ROLE OF ASSOCIATION CORTEX IN CONDITIONAL DISCRIMINATIONS IN CAT

by

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CONTENTS

INTRODUCTION

The function of the "association" areas of the cerebral cortex might well be considered the pièce de résistance for physiological psychology. Even before much evidence was collected about these areas, theories were promulgated which held that the "silent" areas were responsible for the integration of impulses transmitted directly to them from the primary sensory areas of the cortex. The "association" areas are now being studied by a variety of techniques including ablation, mapping of evoked potentials, recording from implanted electrodes and electrical stimulation of the brain of the unanesthetized animal. The results of some recent mapping and ablation studies will now be considered.

When a cat anesthetized with chloralose is stimulated by means of a click, and electrical changes on the surface of the brain are viewed oscilloscopically, short-latency, surface-positive, evoked potentials are found on the middle ectosylvian gyrus (66). These electrical waves are "primary responses" and are characterized by onset latencies of 7 to 9 milliseconds and amplitudes reaching 2.5 millivolts. Similar responses are found on the posterior lateral gyrus when the stimulus is a light flash and on the posterior sigmoid gyrus when the stimulus is a shock to the skin of a paw (75). These response fields constitute

the major primary sensory areas of the cerebral cortex of the cat.

In addition to the primary evoked potentials, longer-latency surface-positive responses to click have been found on the anterior sigmoid gyrus, the anterior lateral gyrus and in two foci on the middle suprasylvian gyrus (65,66). The response field on the anterior sigmoid gyrus has been found to extend along the lower bank of the cruciate sulcus. This field thus overlaps extensively with the precentral motor area. These electrical waves are called "association responses" and are characterized by onset latencies of 15 to 30 milliseconds and amplitudes which are usually less than 1 millivolt. The positive component of these responses is of longer duration than that of the primary response. Responses of the same type and distribution are seen in these same four areas when visual or tactile stimulation is employed (65). The responses in each of these areas are more variable than the primary responses, but tend to occur synchronously with responses in the other three association fields. These four response fields constitute the association response areas of the cerebral cortex of the cat.

Thompson and Sindberg (66) demonstrated that the four association response fields are unaltered by chronic ablation of AI, AII, Ep, SII, and insular-temporal areas bilaterally. The authors pointed out that this finding

suggests the possibility that the principle input to these association fields is derived from subcortical sources. Theories which hold that the principal function of the association areas is to integrate impulses derived directly from the primary sensory areas (29, 40) may require considerable revision in the light of these findings.

When two clicks are presented sequentially at a time interval greater than 0.2 seconds, the evoked response recorded in the primary auditory area to the second click has approximately the same amplitude as the response to the first click. With progressively shorter intervals, the response to the second click declines in amplitude, and finally fails to appear when the interval between clicks is reduced to approximately 25 milliseconds (65). The same phenomenon is observed when responses in the primary visual area are recorded to sequential light flashes, and when responses in the primary somatic sensory area are recorded to sequential shocks to the contralateral forepaw.

When association responses are recorded from the suprasylvian gyrus to sequential clicks, the response to the second click has the same amplitude as the response to the first click if the interval between the clicks is 1.0 second or greater. As the interval is progressively reduced below 1.0 second, the response to the second click declines in amplitude, and fails to appear when the interval is 0.2 second. Thus, the relative and absolute refractory periods

of the association system are longer than those of the primary systems. The findings in the suprasylvian association fields are the same when sequential shocks to the contralateral forepaw are employed. Furthermore, the same phenomenon holds when the first and second stimuli differ in modality. The results are the same for all combinations of the three modalities tested. The authors (65) interpret these results to imply that the three modalities share some neurophysiologic mechanism necessary to the appearance of association responses to adequate peripheral stimulation.

Thus, there is evidence for four long-latency response fields to peripheral stimulation in each cerebral hemisphere of the cat: two on the middle suprasylvian gyrus, one on the anterior lateral gyrus and one on the anterior sigmoid gyrus. The form and distribution of these responses are the same for auditory, visual and tactile stimulation, and the three modalities apparently utilize a common neurophysiologic mechanism which has longer relative and absolute refractory periods than the primary systems.

Starzl and Magoun (61) found the recruiting response to thalamic stimulation to be distributed in the association areas of the cat. Rutledge and Kennedy (59) electrically stimulated the suprasylvian gyrus in chloralosed cats. They recorded a contralateral surface-positive delayed wave complex following the typical transcallosal response. The delayed waves were also seen ipsilaterally. These waves

were best seen in association areas, especially on the suprasylvian gyrus, and were maximal when the stimulus interval exceeded 1 second. The authors suggest that these waves are probably mediated by subcortical conduction through a diffuse multisynaptic system.

Buser and Imbert (12) recorded with microelectrodes from single units in the anterior sigmoid gyrus of cats under chloralose. These investigators found that many units were polyvalent, responding to peripherally applied visual, auditory and tactile stimulation.

Doty, Rutledge and Larsen (17) were able to condition unanesthetized cats to respond by foreleg flexion (CR) to electrical stimulation of the brain (CS) to avoid shock (US). Conditioning occurred when points within the marginal, postlateral, middle suprasylvian and middle and posterior ectosylvian gyri were stimulated. Bilateral trigeminal neurotomy was used to denervate surrounding tissues. Removal of both cortex and meninges in the area of electrode implantation permanently abolished the conditioned reflexes.

What happens to the behavior of a cat after a lesion is made in its association cortex? Meyer and Woolsey (39) demonstrated that bilateral removal of AI, AII, Ep, the suprasylvian gyrus, cerebellar tuber vermis, and temporal cortex in four stages resulted in no deficiency in a cat's ability to discriminate between 1000 c.p.s. and 1100 c.p.s. tones. A massive bilateral one-stage lesion in the cortex

posterior to a vertical line through the anterior limb of the suprasylvian sulcus did not destroy the capacity of a cat to make the frequency discrimination, but retraining was necessary and required about as many trials as the initial preoperative training had. Neff, Fisher, Diamond and Yela (43) performed bilateral ablations of cortex in the suprasylvian and lateral gyri as controls for cats with auditory cortex lesions in an experiment on retention of a preoperatively learned sound localization habit. The suprasylvian controls showed no postoperative deficit.

Hara and Warren (26) trained 9 cats to discriminate visual figures and gave them tests of stimulus equivalence. Five cats were subjected to bilateral lesions in the suprasylvian gyrus. The cats were retested 11 months after training. The operated cats showed slightly greater median savings scores (in trials to relearn) than did the normal controls. The same investigators (27) trained cats in discriminations involving form, size and brightness. Cats then submitted to suprasylvian lesions were not significantly inferior to unoperated controls upon retesting. Preoperatively, brightness was dominant over form and size, but operated animals no longer showed such a preference.

Warren and Sinha (72) found that lesions in the suprasylvian gyrus increased the threshold in visual size discriminations. Billett and Warren (5) compared cats with prefrontal lesions and cats with prestriate lesions to

normal cats with regard to performance on an Umweg problem in a Hebb-Williams maze. The cats with prefrontal lesions were inferior to the normal control group both in original learning and retention, and the cats with suprasylvian lesions were inferior to both of the other groups. Warren, Warren, and Akert (73) trained cats in a Hebb-Williams maze and found cats with bilateral suprasylvian lesions to be inferior to both normal cats and cats with orbitofrontal lesions on original learning. Upon retesting about 7 months later, the cats with suprasylvian lesions were found to be inferior to both groups. Two cats that were subjected to suprasylvian lesions after training showed no less in retention at postoperative testing. Lesions in the suprasylvian gyrus interfered more with initial learning than with retention.

The lesion studies quoted so far have involved discriminations primarily within one sensory modality. However, the three major modalities are represented in the association fields. What would be the effect of a lesion in the association fields of the cat cerebral cortex upon the ability of the cat to learn a discrimination demanding some sort of integration of information from more than one sensory modality?

Evarts (19) trained monkeys (Macaca mulatta) to look for food under a green cover if a buzzer was on, but under a red cover if the buzzer was not on. Some subjects were

trained before and some after bilateral ablation of prestriate cortex (area 18). The lesions resulted in no loss of a preoperatively learned habit. Learning was not retarded when initial training was carried out postoperatively.

Since the cortical homologies between cats and primates have not been adequately established, it is difficult to compare lesions made in the "association areas" of cats to those made in "association areas" of monkeys. Thompson[1] has found that the foci of long-latency "association" evoked potentials in the squirrel monkey (Saimiri sciureus) do not include the parieto-temporo-preoccipital "association" region.

Leary, Harlow, Settlage and Greenwood (37) trained rhesus monkeys on a series of double alternation problems. There were four normal, unoperated control animals. The operated animals, eight in number, all had extensive unilateral lesions. Four of these operated animals had, in addition, extensive damage to contralateral posterior association areas, while the other four had, in addition to the unilateral lesion, extensive damage to the contralateral anterior association cortex. In general, the performance of the groups showed the normals to be superior to both lesion groups, and the posterior lesion group to be superior to the anterior lesion group.

[1]Thompson, R.F. Personal communication, 1962.

Chow, Blum and Blum (15) tested monkeys (Macaca mulatta) which were subjected to bilateral removal of frontal granular cortex subsequent to bilateral parieto-temporo-preoccipital ablations. These animals were found to be deficient in somesthetic discrimination problems, a conditional reaction problem and delayed response problems. No deficits appeared in visual discrimination problems or in a learned auditory association. General activity was found to be greatly increased.

