box problem performance in the neocortically damaged rat was done by Lashley (1935). In this study, brain-damaged and control animals were required to learn four manipulative tasks (pressing a lever, breaking a strip of paper, pulling a door handle, and pulling a chain). Three of the four problems significantly differentiated the brain-damaged animals from the controls. Of considerable importance, however, was the finding that the amount of retardation exhibited on the manipulative tasks was more a function of the size of the lesions than its locus.

Virtually no data exist on subcortical contributions to the performance of manipulative responses involved in latch box problems.

METHOD

Subjects

Eighty-seven adult male albino rats of the Wistar strain were used. After receiving 5 days of extensive handling, all Ss were placed on a 23½-h water-deprivation schedule. This schedule was introduced 5 days prior to preliminary training, maintained until the conclusion of preoperative learning, and subsequently reintroduced 5 days prior to postoperative testing. Three Ss died during original learning, 21 operated Ss died prior to the retention test, and 6 operated Ss were discarded from the experiment because their lesions were either minute or grossly asymmetrical.

Apparatus

The apparatus consisted of a startbox and a goalbox (two modified Lafayette modular testing units, Model A550), each measuring 30.5 x 25.4 x 19.1 cm, and each containing an 8.9 x 30.5 cm one-way-vision window on one side for viewing of the interior (see Fig. 1D). The floors consisted of metal rods spaced 1.9 cm apart, and illumination of each box was provided by two 15-W light bulbs located above the milk glass ceiling. Entrance into the startbox was provided by a vertically sliding door.

Interchangeable 25.4 x 19.1 cm Plexiglas frames, each containing a 8.9 x 12.7 cm Plexiglas door, could be inserted

*This study was supported in part by Grant MH 08377 from the National Institute of Mental Health, and by a grant from the Louisiana State University Council on Research.

Fig. 1. Photographs of the apparatus (D) and latches used for Problems A, B, and C.

between the startbox and the goalbox. During preliminary training, a frame containing a door with no latch was used. Frames containing doors with latches were used during experimental training. Problem A consisted of a button which had to be rotated in a clockwise direction to the vertical position in order to unlock the door (Fig. 1A). Problem B contained a barrel bolt which had to be slid to the right at least 1.7 cm in order to unlock the door (Fig. 1B), and Problem C consisted of a hook which had to be elevated at least 1.9 cm in order to unlock the door (Fig. 1C).

Procedure

Preliminary Training

On the first day, each S was allowed to explore the apparatus for 15 min. During this time, the door between the startbox and the goalbox was wide open and water was available in a dish located at the far end of the goalbox. On subsequent days, S was required to push open the door in order to gain access to the goalbox. Preliminary training was terminated when S readily opened the door from a completely closed position on 10 consecutive trials.

Acquisition

Each S was required to learn, in succession, Problems A, B, and C. A maximum of 10 trials was given daily with an intertrial interval of 180 sec. A trial was initiated by placing the animal into the startbox and was terminated either when the animal successfully manipulated the latch, opened the door, and drank from the water dish for 10 sec or when the animal failed to operate the latch successfully within 180 sec. Upon completion of the trial, the animal was removed from the goalbox (or

startbox) and returned to a restraining cage to await the next trial.

A correct response was defined as unlocking the latch and opening the door within 5 sec after having made initial contact with any part of the Plexiglas frame, door, or latch. (This modification of the time measurement was used to reduce the effects of both inactivity and irrelevant activity.) The criterion of learning consisted of at least 9 correct responses within one daily session of 10 trials.

Daily records were kept of each animal's behavior in the apparatus. Particular attention was paid to the specific manipulative acts used to successfully operate the latch and the level of motivation underlying performance (the time it took S to make contact with the door or latch, the vigor in manipulating the latch, and the speed with which S ran to the water dish after opening the door).

Upon learning Problem C, the Ss were placed on ad lib food and water for 5-7 days. Subsequently, the Ss either sustained brain damage or were used as normal controls.

Retention Test

Following a 3-4-week recovery period (or rest period in the case of the controls), each S was required to relearn the three problems in the order in which they were originally mastered. Postoperative testing involved the same procedures as preoperative acquisition. A maximum of 70 trials was allotted for each problem.

Retention of each problem was measured in terms of percentage error savings scores using the conventional formula.

Surgery and Histology

Bilateral lesions were customarily carried out in one stage under deep chloral hydrate anesthesia. For cortical ablations, the suction method was used. Subcortical lesions were made stereotactically. Depending upon the area to be destroyed, a constant current (anodal), ranging from 2 to 5 mA for a duration of 5-15 sec, was passed through an insulated stainless steel electrode with 1-2 mm of the tip exposed. In some cases, surgical brain damage was carried out in two stages (unilateral lesion followed by a contralateral lesion) with an interoperative period of 10-15 days. Details of the surgical procedures may be found elsewhere (Thompson, 1971).

Upon completion of the postoperative test, each operated S was anesthetized, its vascular system perfused with 10% Formalin, and the brain removed and stored in 10% Formalin for 48 h. For cortical injuries, the lesions were reconstructed on Lashley-type brain diagrams prior to sectioning. Each brain was sectioned frontally at 90 microns with a freezing microtome. Every third section showing the lesion was photographed at 14X with a Leitz enlarger. These photographs of unstained sections yield differentiation of the brain field similar to that obtained with a fiber stain and permit ready identification of the locus and extent of the lesion (see Thompson, 1971, for details of the procedure).

Statistical Analysis

The difference in error savings scores between the control group and each operated group was evaluated by the Mann-Whitney (Siegel, 1956) nonparametric test. However, total reliance upon the results of such a test is neither sound nor realistic. Our techniques in producing brain damage have the fault of leading to lesions which vary significantly in both locus and extent. Thus, lumping a number of animals into one brain-damaged group without regard for anatomical irregularities might conceivably obscure major differences in the localization of specific behavioral deficits.

In the light of these considerations, a description of the lesions suffered by each S was given, and evaluation of the

savings scores earned by each brain-damaged S was made in terms of the range of savings scores earned by the control group. For example, any brain-damaged S earning a savings score on a given problem which fell below the range of the controls was judged to have displayed defective retention of that problem.