None of the cited studies of association area lesions in cats encompassed all of the areas of evoked association responses. The purpose of the present study was to attempt to discover whether lesions in the known foci of evoked "association" responses in the cat cerebral cortex would result in impaired performance of a conditional discrimination problem designed to require the utilization of information from two separate sensory modalities for successful solution.

METHODS

Conditioning Apparatus and Procedure

In the present study an attempt was made to train adult cats to run in a modified form of the Brogden-Culler rotating cage (8) when a tone and light were presented simultaneously, but to remain motionless when either the tone or the light was presented alone.

The rotating cage was constructed of two plexiglass sides, 30 inches in diameter, set 6 inches apart. The sides were connected at their circumference by 3/16 inch brass rods placed ½ inch apart. Through these rods a shock could be delivered to the feet of a cat inside the cage. The rotating cage was provided with a tension adjustment which allowed ease of turning to be roughly equated for cats of different weights.

The cage sat inside a fiberglass-lined box, the inside dimensions of which were 29 by 69 inches. This box was fitted with a plexiglass door and sat inside another box, the outside dimensions of which were 7½ by 3½ feet. The two boxes were separated by a three inch dead air space. The outside box had 3-inch-thick plywood walls, and a door provided with a one-way glass. The inner box was dimly illuminated by enclosed light bulbs. This arrangement allowed the operator to view the subject without being seen, and provided a sound attenuation of 35-50 db.

The auditory stimulus was a pure 1000 c.p.s. tone, generated by a Hewlett-Packard wide range oscillator and filtered high and low by a Spencer-Kennedy variable electronic filter. The level of the tone was adjusted to 50 db by means of a Hewlett-Packard attenuator set. A Grason-Stadler electronic switch provided a rise-fall time of 50 milliseconds. The tone was delivered into the conditioning box through a speaker, set in the ceiling of the inside box, at a height of 2 feet above the rotating cage. A microphone within the inside box enabled the operator to hear the auditory stimulus.

The visual stimulus was provided by two 100 watt bulbs, one of which was placed at a distance of 7 inches from either end of the rotating cage, such that the subject would always be facing an illuminated bulb when the visual stimulus was presented.

All stimuli were of 2-second duration. Timing and triggering of stimuli and shock were effected by means of Tektronix 162 waveform generators and 161 pulse generators. Nine programs composed of ten presentations each of BOTH (B: simultaneous presentation of light and tone), LIGHT (L: light alone) and TONE (T: tone alone) were designed, and were arranged in restricted random orders. Not more than three consecutive presentations of a given stimulus were permitted. Not more than four consecutive presentations of T and L were allowed to occur between

presentations of B. These restrictions were suggested by the findings of an exploratory study. All cats rotated through the same programs in the same order.

The shock was produced by an amplifier-transformer system designed to automatically maintain a constant current. The current did not exceed 10 milliamperes and was usually less than 5 milliamperes. Shock was always administered at the end of a presentation of B if the cat had not turned the wheel during the presentation. The shock was set to occur automatically with the termination of B unless stopped manually (as when a response had occured). Presentation of T and L were never followed by shock. Shock level was adjusted to the minimum necessary to maintain cage-turning responses to the shock. Manual repetitive shock was available to help overcome balking. Initial shock levels were subthreshold. With each presentation of B the shock level was increased until the animal made a locomotor response to the shock.

Interstimulus interval was systematically varied to avoid temporal conditioning. Stimuli were typically administered at 5-, 10-, or 15-second intervals after the subject assumed a motionless waiting posture. Longer intervals were occasionally used, as, for example, following a shock which evoked an unusually marked behavioral response. The intervals mentioned were selected because they seemed to guarantee optimal attentiveness on the part

of the exploratory group of cats. At longer intervals, anxious cats tended to emit spontaneous movement and "unconcerned" cats tended to doze.

Stimuli were not presented while cats were moving, grooming, or sniffing. When a cat demonstrated a preference for a certain posture (e.g. sitting, standing, or lying) for waiting for stimuli, the operator usually allowed him to assume that posture before presenting the next stimulus.

The cats were run 5 to 6 days each week. An attempt was made to run them at approximately the same time of day each day. Each cat was transported in the same cage every day.

A response was defined as locomotion which produced rotation of the wheel, before the termination of the ongoing stimulus. Borderline instances in which a judgment by the operator was demanded were so labeled.

At each conditioning session records were kept of: 1) the programs used; 2) the time of day that each cat's run began; 3) the time taken by the run, if in excess of 20 minutes; 4) the posture of the cat upon presentation of each stimulus; 5) the time interval before presentation of each stimulus, measured from the time of termination of the last locomotor activity; 6) presence or absence of a response to the stimulus; 7) whether response occurred early, middle or late with respect to stimulus onset;

8) shock level when shock was employed; 9) presence or absence of response to shock; 10) whether or not repetitive shock was used; 11) changes in the health of the animals and 12) any medications given.

The criterion for learning was arbitrarily set, after experience with a group of normal exploratory animals, at a five-day average score, in one of the successive five-day periods, that meets all of the following criteria: 1) the average number of responses to B per day during the five-day period must exceed 7.5; 2) responses to T must be less than 2.5 per day; and 3) responses to L must be less than 2.5 per day. Failure to respond to B, and responses to T and L were defined as errors.

The nine programs were inspected with regard to the distribution of the three stimulus conditions. The following table demonstrates the average composition of the first, middle and last thirds of the nine programs.

TABLE M-1

Thirds (presentation)	Both mean	mode	range
first (1-10)	3.0	3	3
middle (11-20)	3.7	3.5	3-5
last (21-30)	3.3	3.5	2-4
	Tone		
first (1-10)	4.1	4	3-5
middle (11-20)	2.9	3	2-4
last (21-30)	3.0	3	2-4

Thirds (presentation)	Light		
	mean	mode	range
first (1-10)	2.9	3	2-4
middle (11-20)	3.4	4	2-4
last (21-30)	3.7	3	3-5

Presentations of B show a slight tendency to cluster in the middle third, T in the first third, and L in the last third of the programs.

The next table illustrates the results of an analysis of sequences of stimulus presentations. The third number in the first column, for example, signifies that of the 90 presentations of B in the 9 programs, 36 were preceded by a presentation of T.

TABLE M-2

Number of Presentations of Both	Tone	Light	Preceded By
2	5	2	0
21	29	39	B
36	22	31	T
31	34	18	L
90	90	90	

Four groups of animals were studied; namely: four normal (N) unoperated cats; four cats with "small lesions" (SL); four cats with "large lesions" (LL); and two cats with "somatosensory lesions" (Som. L.). The small lesions consisted in bilateral removal of the suprasylvian and anterior lateral association fields. The large lesions consisted in removal of these same fields plus bilateral removal of the anterior sigmoid association fields. In

order to visualize the lower bank of the cruciate sufficiently well to guarantee its ablation, the portion of the primary somatic sensory cortex receiving projections from the hind quarters was removed bilaterally. The somatosensory lesion consisted in bilateral removal of the primary and secondary somatic sensory cortical projection fields.

Normal cats included in this study were 61-127 (M), 61-138, 61-188, and 62-14 (M). Small lesion cats were 61-36, 61-72(M), 61-174 and 61-178. Large lesion cats were 61-23 (M), 61-32, 61-73 and 61-166. Somatosensory lesion cats were 61-181 and 61-184 (M). These cats were selected randomly from the animal quarters stock. For each lesion the available cat which had been in animal quarters the longest was selected, provided he appeared to be in good health. Males are indicated by (M). The N, SL and LL groups were originally equated as to sex ratio, but illness of N subjects and the necessary replacement with available stock unbalanced the N group with respect to the SL and LL groups. All cats were experimentally naïve.

All lesion animals were trained postoperatively only. Conditioning was begun 6 to 9 weeks after surgery (SL: 8, 9, 7, 7; LL: 8, 8, 6, 6; Som. L: 7, 7). By this time, all lesion animals were able to walk, and rotate the wheel, efficiently.

Early in the experiment, two LL cats (61-25, 61-32), two SL cats (61-36, 61-72) and one N cat (61-127) were all run during the same period of months. Other normals were run but sickness forced many of them to be discarded. The remaining two LL, two SL, three N and two Som. L. cats were run during essentially the same period of months.

Lesions

All lesions were performed under sterile conditions. Cats were anesthetized with Nembutal (40 mg/kg initially and maintenance doses as needed). The anesthetic, and in some cases saline or dextrose in water, was administered intraperitoneally. The animals received nothing by mouth during the 8 to 16 hours preceding surgery. The anesthetized cat was secured in a head-holder. The head was scrubbed and draped. Operators wore gloves, masks, caps and gowns. Standard aseptic surgical procedure was followed insofar as possible.

A midline incision was made in the scalp, extending from the nasion to the occipital ridge. The skin of the scalp was retracted laterally, after the cut edge was covered with a cloth retainer. All muscle was freed from the dorsal and lateral surfaces of the skull. The skull was entered by means of a trephine applied over the proposed lesion area. The bone of the skull was chipped away with rongeurs until adequate exposure was obtained. The dura was incised and reflected after hemostasis had been ensured, by use of bone wax. A small slit was made with a scalpel in the pia overlying the cortex to be removed. Through this slit, a glass suction tip was inserted and the cortex was removed by gentle suction. Care was taken to minimize injury to the underlying white matter. Hemostasis was

obtained with gelfoam when necessary.

When the lesion was completed, the dura was sutured with 6-0 ophthalmic silk suture, using a continuous running stitch. The muscles of mastication were then approximated in the midline and sutured together with No. 1 silk by means of a crossed mattress stitch. The subcutaneous connective tissue was closed with a running stitch using No. 1 silk suture. The skin was closed with either a subcutaneous running stitch or a mattress stitch using No. 1 silk. The wound was generally covered with plastic spray-on bandage.

In large lesion animals, the frontal sinuses were opened, stripped of their membranes, and sealed with dental cement, followed by Virac decontamination of the operative field and resterilization of the instruments before the calvarium was entered. This permitted removal of the posterior wall of the frontal sinus, for better visualization of the anterior sigmoid gyrus, with a minimum of operative and postoperative bacterial contamination.

All animals were closely observed in the laboratory during the first 7 to 12 hours after surgery. Position of the animal was changed every 2 to 4 hours to guard against hypostatic pneumonia and a heat lamp was applied for the first 12 to 24 hours. All animals were given intramuscular penicillin (300, 000 units/day) for a minimum of three days. All animals were fed milk and solids by hand

until they were able to eat by themselves. Animals were returned to general quarters by the fourth or fifth post-operative day, if their condition permitted.

Dr. Richard F. Thompson was in attendance at the performance of all of these lesions. He did the bulk of the actual lesions of cats 61-23, 61-32, 61-36, and 61-72. The remainder of the lesions were chiefly the work of the author.

Post-operative mortality and morbidity was low. The only death was 61-127, who was operated after training.

The small lesions were intended to be bounded in their maximum extent: medially, by the cortex of the medial wall; anteriorly, by the ansate sulcus (and imagined extensions of it); inferiorly, by the suprasylvian sulcus; and, posteriorly, by the cortex just anterior to 1) the descending portion of the lateral sulcus (for the suprasylvian lesion), and 2) the junction of the anterior and middle thirds of the lateral gyrus (for the anterior lateral lesion). The large lesion included all of the cortex removed in the small lesion procedure. In addition, the boundaries were expanded anteriorly to an imagined line about 3 to 4 mm anterior to, and parallel to the cruciate sulcus, including the cortex of the lower (anteromedial) bank of the cruciate sulcus to the midline. The inferior limit of this anterior lesion was a plane

passing through the inferior tip of the cruciate sulcus, and approximately perpendicular to the plane of that sulcus. Primary somatic sensory cortex was removed far enough medially to ensure adequate visualization of the lower bank of the cruciate sulcus. The somatosensory lesion spared the middle suprasylvian, anterior lateral and anterior sigmoid gyri. Its boundaries were: superiorly, the medial wall; anteriorly, the cruciate sulcus and an imagined inferiorly-directed extension of it; inferiorly, the anterior ectosylvian sulcus; and, posteriorly, 1) the ansate sulcus above, and 2) an imagined line from the inferior tip of that sulcus to the superior tip of the anterior ectosylvian sulcus below. Thus the gyri chiefly involved were the posterior sigmoid, anterior ectosylvian and anterior suprasylvian gyri. This lesion crossed, therefore, the coronal sulcus and the anterior suprasylvian sulcus.

RESULTS

Analysis of Response Data

The responses of the individual cats to each of the three stimulus conditions are presented in Tables I-IV. The numbers in these tables represent five-day average response levels. These averages are derived by finding the sum of all responses made by a given cat to one of the three stimulus conditions and dividing that sum by five. Each experimental group is presented in a separate table.

Figures 1 - 6 present graphs of these five-day averages for three of the normal, three of the small lesion and two of the large lesion animals. In these figures, the two lines parallel to the x-axis represent the criterion limits of 7.5 and 2.5.

Note that among the normal group of cats (Table I, Figures 1 and 2), Cat 61-127 first reached criterion in the period beginning with day 21, Cats 61-138 and 61-188 in the period beginning with day 31, and Cat 62-14 in the period beginning with day 41. Thus, all normal cats attained criterion by the 45th day of training.

Cat 61-127 was run for one five-day period after he reached criterion. His training was then discontinued. Forty-one days later he was tested for a period of five days. His average performance in that period met the criterion.

Of the small lesion animals (Table II, Figures 3 and 4), two cats, 61-72 and 61-174, were able to reach the criterion in the periods beginning with days 36 and 26 respectively. Both of these cats illustrate that once a cat reaches criterion he may fall back below criterion in at least some of the subsequent five-day periods. Two of the small lesion animals failed to reach criterion within 45 days.

None of the cats in the large lesion group (Table III, Figures 5 and 6) reached criterion by 45 days of training.

Thus at the end of 45 days of training all of the normal animals, one-half of the small lesion animals and none of the large lesion animals had attained a criterion level of performance.

A sign test analysis (60) was performed to compare the day by day number of responses to B and T by each animal in the study. On this test, all of the normal cats and all of the small lesion cats showed a difference which was significant at better than the 0.001 level of confidence when daily responses to B and T were compared through the 30th day of training. On comparisons through the 25th day of training, one somatosensory lesion animal (61-181) showed a difference which was significant at the 0.001 level, and the other animal in that group (61-184) showed a difference which was significant at better than the 0.05 level. In contrast to these findings, only one of the

large lesion animals (61-73) showed a difference which was significant at the 0.05 level on comparison through the 30th day of training. However, by the 45th day of training, three of the large lesion animals showed a difference which was significant at the 0.001 level, and the remaining member of that group (61-23) showed a difference at the 0.01 level. It took the animals with large lesions longer (in terms of days of training) to establish a statistically significant response differential between B and T. All cats eventually showed a differential response tendency which was statistically significant.

Inspection of Table III and Figures 5 and 6 suggest that the large lesion animals, especially 61-23 and 61-32, may differ from the normal cats principally by virtue of their higher level of response to T. Some t-tests were performed on the total number of responses to T by N, LL, and SL cats during the last 10 days of training. The last 10 days of training were selected because in the terminal stages of training the response tendencies of each cat become fairly stable, whether he has reached criterion or not. The large lesion cats were found to respond significantly more frequently to T than the normal cats. The difference was significant at the 0.01 level of confidence. Similar comparisons of the small and large lesion groups, and of the small lesion and normal groups, produced no significant differences.

Average cumulative number of responses by experimental group is illustrated in Tables V-VII. The numbers in these tables were derived by finding the sum of all the responses made to a given stimulus by all the members of a group by a certain day of training. That sum was then divided by the number of animals in the group.

Inspection of Table V suggests that the large lesion animals were slower than the others in learning to respond in the training situation. Analysis of variance on the cumulative responses to B by the normal, small lesion and large lesion animals through day 30 gave a value for F that was significant at the 0.05 level (see Table IX). A Duncan analysis demonstrated that the small lesion and normal groups did not differ from one another on this measure, and that both of these groups were significantly different from the large lesion group.

Table VIII presents the average cumulative total number of errors by experimental group. The numbers in this table were derived by finding the sum of the responses to T, responses to L and failures to respond to B for each cat. These error scores were cumulated for each cat, and then the averages were found for the cats within each group. Numbers in parentheses were derived with the inclusion of extrapolated scores for one or more members of the group. When a cat learned, and was discontinued, it was assumed that his scores in later five-day periods would

continue to be what they were in the last five-day period in which he was run. Analysis of variance of the average cumulative total errors through 30 days produced a value for F which was significant at the 0.05 level. A Duncan analysis demonstrated that on this measure the large lesion and normal groups differed significantly, but the small lesion group did not differ significantly from either of the other two groups. The analysis was repeated for data carried out to the 45th day with the same result.

TABLE I

Average Number of Responses in Each Five-Day Training Period

Normal Group

B: Both (simultaneous presentation of tone and light)
T: Tone alone
L: Light alone

Days	Cat 61-127			Cat 61-138			Cat 61-188			Cat 62-14		
	B	T	L	B	T	L	B	T	L	B	T	L
1-5	4.6	4.0	2.0	3.0	3.2	0.8	2.0	1.8	0.4	2.0	1.0	0.2
6-10	2.6	1.0	0.0	5.0	6.4	1.6	5.2	3.8	0.6	5.0	2.6	0.4
11-15	8.6	4.2	0.2	7.6	6.4	0.2	3.8	2.2	0.0	5.2	2.4	0.6
16-20	6.6	1.4	1.0	7.4	3.8	0.0	8.2	2.8	0.4	4.4	3.2	0.4
21-25	7.8	0.4	0.6	8.0	6.6	0.4	7.2	3.8	0.2	6.2	3.6	0.2
26-30	8.4	0.8	0.2	6.0	1.0	0.0	7.4	0.6	0.0	7.4	3.0	0.2
31-35				8.2	2.0	0.0	7.6	1.2	0.0	7.6	3.4	0.4
36-40										6.8	3.2	0.2
41-45										7.6	1.2	0.0

FIGURE I

Cat 61-127 (Normal): Graphs of average number of responses to each of the three stimulus conditions by five-day training periods.

Each dot represents the average number of responses per day over five-day period. The numbers along the x-axis identify the periods by stating the first day; i.e. the dots over 16 represent averages for the period including days 16 through 20. Horizontal lines joining x-axis at 7.5 and 2.5 identify the criterion limits.

Note that this cat reached criterion during the 5-day period beginning with the 21st day. When retested after 41 days without practice, his performance still met the criterion.