RESULTS

Original Learning

All animals, except five, succeeded in reaching the criterion of learning within 70 trials on each of the three latch box problems. Of the five failing to achieve this level of performance, four learned Problems A and B, but failed on Problem C. The remaining animal was overly timid and failed to learn Problem A. The data derived from these five Ss were not included in any of the analyses to follow.

Table 1 presents the mean trials and errors to criterion on each of the three problems. The Wilcoxon test for paired replicates (Siegel, 1956) disclosed that Problem A was significantly easier to master than either Problem B or Problem C ($ps < .01$). Although Problem B tended to be somewhat more difficult than Problem C, the differences fell considerably short of statistical significance.

Examination of the individual records indicated that acquisition of Problem A was very rapid once the animal made his first "correct response." That is to say, a string of errors would be made during the early phase of training, but once a correct response appeared, the majority of Ss promptly reached the criterion of learning. A similar, though less striking, tendency to reach the criterion soon after the first appearance of a correct response was also seen for Problem C. Performance on Problem B was the most variable after the Ss made their first correct response. A comparison of the intraproblem difference in the mean trial and error scores shown in Table 1 will also reflect the relative strength of this tendency.

The type of manipulatory response used to unlock each latch during the criterion run varied somewhat from one animal to the next. On Problem A, for example, 70% of the Ss unlocked the latch by means of manipulatory movements of the head—they pushed the left side of the button upwards with their noses. Another 20% used their heads and forepaws together to spin the button to the right, while the remaining 10% operated the latch exclusively with their forepaws. With respect to Problem B, 42% of the Ss pushed the left end of the barrel to the right exclusively with their heads. Another 30% placed their heads at the left end of the barrel, with their right forepaws on the knob, and pushed to the right. The remaining Ss either grasped the knob with their teeth and pulled the barrel to the right (11%) or pushed the barrel to the right with their forepaws only (17%). On Problem C, the Ss operated the hook and eye latch by pushing the hook upwards with

Table 1
Mean Learning Scores for All Latch Box Problems

Problem	Trials		Errors	
	Mean	Range	Mean	Range
A	8.1	2-32	7.3	2-27
B	18.2	4-58	13.9	4-50
C	15.9	4-54	13.7	4-50

their heads (48%), by lifting the hook off the eye with their teeth (42%), or by using their forepaws in combination with one of the foregoing responses (10%).

Postoperative Behavior of "Motivated" Animals

During the course of the retention test, a small proportion of brain-damaged Ss was found to be either overly timid or operating under low thirst motivation. These Ss were slow to respond to the latch or door, fatigued rapidly after one or two attempts to manipulate the latch or to push open the door, and occasionally failed to drink from the water dish located in the goalbox. The performance of these Ss will be described in a subsequent section.

Retention

Control group. Retention of the three latch box problems by the control animals was excellent. As shown in Table 2, the mean error savings scores earned on each of the three habits exceeded 90%. None of the differences in savings scores obtained on the three problems approached statistical significance.

It is important to point out that the manipulatory responses used by these animals to open each latch during the retention test were the same as those used during the criterion run in original learning. These findings, coupled with the high savings scores, strongly indicate that a specific kind of sensorimotor learning had taken place during acquisition.

Anterior neocortex. Three Ss received bilateral two-stage ablations of the anterior neocortex (Fig. 2, top). In all cases, the damaged region included the frontal poles and the major portions of what Krieg (1946) has designated as Areas 10, 6, and 2. Two animals sustained damage which extended as far caudally as Areas 4 and 3. The average extent of neocortical damage was 30.0% with a range of 22%-36%. The caudate-putamen complex was not damaged in any of these Ss.

With respect to Problem A, the animal with the largest frontal ablation earned a savings score of 50%, while the remaining two earned negative savings scores. All three Ss failed to relearn Problem B within the allotted 70 trials, and all earned negative savings scores on Problem C.

Table 2
Mean Retention (Percentage of Error Savings) Scores for All Groups

Group	N	Problem A		Problem B		Problem C	
		Mean	Range	Mean	Range	Mean	Range
Control	5	93.4	67 to 100	92.6	63 to 100	96.0	80 to 100
Anterior Neocortex	3	-711.0*	-2050 to 50	-757.3*	-1066 to -431	-64.3*	-100 to -10
Posterior Neocortex	3	16.0	-125 to 100	96.7	90 to 100	100	
Septal Area	1	100		42		100	
Amygdala	1	33		100		96	
Anteromedial Thalamus	4	92.8	71 to 100	86.0	44 to 100	65.5	-38 to 100
Posterior Thalamus	3	-653.3	-1260 to 100	-267.8*	-570 to 75	-1066.7	-2233 to 100
Subthalamus	3	38.0*	20 to 54	-66.0*	-331 to 83	-32.3*	-238 to 78
Pretectum	1	100		82		100	
Superior Colliculus	2	100		68.0	36 to 100	100	
Ventral Tegmental Area	1	-114		-40		86	
Substantia Nigra	1	Failed		Failed		Died	
Red Nucleus	3	-725.0*	-1000 to -350	-104.3	-340 to 100	-101.0*	-153 to 0
IPN-Central Tegmentum	4	75.8	0 to 90	-24.0	-279 to 100	81.8	63 to 100
Midbrain RF	4	-114.0*	-350 to 50	-345.7*	-900 to 12	-379.0*	-1650 to 86
Pontine RF	4	-42.5	-200 to 100	-69.2	-560 to 100	-100.0	-660 to 100

*Differed from the controls at least at the .05 level

Posterior neocortex. Three Ss received bilateral one-stage ablations of the posterior neocortex which completely destroyed Areas 17, 18, 18a, 41, and 7 of Krieg and partially damaged Areas 4, 3, 2, and 1 along with the caudal one-third of the cingulate and pyriform cortices (Fig. 2, bottom). The amount of damage to the total neocortical surface ranged from 59% to 65% (mean = 62.7%). In one of these animals, the hippocampus was intentionally ablated: the estimated extent of damage to the hippocampus was 90%.