Both = simultaneous presentation of light and tone
Tone = tone alone
Light = light alone

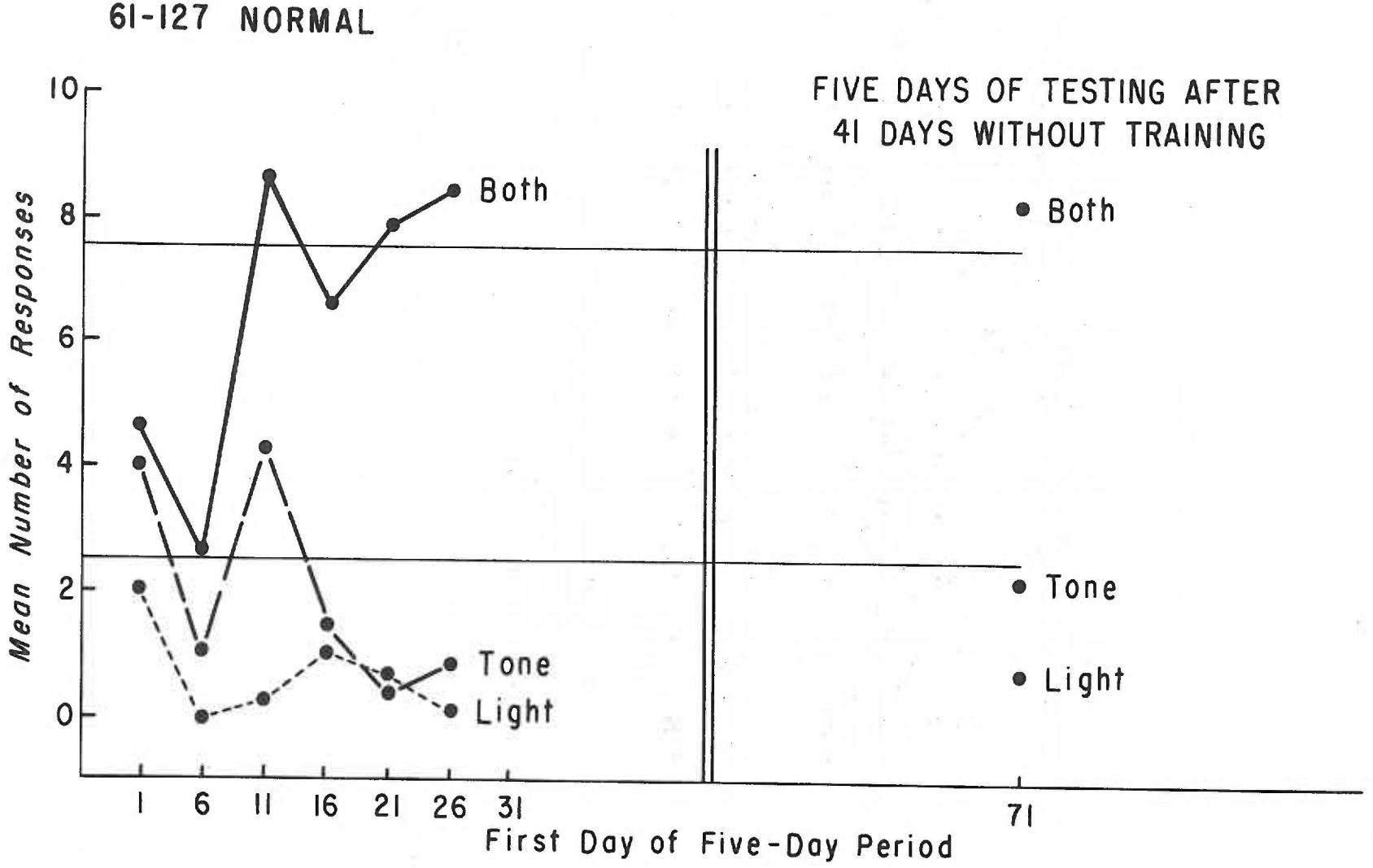

61-127 NORMAL
FIVE DAYS OF TESTING AFTER
41 DAYS WITHOUT TRAINING
Mean Number of Responses
10
8
6
4
2
0
Both
Tone
Light
Both
Tone
Light
1
6
11
16
21
26
31
71
First Day of Five-Day Period

FIGURE 2

Graphs of average number of responses to each of the three stimulus conditions by five-day training periods.

Cat 61-138 (Normal): This cat first reached criterion during the period including days 31-35. Note abrupt drop in number of responses to tone.

Cat 61-188 (Normal): This cat also first reached criterion during days 31-35. Contrast the tone-response curve with that of Cat 61-138.

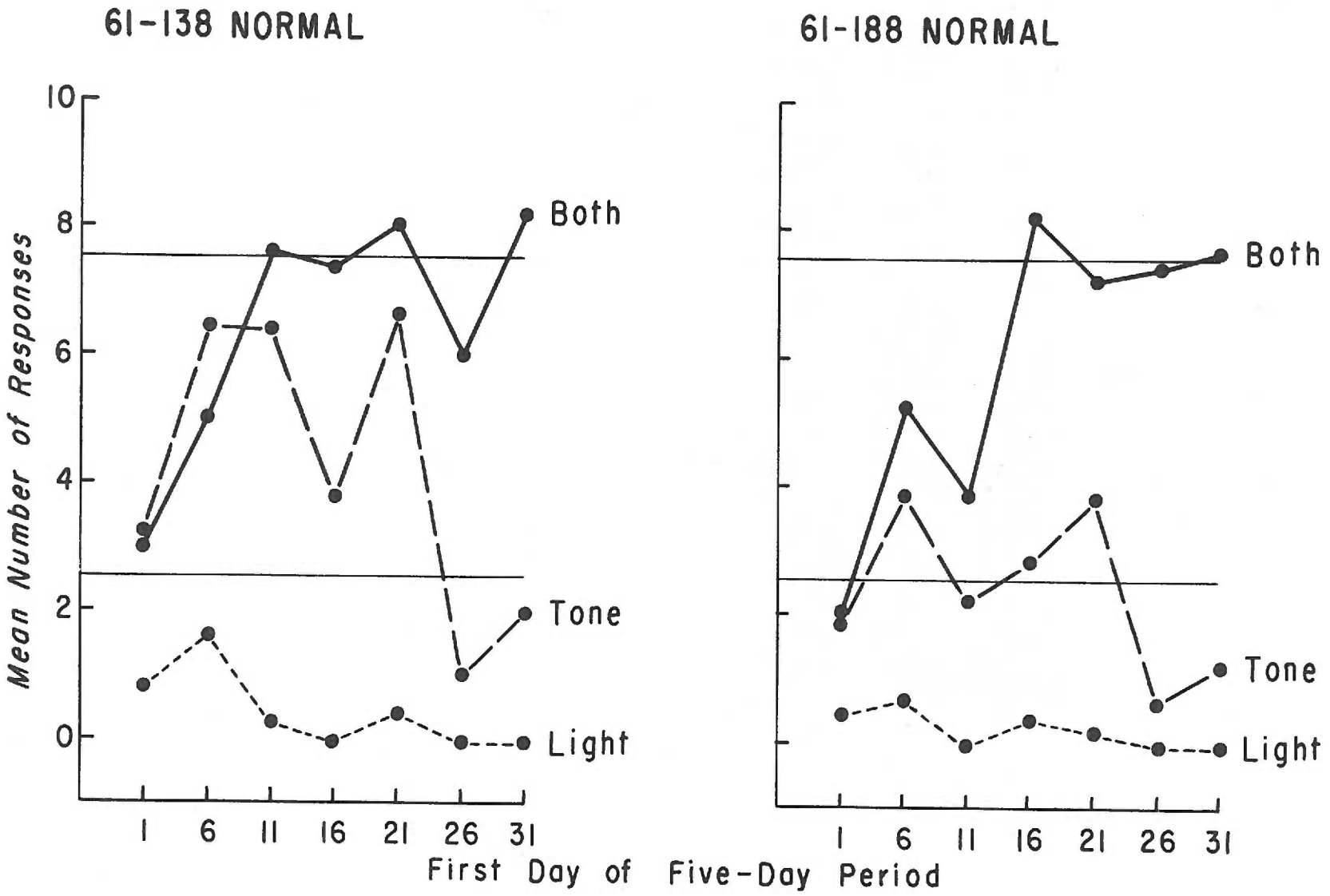

61-138 NORMAL
61-188 NORMAL
Mean Number of Responses
10
8
6
4
2
0
Both
Tone
Light
1
6
11
16
21
26
31
First Day of Five-Day Period

TABLE II

Average Number of Responses in Each Five-Day Training Period

Small Lesion Group

B: Both (simultaneous presentation of tone and light)
T: Tone alone
L: Light alone

Days	Cat 61-36			Cat 61-72			Cat 61-174			Cat 61-178		
	B	T	L	B	T	L	B	T	L	B	T	L
1-5	4.2	3.8	3.6	1.8	2.2	2.8	1.6	0.8	0.0	5.4	3.0	1.4
6-10	8.6	5.0	3.6	6.4	3.4	3.8	4.0	1.8	0.2	4.6	2.8	2.6
11-15	9.2	7.8	4.6	7.2	2.4	1.8	5.2	2.8	0.2	4.8	1.0	1.8
16-20	9.4	7.0	3.0	7.4	2.0	1.8	7.4	2.2	0.2	7.8	3.4	4.6
21-25	8.8	5.0	2.8	6.6	2.6	0.0	7.4	3.4	0.2	8.0	3.0	0.8
26-30	7.8	5.8	1.6	6.0	1.2	0.8	7.8	2.0	0.2	7.0	5.0	0.0
31-35	7.2	4.0	2.0	7.4	1.[illegible]	0.6	7.4	2.4	0.2	4.2	3.4	0.0
36-40	8.2	7.0	3.0	8.8	0.6	0.0	7.0	1.4	0.4	8.8	4.4	0.0
41-45	7.6	4.8	2.6	6.8	0.0	0.0				8.2	3.2	0.2
46-50	6.2	4.2	1.4	7.6	0.6	0.2						
51-55	6.8	4.6	1.8	7.6	0.2	0.0						
56-60	7.8	5.6	3.8									
61-65	8.6	7.2	5.4									
66-70	8.8	5.6	2.0									
71-75	8.8	4.2	2.6									

FIGURE 3

Graphs of average number of responses to each of the three stimulus conditions by five-day training periods.