Despite the extent of damage, all three Ss earned savings scores on Problems B and C that fell within the range earned by the controls. On Problem A, the animal with hippocampal damage earned a negative savings

score, while the remaining two earned scores of 73% and 100%.

Septal area. One rat sustained a bilateral one-stage lesion, destroying virtually the entire mediolateral and rostrocaudal extent of the septal region, including complete interruption of the fornix column (Fig. 3A). This animal showed perfect retention of Problems A and C, but exhibited a moderate loss on Problem B.

Amygdala. One animal sustained a massive one-stage

Fig. 2. Brain diagrams showing the largest (entire blackened area) and smallest (blackened area delimited by interrupted white lines) lesions in the anterior (top) and posterior (bottom) cortical groups.

Fig. 3. Unstained sections derived from two rats showing a septal (A) and an amygdaloid (B) lesion. Both animals exhibited defective retention of only one problem.

lesion which bilaterally destroyed major portions of the corticomedial and basolateral nuclei of the amygdaloid complex (Fig. 3B). After showing a moderate loss on Problem A, this S earned savings scores in excess of 95% on Problems B and C.

Anterior-medial thalamus. Four animals were subjected to multiple lesions (one-stage operations) which damaged varying amounts of the anterior, medial, lateral, and ventral nuclei of the thalamus (Fig. 4). Three Ss exhibited perfect retention of all problems, while the fourth showed a loss on Problems B and C. The latter S sustained the greatest amount of damage to the anterior thalamic nuclei.

Posterior thalamus. Three animals sustained extensive two-stage lesions which bilaterally damaged the nucleus posterior thalami, parafascicularis, and ventralis (Fig. 5). Two of these Ss failed to reach the criterion run on any one of the three problems despite their success in opening the door on most trials. The third animal, having a lesion of similar magnitude and locus to the other two, earned savings scores on the three problems which fell within the normal range.

Fig. 4. Unstained sections derived from three rats showing lesions of the anterior and medial thalamic nuclei. The latter exhibited defective retention of two problems, while the former two exhibited perfect retention of all three problems.

Fig. 5. Three unstained sections showing an extensive lesion of the posterior thalamus. This animal exhibited defective retention of all three problems.

Subthalamus. One S, sustaining a one-stage bilateral lesion to the subthalamic nucleus and subjacent cerebral peduncle (Fig. 6A), showed a serious impairment in retention of all three problems. Two additional Ss received one-stage bilateral lesions damaging the zona incerta at the level of the subthalamic nucleus. One of these Ss (Fig. 6B) showed slight retention losses (savings scores ranging from 50% to 63%) on all three problems, while the second showed slight retention losses on Problem A (40%) and Problem C (78%).

Pretectum. One animal, suffering extensive bilateral damage to the pretectal and subcollicular areas (one-stage operation), earned savings scores on all problems which fell within the range earned by the controls.

Superior colliculus. One animal with one-stage lesions and one with two-stage lesions suffered bilateral damage to the superior colliculus and adjoining pretectal area. The S with the largest lesion (Fig. 7A) exhibited perfect retention of all problems, while the second showed a moderate retention loss on Problem B only.

Ventral tegmental area. One animal, having bilateral one-stage lesions to the ventral tegmental area of Tsai,

Fig. 6. Unstained sections derived from two rats showing lesions of the subthalamus. Both animals exhibited defective retention of all three problems.

Fig. 7. Unstained sections derived from three rats showing lesions of the superior colliculus (A), ventral tegmental area (B), and substantia nigra (C). The former exhibited perfect retention of all three problems, while the latter two exhibited defective retention of two problems.

earned negative savings scores on Problems A and B, and achieved a savings score of 86% on Problem C (Fig. 7B).

Substantia nigra. In one animal, the substantia nigra was extensively damaged bilaterally (two-stage operation). This S earned a negative savings score on Problem A, failed to relearn Problem B, and died prior to testing retention of Problem C (Fig. 7C).

Red nucleus. Three rats sustained two-stage bilateral lesions to the area of the red nucleus. In all cases, the red nucleus received a significant amount of damage, but the lesions tended to be asymmetrical either in the lateral or vertical planes (Fig. 8). Two of these Ss earned negative savings scores on all problems, and the remaining S earned scores of zero or less on Problems A and C, while exhibiting perfect retention of Problem B.

Interpedunculo-central tegmental area. Four rats sustained midline lesions damaging various portions of the interpeduncular nucleus and/or the overlying central tegmentum (Fig. 9). Three animals showed defective retention of only one problem, and the fourth showed defective retention of Problems B and C.

Midbrain reticular formation. Three rats sustained

Fig. 8. Unstained sections derived from three rats showing lesions in the area of the red nucleus. The former two exhibited defective retention of all three problems, while the latter exhibited defective retention of two problems.

Fig. 9. Unstained sections derived from three rats showing lesions of the interpedunculo-central tegmental area. The former exhibited defective retention of two problems, while the latter two exhibited defective retention of only one problem.

Fig. 10. Unstained sections derived from three rats, showing lesions of the diencephalic reticular formation. The former two exhibited defective retention of all three problems, while the latter exhibited defective retention of two problems.

one-stage bilateral lesions to the rostromedial extension of the reticular formation at the diencephalic juncture. In all cases, the lesions began at the level of the anterior limb of the posterior commissure and terminated just oral to the red nucleus (Fig. 10). One of these Ss failed to relearn any of the three problems within the allotted 70 trials. The second S earned savings scores below 51% on all problems, and the third showed normal retention of Problem C, but earned negative savings scores on Problems A and B.

One additional rat sustained bilateral two-stage lesions to the reticular formation immediately caudal to the red nucleus. Negative savings scores were earned on the first two problems, and a score of 42% was earned on the last problem.

Pontine reticular formation. Four animals sustained one-stage bilateral lesions to the reticular formation at pontine levels. The nucleus reticularis pontis oralis was damaged in all cases. One S with a lesion immediately dorsal to the corticospinal tracts earned negative savings scores on all problems (Fig. 11). A second S with a similarly placed lesion, though somewhat smaller, earned a negative savings score on Problem A, but then showed perfect retention of Problems B and C. The remaining two Ss had more dorsally placed lesions which were asymmetrical in the lateral plane; one showed a slight

Fig. 11. Three unstained sections showing a lesion of the pontine reticular formation. This animal exhibited defective retention of all three problems.

retention loss on Problem C, while the other showed perfect retention of all three problems.