Cat 61-36 (Small Lesion): This cat failed to reach criterion. Note the relatively high level of response to light and the "parallel" courses of the three curves.

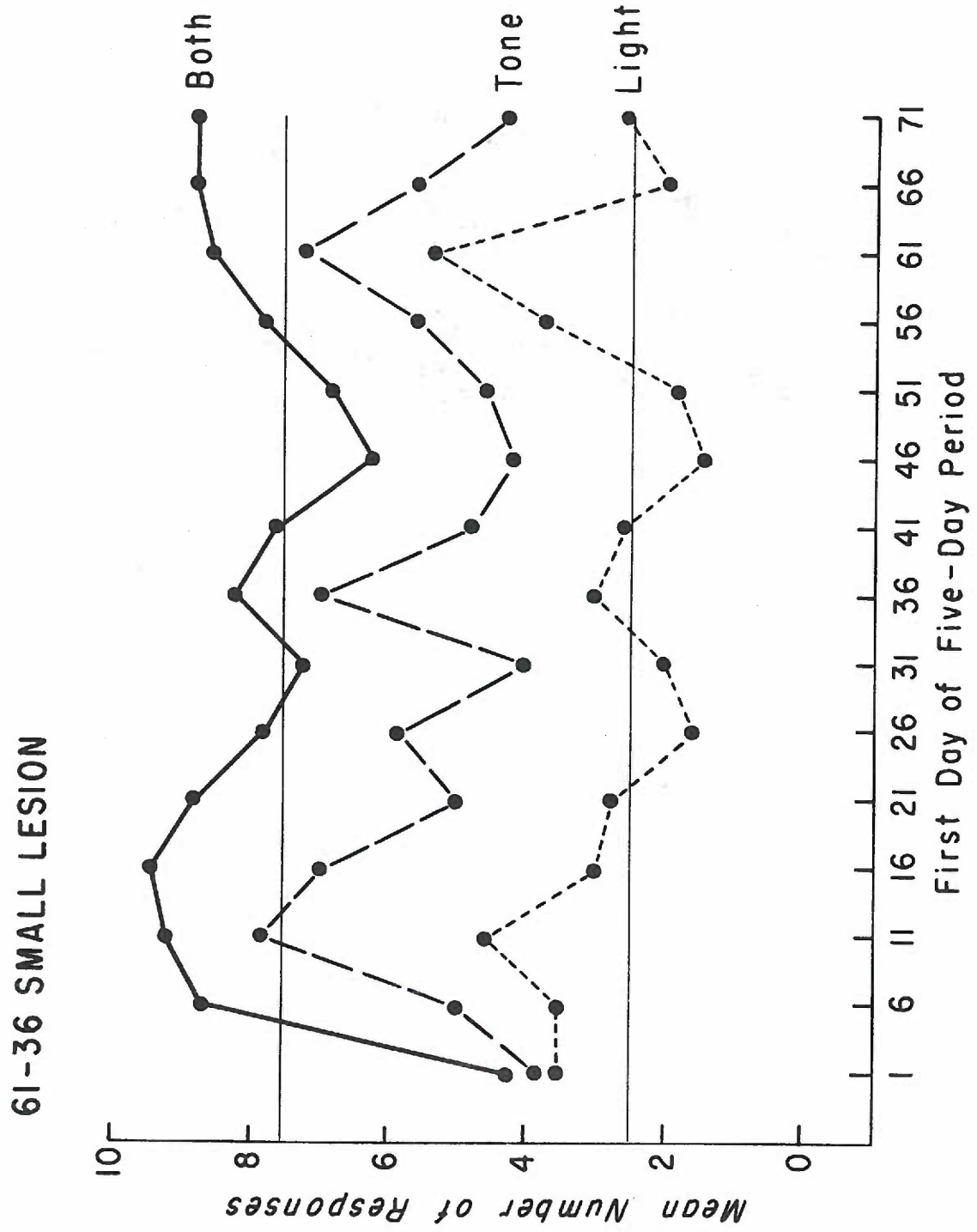

61-36 SMALL LESION
Both
Tone
Light
Mean Number of Responses
0
2
4
6
8
10
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
First Day of Five-Day Period

FIGURE 4

Graphs of average number of responses to each of the three stimulus conditions by five-day training periods.

Cat 61-72 (Small Lesion): This cat reached criterion during the period of days 36-40. Compare to curves for Cats 61-127 and 61-188.

Cat 61-174 (Small Lesinn): This cat reached criterion in period of days 26-30, then fell back.

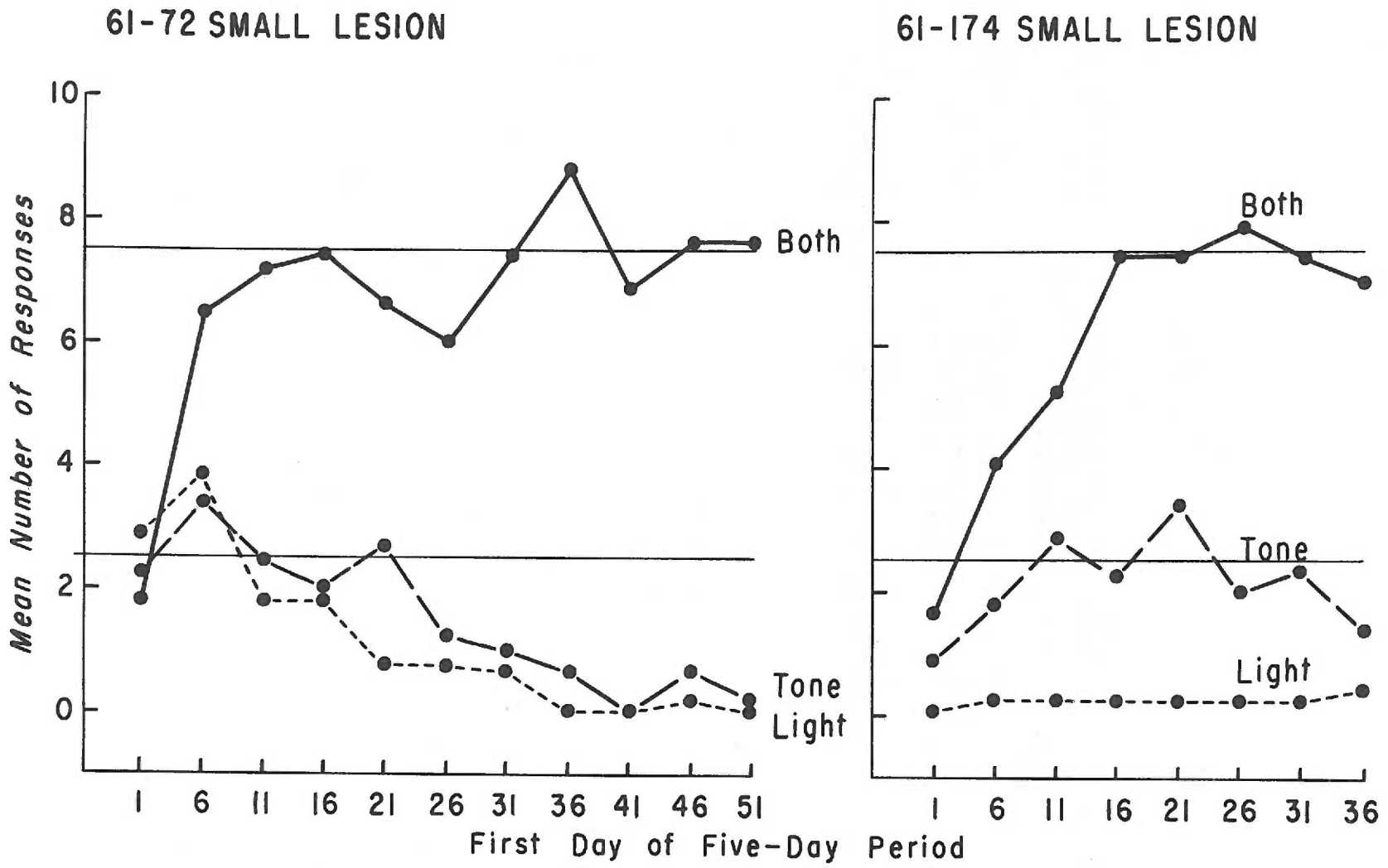

61-72 SMALL LESION
61-174 SMALL LESION
Mean Number of Responses
10
8
6
4
2
0
Both
Tone
Light
1 6 11 16 21 26 31 36 41 46 51
1 6 11 16 21 26 31 36
First Day of Five-Day Period