Summary

Of the 38 "motivated" brain-damaged animals involved in this experiment, 13 showed defective retention of all three latch box problems. Three sustained damage to the anterior neocortex, two to the posterior thalamus, two to the subthalamus, two to the red nucleus, three to the midbrain reticular formation, and one to the pontine reticular formation. An additional seven animals showed defective retention of two of the three problems. One suffered damage to the anterior-medial thalamus, one to the subthalamus, one to the midbrain reticular formation, one to the red nucleus, one to the substantia nigra (this animal died prior to testing of Problem C), one to the ventral tegmental area, and one to the interpedunculo-central tegmental area. The remaining 18 animals showed either normal retention of all three problems or defective retention of only one problem. Their lesions were found to be distributed within the posterior neocortex, hippocampus, cingulate cortex, pyriform cortex, septal area, amygdala, anterior-medial thalamus, posterior thalamus, pretectal area, superior colliculus, interpedunculo-central tegmental area, or pontine reticular formation.

Changes in Manipulatory Responses

As noted earlier, all five control animals exhibited virtually the same manipulatory responses to operate a particular latch in the retention test that were observed during the criterion run in original learning. This was also the case for 17 of the 18 brain-damaged animals showing normal retention of at least two of the three latch box problems.

A total of 11 brain-damaged animals, however, failed to employ the preoperatively used manipulatory responses on at least one of the three problems.¹ Of the 20 occurrences of this phenomenon, defective retention scores were earned in every case, except one. (The animal responsible for this exception suffered a posterior neocortical-hippocampal ablation). The newly observed manipulatory responses were "random" movements of the head and forepaws (10 occurrences), biting combined with head movements (6 occurrences), forepaw movements (2 occurrences), or head movements (2 occurrences). The preoperatively observed manipulatory responses in these Ss were head movements (12 occurrences), biting combined with head movements (3 occurrences), head and forepaw movements (3 occurrences), or forepaw movements (2 occurrences).

Two rats (one with posterior thalamic damage and one with damage to the rostral extension of the reticular formation at dimesencephalic levels) failed to exhibit a

distinctive manipulatory act that was repeatedly used to open any one of the latches—successful operation of each latch seemed to depend upon the right combination of random movements. Neither of these animals was able to reach the criterion run on any problem. One animal with rubral damage, one with subthalamic damage, one with nigral damage, and one with interpedunculo-central tegmental damage performed in random fashion on either Problem A or Problem B. Only the latter animal succeeded in relearning the problem (savings score = -279%).

Five animals switched from one kind of manipulatory response seen preoperatively to another postoperatively on two of the three problems. Four of these (one with anterior neocortical damage, one with subthalamic damage, one with rubral damage, and one with damage to the caudal mesencephalic reticular formation) showed defective retention of all three problems, while the fifth (damage to the substantia nigra) showed defective retention of two problems.

Finally, four animals employed a different kind of manipulatory response on only one problem. Two of these animals (one with damage to the pontine reticular formation and one with damage to the rostral extension of the reticular formation at dimesencephalic levels) showed defective retention of all three problems, one (damage to the interpedunculo-central tegmental area) showed defective retention of two problems, and one (damage to the posterior neocortex and hippocampus) showed defective retention of only one problem.

"Unmotivated" Animals

Nine brain-damaged animals performed in the apparatus in a manner suggesting a motivational and/or emotional involvement. Five failed to relearn any one of the three problems, and the remaining four earned negative savings scores on at least two of the three problems.

One of these Ss sustained bilateral ablations of the posterior neocortex, including Areas 4, 3, and 1 (72% damage to the total neocortical surface) and hippocampus (95% damage to its total volume). The entire posterior two-thirds of the cingulate cortex was destroyed along with portions of the septal nuclei and dorsal thalamus. This S spent most of his time exploring the startbox chamber and showed virtually no responsivity to the latches throughout the retention test.

Three rats received bilateral lesions to the caudate-putamen-pallidum complex by means of two-stage operations. One S, suffering damage mainly to the caudate nucleus at levels rostral to the anterior commissure, failed to relearn Problems A and B and died prior to testing on Problem C. The remaining two Ss sustained somewhat more posterior lesions which damaged significant amounts of the globus pallidus. Neither animal was able to relearn any one of the three problems within the allotted 70 trials. All three exhibited

a low motivational state throughout the retention test. Rather than proceeding directly to the door, they would either explore the startbox or cautiously extend their heads toward the door (or latch). When the door was opened (usually by the E), they frequently explored the goalbox before approaching the water dish. Responsivity to the latches was minimal. In fact, only one animal (Fig. 12) succeeded in unlocking the latches within 180 sec—68% of the time on Problem A, 23% on Problem B, and 33% on Problem C. After a period of hesitation, this S would approach the door and then vigorously attempt to operate the latch with manipulative movements of the head which did not resemble preoperative performance.

One animal sustained a huge one-stage bilateral lesion, destroying virtually the entire posterior one-fourth of the hypothalamus (Fig. 13). This rat failed to reach the criterion run on Problem A, earned a negative savings score on Problem B, and exhibited perfect retention of Problem C. This S showed very little responsivity to the latch on Problem A, making contact with the door or latch on 21 trials and successfully opening the door on only 11 trials. Responsivity to the latches abruptly increased on Problem B and continued at a high level on Problem C.

Three animals with lesions of the brainstem reticular

Fig. 13. Three unstained sections showing an extensive lesion of the posterior hypothalamus. This animal showed defective retention of two problems.