TABLE III

Average Number of Responses in Each Five-Day Training Period

Large Lesion Group

B: Both (simultaneous presentation of tone and light)
T: Tone alone
L: Light alone

Days	Cat 61-23			Cat 61-32			Cat 61-73			Cat 61-166		
	B	T	L	B	T	L	B	T	L	B	T	L
1-5	0.6	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.0	0.2	0.0	0.0
6-10	1.2	1.0	0.2	5.0	5.0	3.6	0.6	1.0	0.2	0.4	0.4	0.4
11-15	1.8	2.2	0.4	6.0	5.6	2.6	3.0	2.8	0.2	0.6	0.4	0.2
16-20	4.8	2.6	0.8	7.2	5.8	2.2	4.2	3.2	1.4	0.8	1.2	0.0
21-25	6.2	5.0	0.8	6.8	6.8	1.0	2.8	1.8	1.4	4.4	4.0	3.0
26-30	6.2	5.0	0.2	9.2	8.4	2.6	4.4	2.2	1.6	6.6	2.4	0.8
31-35	8.0	7.4	0.2	8.8	6.4	2.0	5.2	2.0	0.8	7.2	3.2	1.0
36-40	8.4	7.2	0.0	7.6	4.6	2.2	7.2	3.8	2.2	7.2	3.0	0.8
41-45	9.2	7.0	0.4	7.2	3.8	0.8	7.0	5.4	1.0	8.0	4.0	2.0
46-50	8.2	4.4	0.2	6.8	3.6	1.2						
51-55	9.6	8.6	0.0	8.6	7.0	2.8						
56-60	9.6	8.8	0.2	9.2	5.8	1.8						
61-65	9.0	5.0	0.0	8.6	4.6	1.6						
66-70	7.2	3.2	0.2	8.2	4.8	0.4						
71-75	5.8	2.6	0.2	8.6	5.0	0.8						

FIGURE 5

Graphs of average number of responses to each of the three stimulus conditions by five-day training periods.

Cat 61-23 (Large Lesion): This cat failed to reach criterion. Note proximity of B and T curves.

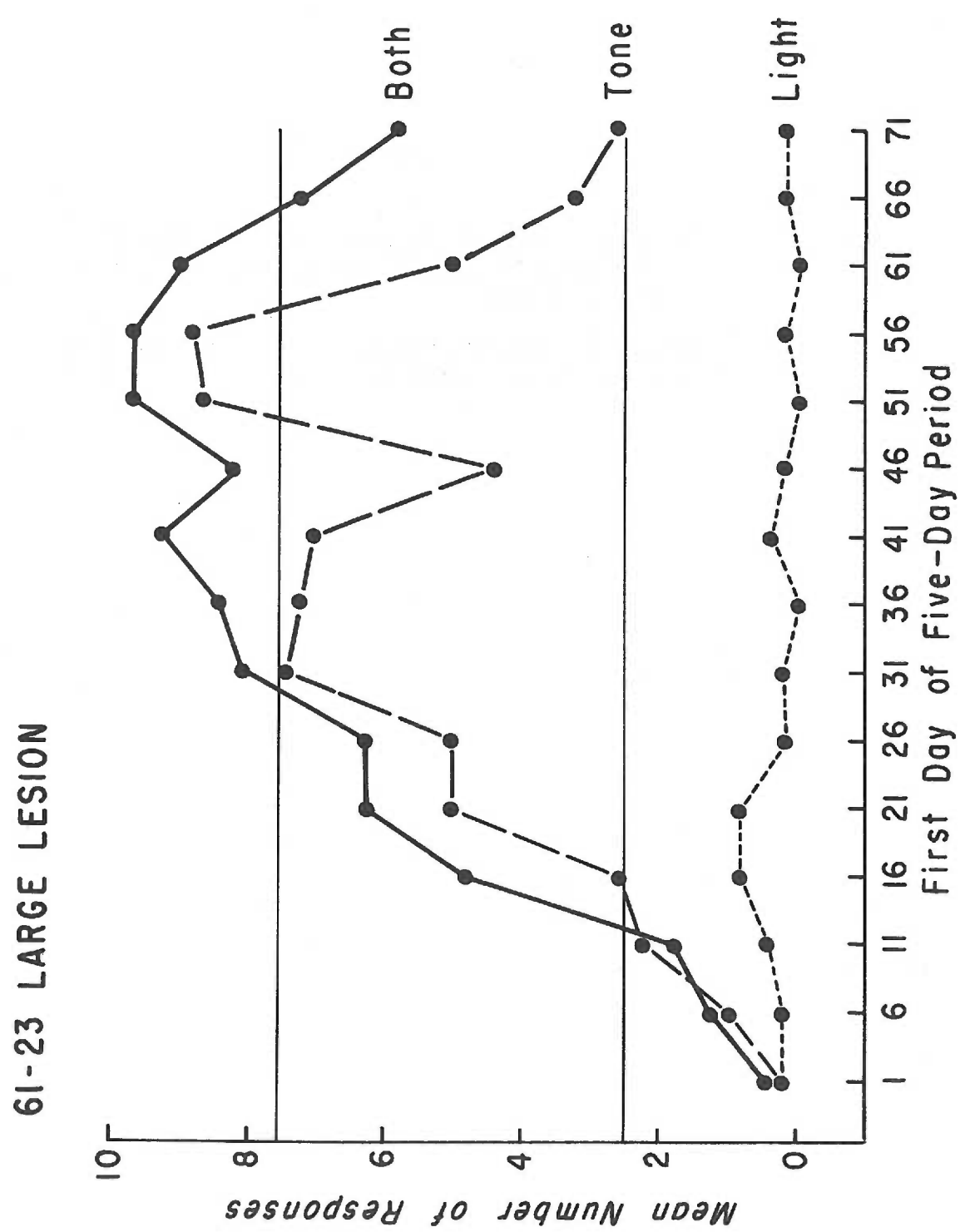

61-23 LARGE LESION
Both
Tone
Light
Mean Number of Responses
0
2
4
6
8
10
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
First Day of Five-Day Period

TABLE 6

Graphs of average number of responses to each of the three stimulus conditions by five-day training periods.

Cat 61-32 (Large Lesion): This cat failed to reach criterion.

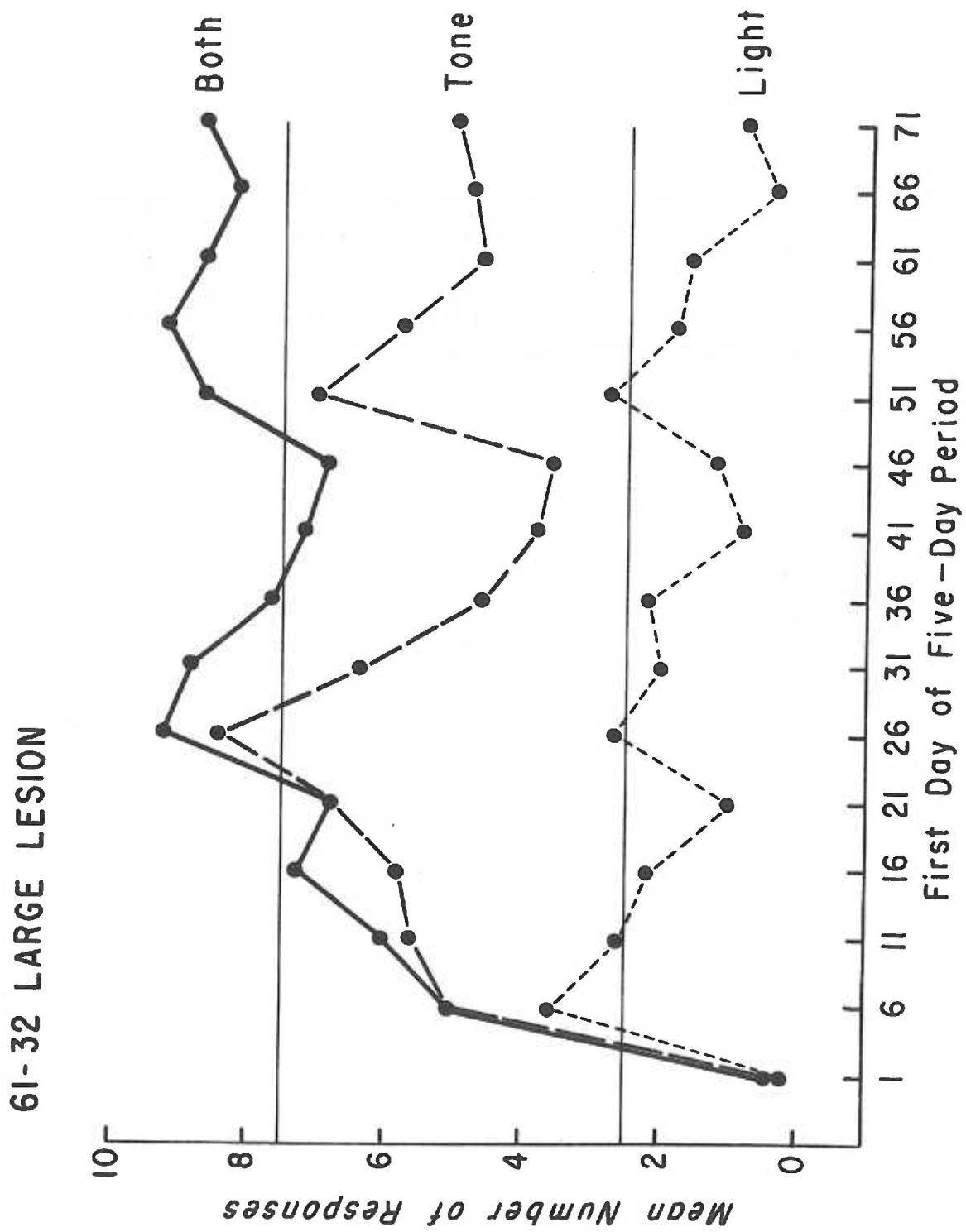

61-32 LARGE LESION
Both
Tone
Light
Mean Number of Responses
0
2
4
6
8
10
1
6
11
16
21
26
31
36
41
46
51
56
61
66
71
First Day of Five-Day Period