Fig. 12. Three unstained sections showing a lesion of the caudate-putamen-pallidum complex. This animal showed defective retention of all three problems.

formation appeared "frightened" throughout the retention test. They were slow to respond to the door or latch and frequently hesitated before entering the goalbox once the door was opened. In most instances, responsivity to the latch progressively increased from the first trial to the last within any daily session. Two of these Ss sustained two-stage bilateral lesions to the midbrain tegmentum immediately lateral to the red nucleus, while the third received one-stage bilateral lesions to the reticular formation at diencephalic levels. All three rats relearned Problem A with negative savings scores, but failed to reach the criterion run on Problems B and C.

Finally, one rat was subjected to a one-stage operation in which the cerebellum was ablated bilaterally. Only a small fragment of the paraflocculus was spared. This S exhibited the typical cerebellar syndrome (locomotor ataxia). Although vertical and horizontal movements of the head appeared to be intact, this animal failed to make any attempt to operate the latches throughout the retention test.

DISCUSSION

Preliminary Considerations

It must be emphasized at the outset that attainment

of the criterion run on each latch box problem (postoperatively as well as preoperatively) appeared to depend upon the formation (learning) and utilization of coordinated manipulatory movements of the head, teeth, and/or forepaws rather than an outburst of haphazard acts directed toward the latch. This conclusion is based upon the following observations: (a) Although all latches were often opened by means of "random" movements during the early trials of original learning, each animal gradually exhibited a distinctive manipulative act in operating a particular latch which was consistently observed throughout the criterion run, (b) in most cases, responsivity to the latches reached a peak during the early trials of original learning rather than reaching a peak just prior to (or during) the attainment of the criterion run, (c) each animal composing the control group (and 17 of the 18 brain-damaged animals exhibiting excellent retention of at least two of the three problems) used virtually the same manipulative act in opening a particular latch in the retention test that was used in original learning, (d) of the 6 brain-damaged animals consistently displaying an outburst of haphazard acts during the retention test of a particular problem, 5 failed to relearn the problem and 1 earned negative savings scores, and (e) of the 20 occurrences in which a different manipulative act was employed postoperatively, 19 resulted in defective retention scores.

It is also important to note that the defective retention scores earned on the latch box problems do not necessarily reflect an "apraxic" disturbance. Although none of the motivated brain-damaged animals appeared to be suffering from paralysis, sluggishness of movement, or a disturbance in tone, no neurological tests were applied to assess the integrity of the motor system. Conceivably, such tests might have disclosed defects in postural and other reflex mechanisms which are essential for the expression of even semi-skilled movements.

Neocortical Lesions

In contrast to Lashley's (1935) findings, a high degree of localization of function at the neocortical level was found for the performance of latch box problems. The three animals with anterior neocortical ablations showed retention losses on all three problems. On the other hand, the three animals with posterior neocortical ablations exhibited normal retention of at least two of the three problems. While the number of animals comprising each group is small, the results are nevertheless dramatic when it is considered that the posterior ablations were substantially more extensive (mean damage of 62.7%) than the anterior ablations (mean damage of 30.0%). The extent to which the discrepancy between our results and those of Lashley is a function of the study of acquisition (Lashley's experiment) vs retention (current experiment) is not

entirely clear. The finding that all three animals of the anterior group failed to relearn Problem B and earned negative savings scores on Problem C suggests that the acquisition-retention variable is not totally responsible for the difference in outcomes of the two experiments. Although differences in the difficulty of the latch box problems could conceivably account for the disparate results, such a possibility appears very unlikely. The most difficult manipulative task used by Lashley was the single lever problem which was learned by the control group in an average of 36.0 trials. This problem failed to differentiate the control group from the brain-damaged group. The three latch box problems which successfully differentiated the groups in Lashley's study (paper strip, spring door, and pull chain) required anywhere from 1 to 29 trials for mastery. These scores are comparable to those obtained on Problem A of the current study (see Table 1). Differences in the nature of the manipulative responses used to operate the latches might provide a basis for explaining the conflicting results. In Lashley's experiment, most of the animals were observed to use their forepaws in manipulating the latches. In contrast, the majority of animals in the current study employed manipulative movements of the head to operate the latches. In order to construct an explanation based upon this difference, it would be necessary to assume that digital usage is a nonlocalized function which is equally dependent upon the activities of both the anterior and posterior halves of the cerebrum. Such an assumption does not fit in with current neuropsychological views and, moreover, is totally at variance with the recent lesion study by Castro (1972) on digital usage in the rat.

In the face of the foregoing abortive attempts to reconcile the different outcomes (and conclusions) of the two experiments, we reanalyzed Lashley's data² and discovered that anterior cortical lesions did, in fact, tend to produce greater retardation in latch box learning than did posterior cortical lesions. It now appears that Lashley's results are more in line with our own, at least to the extent that the anterior (sensorimotor) cortex is more concerned with the formation and execution of manipulative responses than is the posterior (visual) cortex.

Subcortical Lesions

The present study also disclosed a considerable amount of localization of function at subcortical levels. No serious disturbance in retention of more than one problem was observed in the presence of extensive damage to either the hippocampus, cingulate cortex, pyriform cortex, septal area, amygdala, preteectum, or superior colliculus. Those subcortical regions which were found to be critical for normal retention of all three latch box problems include the posterior thalamus, subthalamus, red nucleus, and the brainstem reticular formation.

It is not unreasonable to assume that the substantia

nigra, cerebellum, and corpus striatum also belong to the above-mentioned group of subcortical structures critical for the expression of manipulative acts. Although our animal with nigral damage expired prior to the retention test of Problem C, his performance on the first two tasks clearly reflected a dramatic loss in retention. Furthermore, this animal failed to employ in the retention test those distinctive manipulative responses that were used preoperatively. With respect to the cerebellum, the gross postural disturbances and poverty of movements in the presence of a bilateral cerebellectomy can hardly be viewed as conditions favorable to the performance of manipulative acts. The recent report that small cerebellar lesions impair forelimb reaching movements in cats (Chambers, Konorski, Liu, & Anderson, 1972) further attests to the significance of the cerebellum in the execution of manipulatory responses. Concerning the corpus striatum, the one "responsive" animal with caudate-putamen-pallidum damage, on occasion, vigorously attacked the latch during the retention test of each problem. In every instance, however, this animal was unable to operate the latch within 5 sec and, moreover, failed to exhibit those manipulative acts employed preoperatively. Further support for the notion that sensorimotor disorders (independent of an emotional-motivational involvement) can arise from damage to the corpus striatum comes from the findings that unilateral lesions of either the caudate nucleus (Hansing, Schwartzbaum, & Thompson, 1968) or globus pallidus (Levine, Ferguson, Kreinick, Gustafson, & Schwartzbaum, 1971) abolish lever pressing with the forepaw contralateral to the lesion without altering responsiveness of the ipsilateral forepaw.

On the strength of the foregoing analysis, it is proposed that the *sensorimotor cortex, corpus striatum, posterior thalamus, subthalamus, red nucleus, substantia nigra, brainstem reticular formation, and the cerebellum* comprise the main components of the "manipulative response memory system" in the rat.

Comparison of Four Specific Memory Systems

The visual memory system (VMS) has been found to be composed of the posterior (visual) cortex, posterior thalamus, posterolateral hypothalamus (and probably adjacent subthalamus), interpedunculo-central tegmental area, red nucleus, substantia nigra, and the brainstem reticular formation (Thompson, 1969; Thompson & Thorne, 1973).

The kinesthetic memory system (KMS) includes all of the foregoing brainstem structures composing the VMS (Thompson et al, 1967; Thompson & Thorne, 1973). However, while the sensorimotor cortex and the corpus striatum are components of the KMS, the visual cortex is not (Lashley, 1929; Thompson et al, 1961).

The conditioned avoidance response memory system (CARMS) also contains all of the brainstem structures

composing the VMS (Thompson et al, 1964). Other components of the CARMS include the sensorimotor cortex (Thompson, 1964), elements of the limbic system, such as the cingulate cortex, hippocampus, septal area, and amygdala (Rich & Thompson, 1965), virtually all nuclei of the medial and anterior thalamus (Rich and Thompson, 1965), and probably the corpus striatum (Mitcham & Thomas, 1972) and cerebellum.

As shown in the current study, the components of the manipulative response memory system (MRMS) roughly correspond to those making up the KMS.

The overall results derived from the mapping of four different memory systems in the white rat are of interest for a number of reasons. First, they show that the expression of previously learned responses is generally dependent upon the integrity of a limited number of structural units within the brain. The degree of localization appears to be relatively high for conventional two-choice discrimination habits based upon visual or kinesthetic stimuli, low for conditioned avoidance responses, and intermediate for latch box problems. While these findings demonstrate that disturbances in retention of learned responses may develop from lesions in widely separated parts of the brain, they can hardly be taken as support for the notion that virtually all cortical and subcortical tissue participates in the mechanisms of storage, retrieval, and utilization of memory traces (Eccles, 1966; John, 1967; McConnell, 1968; Pribram, 1969), nor can they be reconciled with the view that the extent of any lesion-induced "amnesia" is a function of the amount of tissue destruction independent of its locus (Lashley, 1929, 1950).

Second, all four specific memory systems have areas of overlap within the posterior diencephalon (nucleus posterior thalami, lateral hypothalamo-subthalamic area, and the rostral extension of the brainstem reticular formation), ventral mesencephalon (red nucleus, substantia nigra, and midbrain reticular formation), and pontine reticular formation. As pointed out earlier (Thompson & Thorne, 1973), these areas of the brainstem may constitute the common denominator for all specific memory systems, and tentatively qualify as the "general" memory system of the brain. Furthermore, since these brainstem regions roughly parallel the trajectory of the ascending reticular activating system (Moruzzi & Magoun, 1949) and conspicuously coincide with the brainstem reticular core (Scheibel & Scheibel, 1958) as well as the cholinergic reticular system (Shute & Lewis, 1967), the possibility must be considered that the proposed general memory system and the brainstem reticular formation are coextensive.

Third, in those three specific memory systems in which the anterior neocortex is included (KMS, CARMS, and MRMS), the corpus striatum is also included. These results provide striking confirmation, at the rodent level, of Rosvold's contention (1968) that the frontal cortex

and the caudate nucleus comprise a functional system to the extent that behavioral deficits induced by lesions of one are duplicable by lesions of the other. On the other hand, the notion that the substantia nigra and the caudate nucleus constitute a similarly organized functional system (Mitcham & Thomas, 1972; Ungerstedt, 1971) may have to be qualified. With respect to retention of visual discrimination habits, for example, extensive damage to the caudate nucleus has only slight effects when compared to those induced by nigral damage (Thompson, 1969).

Fourth, the only specific memory system encompassing the anterior-medial thalamic complex and the major components of the limbic system is the CARMS. This finding suggests that these structures of the brain become significant in retention only when *the learned response is initiated and maintained by the fear drive*.

Fifth, the two specific memory systems that bear the greatest similarity to each other are the MRMS and the KMS. This finding is especially intriguing when it is considered that the tasks used to map each system were grossly dissimilar—operation of latches vs selection of an upward (as opposed to a downward) sloping pathway. These results not only emphasize the kinesthetic basis of learned manipulative responses, but further suggest that the afferent (kinesthetic) and efferent (motor) elements participating in the expression of skilled movements may be inextricably organized within the same regions of the brain. These notions bear a striking resemblance to those emerging from the analysis of the pathophysiological mechanisms of voluntary activity in humans (Luria, 1966).

Some Functional Considerations

The finding that the MRMS and the KMS inhabit practically the same cortical and subcortical regions suggests that the retention losses on manipulative tasks seen in our brain-damaged rats are manifestations of a disorganization of the afferent (kinesthetic) systems underlying the "construction" or "control" of the manipulative act rather than a disorganization of the efferent (motor) systems evoking the manipulative act. This suggestion is consistent with the observations that none of the lesions investigated in the current study abolished from the animal's response repertory those acts which are sufficient to operate the latches, such as vertical and lateral head movements, biting, and movements of the forepaws. Thus, disturbances either in the "stream of volitional impulses" (Penfield, 1954), "corollary discharge" (Teuber, 1964), "kinetic organization of movement" (Luria, 1966), "body image" (Schilder, 1950), "central facilitory set" (Sperry, 1955), or other like "functions" having a kinesthetic basis probably characterize the impairments in latch box performance more aptly than paralysis, muscular weakness, or hypokinesia. (The impairments observed in

the cerebellectomized animal, however, may constitute the only exception). Even some sort of amnesia for certain elements of the latch box situation cannot be overlooked. To illustrate, those animals showing defective retention of all three problems required a considerable amount of time to operate each latch during the early trials of the retention test due to a persistence in responding to that section of the door *located immediately below the latch*. These misdirected responses can hardly reflect a visuomotor disturbance because our occipitlectomized animals neither responded in this fashion nor did they earn defective retention scores on more than one problem.