TABLE IV

Average Number of Responses in Each Five-Day Training Period

Somatosensory Lesion Group

B: Both (simultaneous presentation of tone and light)
T: Tone alone
L: Light alone

Days	Cat 61-181			Cat 61-184		
	B	T	L	B	T	L
1-5	0.8	0.6	0.0	0.4	0.8	0.4
6-10	3.8	1.6	0.2	3.8	4.0	1.6
11-15	6.8	4.8	0.2	7.0	5.4	1.6
16-20	7.2	4.2	0.0	5.4	2.4	1.0
21-25	6.8	1.8	0.0	8.6	5.2	1.2
	8.8	2.2	0.0	7.5	3.6	0.4

TABLE V

Average Cumulative Number of Responses to BOTH By Experimental Group

By Day	Normal	Small Lesion	Large Lesion	Somatosensory Lesion
5	14	16	2	3
10	36	46	10	22
15	68	78	25	56
20	102	118	46	88
25	138	157	72	126
30	174	193	104	
35			141	
40			179	

TABLE VI

Average Cumulative Number of Responses to TONE by Experimental Group

By Day	Normal	Small Lesion	Large Lesion	Somatosensory Lesion
5	12	12	1	4
10	20	28	10	17
15	48	46	24	43
20	62	64	40	60
25	80	82	62	77
30	88	99	84	
35			108	
40			131	

TABLE VII

Average Cumulative Number of Responses to LIGHT by Experimental Group

By Day	Normal	Small Lesion	Large Lesion	Somatosensory Lesion
5	4	10	1	1
10	8	25	6	6
15	8	33	10	10
20	11	45	16	12
25	12	50	24	16
30	13	54	30	
35		58	35	
40			42	

TABLE VIII

Average Cumulative Total Number of Errors by Experimental Group

By Day	Normal	Small Lesion	Large Lesion	Somatosensory Lesion
5	52	56	50	52
10	100	104	105	101
15	139	150	159	147
20	172	190	209	184
25	206	225	264	216
30	226	260	312	
35	(246)	294	352	
40	(267)	324	394	
45	(282)	(353)	428	

TABLE IX

Analysis of Variance Summary Tables

A

Cumulative Responses to BOTH

Source	df	SS	MS	F
Between	2	17,433	8,717	6.96
Within	9	11,266	1,252	
Total	11			

F_{05}: 4.26

B

Cumulative Total Errors

Source	df	SS	MS	F
Between	2	15,505	7,503	5.03
Within	9	13,440	1,493	
Total	11			

F_{05}: 4.26

Miscellaneous Observations

There was a difference between the groups in the amount of spontaneous activity in the cage. The typical normal cat finished a 30-trial program in 10 to 20 minutes. Small lesion animals made runs lasting more than 20 minutes about four times more often than normal cats. Large lesion animals made such runs about ten times as often as the normal cats. The somatosensory lesion group made only a few more such runs than did the normal animals.

The average level of the first shock responded to in the cage on the first day of training was greatest for the somatosensory lesion cats (setting of "88" on dial with range of "0-100") and least for the normal animals ("56"). Large lesion cats required a higher shock level than the small lesion cats ("76" versus "66"). The level given above for the somatosensory lesion group may be somewhat high. The group was small, and one of the cats was a long-haired animal that was moderately refractory to shock until his legs and paws were shaved.

All subjects oriented to and, on occasion, responded to both the auditory and visual stimuli.

The normal and small lesion animals usually assumed a sitting or lying posture between stimuli. The large lesion animals demonstrated a greater tendency to stand between stimuli. When these cats went through a period of sitting or lying, however, their differential response tendency

remained low.

One cat with a large lesion (61-32) exhibited behavior, in addition to hyperactivity, suggestive of the "frontal syndrome." For about 3 weeks her movements were robot-like. When she encountered an obstacle in her path, she seemed unable to solve her problem by circumnavigating the obstacle. She mechanically followed persons moving in the room. These symptoms were no longer obvious by 4 to 6 weeks, although this animal turned out to be the most hyperactive of all the animals run in this study.

Immediately after surgery, small lesion animals exhibited some extensor rigidity, which was most noticeable in the hind limbs and which gradually disappeared. Tactile placing was present after the immediate postoperative period. These animals could run and jump in less than 10 days after surgery. Large lesion animals exhibited a more severe rigidity which gradually decreased but did not completely disappear. Tactile placing in the forelimbs was present after the immediate postoperative period. Tactile placing in the hind limbs gradually reappeared in some animals, but was harder to elicit and more variable than in normal cats.

All cats could feed themselves and move around the room in less than four days after surgery.

Anatomic Considerations

Photographs of the gross brains of four lesion animals are presented here. For each of these cats, photographs were taken of four views of the gross brain, viz. superior, left lateral, right lateral and anterior-superior oblique. These brains are being processed for cortical reconstruction and subcortical degeneration studies. The same procedure will be followed for the remaining lesion animals after they have been submitted to further behavioral testing.

Gross examination of the four available brains was carried out. In the case of 61-32 (LL) the left anterior medial wall was violated. Posteriorly, V II was entered. On the right, the forelimb somatic sensory area would appear to have been partially removed. The lesions in 61-23, 61-36, and 61-72 appeared adequate, except that there may have been some sparing in 61-23 of the cortex at the lateral tip of the right cruciate sulcus. In cats 61-32 and 61-72 the suprasylvian lesions extended further posteriorly than in cats 61-23 and 61-36. The lesions in the remaining cats were all deemed complete at surgery.

Distortion due to healing helps render gross examination an inadequate means of checking lesion limits.

FIGURE 7

Cat 61-36 (Small Lesion): Superior view of brain, demonstrating lesion involving suprasylvian and anterior lateral gyri. The lesion is L-shaped. The short limb of the L represents the lesion in the anterior lateral gyrus. Anterior pole toward left.

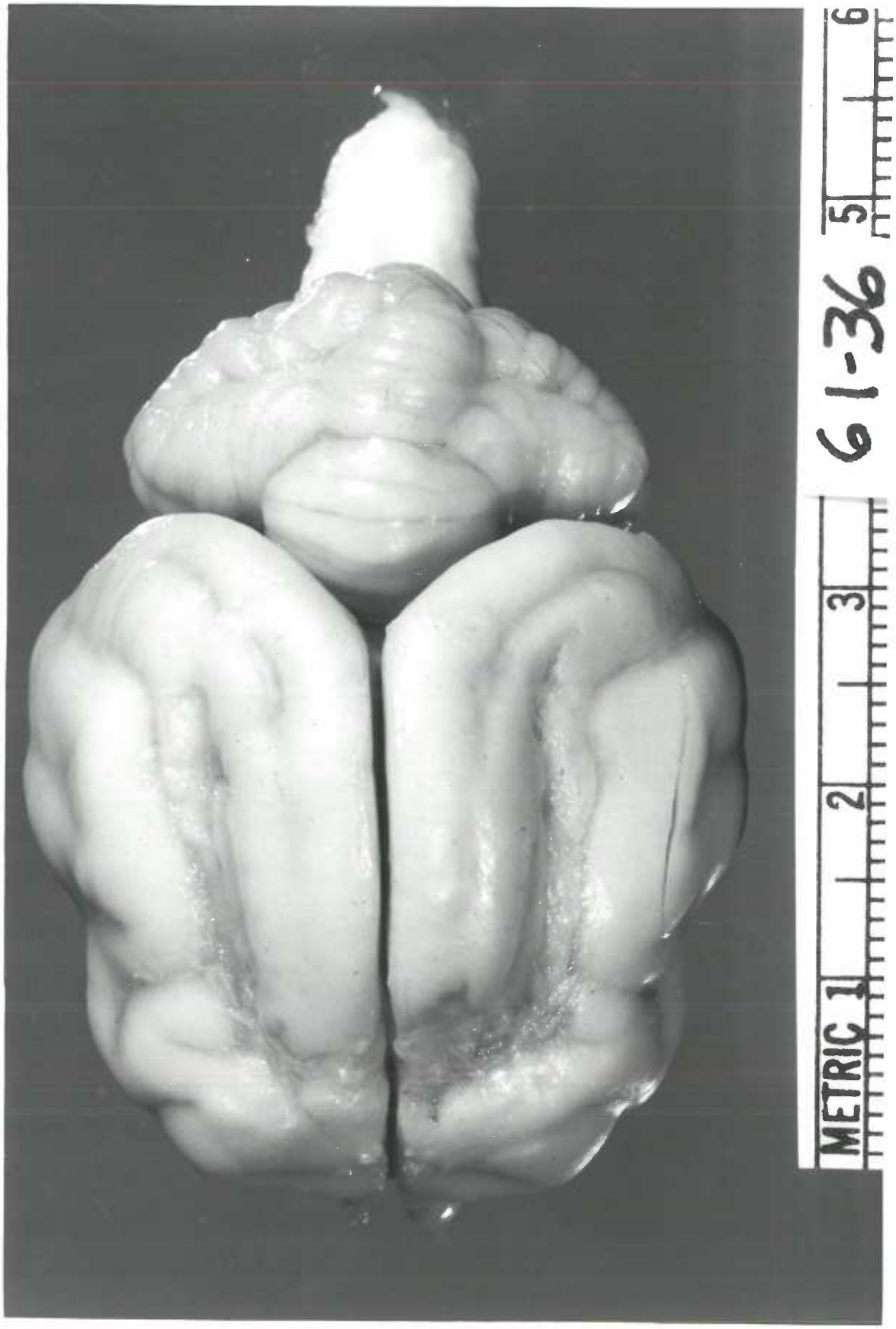

METRIC 1
2
3
5
6
61-36

FIGURE 8

Cat 61-72 (Small Lesion): Superior view of brain, demonstrating lesion involving suprasylvian and anterior lateral gyri.