The extent to which any one (or any combination) of the foregoing disturbances developed in the presence of anterior cortical, corpus striatal, posterior diencephalic, ventral mesencephalic, or metencephalic damage cannot be determined from the results of the current experiment. However, it is not unreasonable to suppose that the retention losses induced by anterior cortical and corpus striatal lesions resulted from disorders in the initiation (Breen & Thompson, 1966; Levine et al, 1971), programming (Konorski, 1972; Luria, 1966; Penfield, 1954), correction (Bossom, 1965; Luria, 1966; Rosvold, 1968), and/or inhibition (Buchwald, Wyers, Lauprecht, & Heuser, 1961; Konorski, 1972) of response mechanisms.

The role of the brainstem reticular formation in the performance of latch box problems must be viewed from the broader perspective that lesions of this anatomical system (including the subthalamic area, nucleus posterior thalami, red nucleus, and substantia nigra) impair retention of a wide variety of learned tasks, including visual and kinesthetic discriminations, conditioned avoidance responses, and maze habits (see Thompson & Thorne, 1973). The notion that these generalized amnesic effects are due to a depression of cortical function (Luria, 1970) cannot be entirely ruled out. However, the lesions investigated in the current study were small and failed to produce somnolence in any of our rats. In fact, the majority of rats with brainstem reticular formation lesions were highly motivated to gain entrance into the goalbox and exhibited a degree of responsivity to the door and latches which was hardly suggestive of either a comatose state, lethargy, or even inattention.

The possibility that the brainstem reticular formation plays a central role in learning and memory cannot be ignored, especially in the light of the recent studies of Olds and his associates (Disterhoft & Olds, 1972; Olds, Segal, Hirsh, Disterhoft, & Kornblith, 1972) on the identification of those units of the brain that exhibit "conditioned responses" with the shortest latencies. Although these units were identified at cortical as well as subcortical levels, their distribution within the brainstem remarkably coincides with the reticular regions that have been found to be important for the expression of various learned habits, including learned manipulative responses

(see Thompson & Thorne, 1973). Thus, these neurophysiological results coupled with our lesion data constitute sufficient grounds for reexamining those notions relating the brainstem reticular system to engrammic formation (Gastaut, 1958) and "executive" functions (Penfield, 1954; Thompson, 1965).

REFERENCES

- Bossom, J. The effect of brain lesions on prism-adaptation in monkey. *Psychonomic Science*, 1965, 2, 45-46.
- Breen, T., & Thompson, R. Cortical and subcortical structures mediating a visual conditioned response motivated by thirst. *Journal of Comparative & Physiological Psychology*, 1966, 61, 144-150.
- Buchwald, N. A., Wyers, E. J., Lauprecht, C. W., & Heuser, G. The "caudate-spindle": IV. A behavioral index of caudate-induced inhibition. *Electroencephalography & Clinical Neurophysiology*, 1961, 13, 531-537.
- Castro, A. J. The effects of cortical ablations on digital usage in the rat. *Brain Research*, 1972, 37, 173-186.
- Chambers, W. W., Konorski, J., Liu, C. N., Yu, J., & Anderson, R. The effects of cerebellar lesions upon skilled movements and instrumental conditioned reflexes. *Acta Neurobiologiae Experimentalis*, 1972, 32, 721-732.
- Disterhoft, J. F., & Olds, J. Differential development of conditioned unit changes in thalamus and cortex of rat. *Journal of Neurophysiology*, 1972, 35, 665-679.
- Eccles, J. C. Conscious experience and memory. In J. C. Eccles (Ed.), *Brain and conscious experience*. New York: Springer-Verlag, 1966.
- Gastaut, H. The role of the reticular formation in establishing conditioned reactions. In H. H. Jasper (Ed.), *Reticular formation of the brain*. Boston: Little, Brown, 1958.
- Hansing, R. A., Schwartzbaum, J. S., & Thompson, J. B. Operant behavior following unilateral and bilateral caudate lesion in the rat. *Journal of Comparative & Physiological Psychology*, 1968, 66, 378-388.
- Jacobsen, C. F. Influence of motor and premotor area lesions upon the retention of skilled movements in monkeys and chimpanzees. *Proceedings of the Association on Research in Nervous & Mental Diseases*, 1932, 13, 225-247.
- John, E. R. *Mechanisms of memory*. New York: Academic Press, 1967.
- Konorski, J. Some hypotheses concerning the functional organization of prefrontal cortex. *Acta Neurobiologiae Experimentalis*, 1972, 32, 595-613.
- Krieg, W. J. S. Connections of the cerebral cortex: I. The albino rat: A. Topography of the cortical areas. *Journal of Comparative Neurology*, 1946, 84, 221-275.
- Lashley, K. S. Studies of cerebral function in learning. V. The retention of motor habits after destruction of the so-called motor areas in primates. *Archives of Neurology & Psychiatry*, 1924, 12, 249-276.
- Lashley, K. S. *Brain mechanisms and intelligence*. Chicago: University of Chicago Press, 1929.
- Lashley, K. S. Studies of cerebral function in learning. XI. The behavior of the rat in latch box situations. *Comparative Psychological Monographs*, 1935, 11, 1-42.
- Lashley, K. S. In search of the engram. *Symposia of the Society for Experimental Biology*, 1950, No. IV, 454-482.
- Levine, M. S., Ferguson, N., Kreinick, C. J., Gustafson, J. W., & Schwartzbaum, J. S. Sensorimotor dysfunctions and aphagia and adipsia following pallidal lesions in rats. *Journal of Comparative & Physiological Psychology*, 1971, 77, 282-293.
- Luria, A. R. *Higher cortical functions in man*. New York: Basic Books, 1966.
- Luria, A. R. The functional organization of the brain. *Scientific American*, 1970, 222, 66-78.
- McConnell, J. V. The modern search for the engram. In W. C. Corning and M. Balaban (Eds.), *The mind: Biological approaches to its functions*. New York: Wiley, 1968.
- Mitcham, J. C., & Thomas, R. K. Effects of substantia nigra and caudate nucleus lesions on avoidance learning in rats. *Journal of Comparative & Physiological Psychology*, 1972, 81, 101-107.
- Moruzzi, G., & Magoun, H. W. Brain stem reticular formation and activation of the EEG. *Electroencephalography & Clinical Neurophysiology*, 1949, 1, 455-473.
- Olds, J., Disterhoft, J. F., Segal, M., Kornblith, C. L., & Hirsh, R. Learning centers of rat brain mapped by measuring latencies of conditioned unit responses. *Journal of Neurophysiology*, 1972, 35, 202-219.
- Penfield, W. Studies of the cerebral cortex of man: A review and an interpretation. In J. F. Delafresnaye (Ed.), *Brain mechanisms and consciousness*. Springfield, Ill: Thomas, 1954.
- Pribram, K. H. The neurophysiology of remembering. *Scientific American*, 1969, 220, 73-86.
- Pribram, K. H., Kruger, L., Robinson, F., & Berman, A. J. The effects of precentral lesions on the behavior of monkeys. *Yale Journal of Biology & Medicine*, 1955, 28, 428-443.
- Rich, I., & Thompson, R. Role of the hippocampo-septal system, thalamus, and hypothalamus in avoidance conditioning. *Journal of Comparative & Physiological Psychology*, 1965, 59, 66-72.
- Rosvold, H. E. The prefrontal cortex and caudate nucleus: A system for effecting correction in response mechanisms. In C. Rupp (Ed.), *Mind as a tissue*. New York: Harper & Row, 1968.
- Scheibel, M. E., & Scheibel, A. B. Structural substrates for integrative patterns in the brain stem reticular core. In H. H. Jasper (Ed.), *Reticular formation of the brain*. Boston: Little, Brown, 1958.
- Schilder, P. *The image and appearance of the human body*. London: Kegan Paul, 1950.
- Shute, C. C. D., & Lewis, P. R. The ascending cholinergic reticular system: Neocortical, olfactory and subcortical projections. *Brain*, 1967, 90, 497-520.
- Siegel, S. *Nonparametric statistics for the behavioral sciences*. New York: McGraw-Hill, 1956.
- Sperry, R. W. On the neural basis of the conditioned response. *British Journal of Animal Behaviour*, 1955, 3, 41-44.
- Teuber, H. L. The riddle of frontal lobe function in man. In J. M. Warren and K. Akert (Eds.), *The frontal granular cortex and behavior*. New York: McGraw-Hill, 1964.
- Thompson, R. A note on cortical and subcortical injuries and avoidance learning by rats. In J. M. Warren and K. Akert (Eds.), *The frontal granular cortex and behavior*. New York: McGraw-Hill, 1964.
- Thompson, R. Centrencephalic theory and interhemispheric transfer of visual habits. *Psychological Review*, 1965, 72, 385-398.
- Thompson, R. Localization of the "visual memory system" in the white rat. *Journal of Comparative & Physiological Psychology Monograph*, 1969, 69, 1-29.
- Thompson, R. Introducing subcortical lesions by electrolytic methods. In R. D. Myers (Ed.), *Methods in psychobiology*. New York: Academic Press, 1971.
- Thompson, R., Lukaszewska, I., Schweigerdt, A., & McNew, J. J. Retention of visual and kinesthetic discriminations in rats following pretecto-diencephalic and ventral mesencephalic damage. *Journal of Comparative & Physiological Psychology*, 1967, 63, 458-468.
- Thompson, R., Malin, C. F., & Hawkins, W. F. Effect of subcortical lesions on retention of a kinesthetic discrimination habit. *Experimental Neurology*, 1961, 3, 367-374.
- Thompson, R., Rich, I., & Langer, S. K. Lesion studies on the functional significance of the posterior thalamo-mesencephalic tract. *Journal of Comparative Neurology*, 1964, 123, 29-44.

- Thompson, R., & Thorne, B. M. Brainstem reticular formation lesions: Amnesic effects on learned habits in the rat. *Physiological Psychology*, 1973, 1, 61-70.
- Ungerstedt, U. Stereotaxic mapping of the monoamine pathways in the rat brain. *Acta Physiologica Scandinavica*, 1971, Supplementum 367, 1-48.

NOTES

1. The postoperatively used manipulative response on a particular problem was considered to differ from the preoperatively used manipulative response only when S consistently employed head, teeth, and/or forepaw movements which were not observed singly or in combination with any other movements preoperatively. Thus, the preoperative use of forepaw movements followed by the postoperative use of head movements was counted as a change in the manipulative response. On the other hand, the preoperative use of forepaw movements followed by the postoperative use of forepaw and head movements was not counted as a change in the manipulative response.

2. We divided Animals 31-53 into an "anterior" cortical group (those animals having lesions which extended anterior to Level 10 on the brain diagrams used—this corresponds to Level 6 on our diagrams) and a "posterior" cortical group (those animals having lesions which did not extend anterior to Level 10). For each animal, we pooled the trial scores earned on the three latch box problems that successfully differentiated the control group from the brain-damaged group. The resulting means were 28.2 (control group), 60.6 (posterior group), and 95.1 (anterior group). Using the Mann-Whitney nonparametric test (one-tailed test), the differences between the control group and each operated group were significant ($p < .01$) and the difference between the two operated groups was also significant ($p = .05$). Since the extent of neocortical damage suffered by the two groups was virtually equivalent (29.8% for the anterior group and 28.4% for the posterior group), the difference in trial scores can be assumed to be the result of the difference in the locus of the lesions.

(Received for publication February 6, 1973;
revision received April 23, 1973.)