Compare to Figure 7.

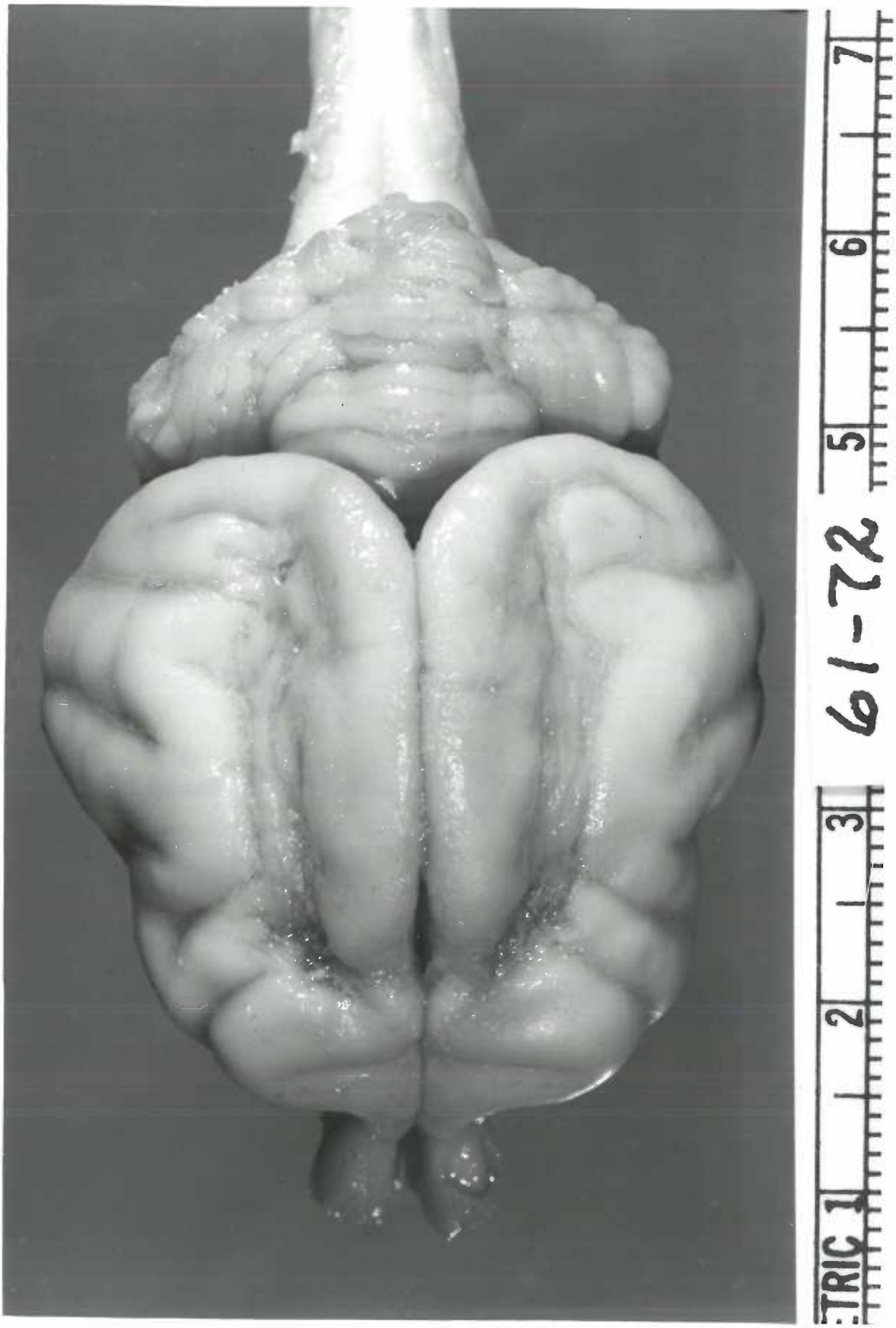

61-72

FIGURE 9

Cat 61-23 (Large Lesion): Superior view of brain demonstrating lesion involving suprasylvian, anterior lateral and sigmoid gyri. The anterior and posterior portions of the sigmoid gyrus lie on either side of the cruciate sulcus which is well visualized in cat 61-72 (Figure 8).

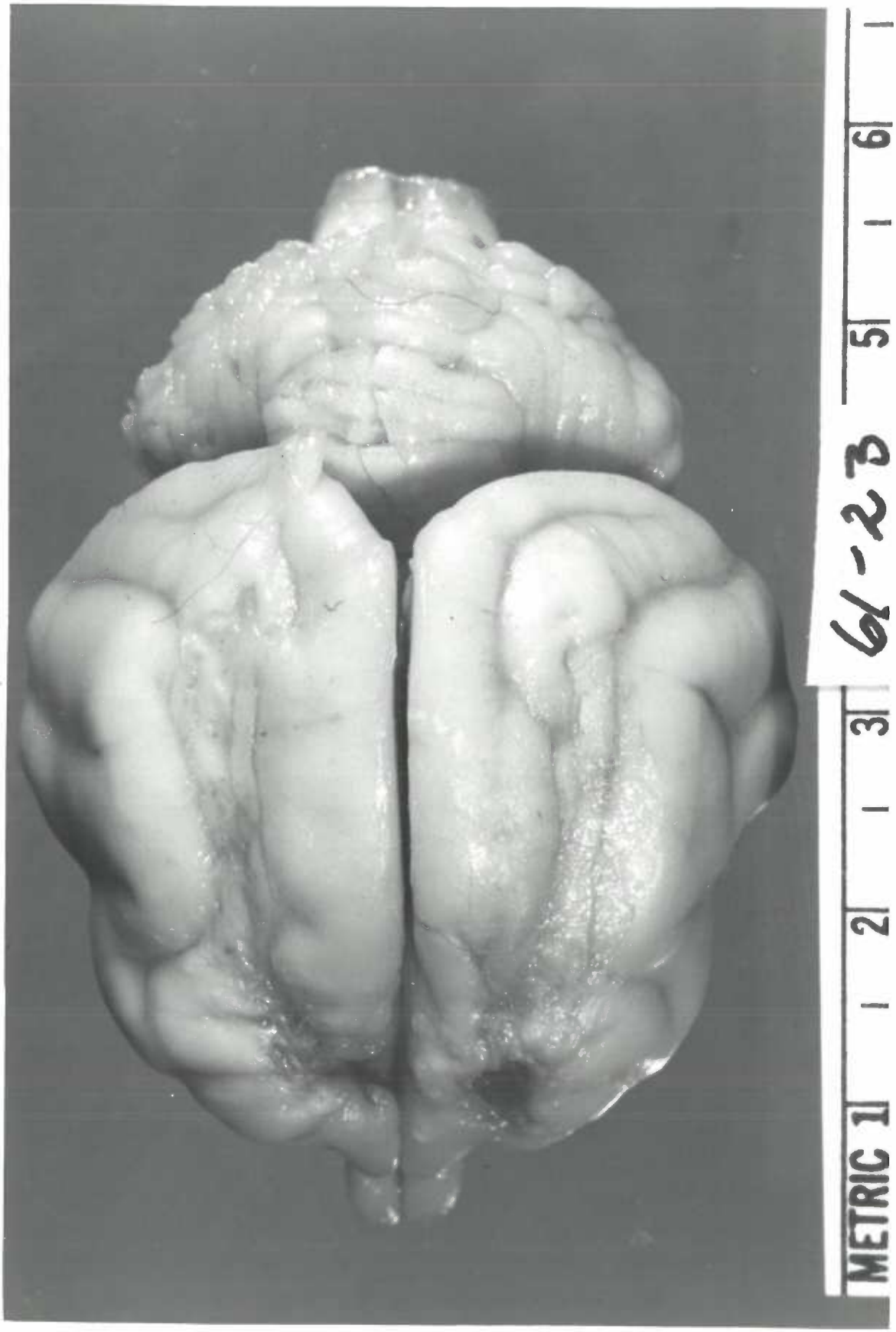

METRIC 1
2
3
5
6
61-23

FIGURE 10

Cat 61-23 (Large Lesion): The anterior pole of the brain has been tilted up toward the viewer to permit better visualization of the anterior portion of the lesion.

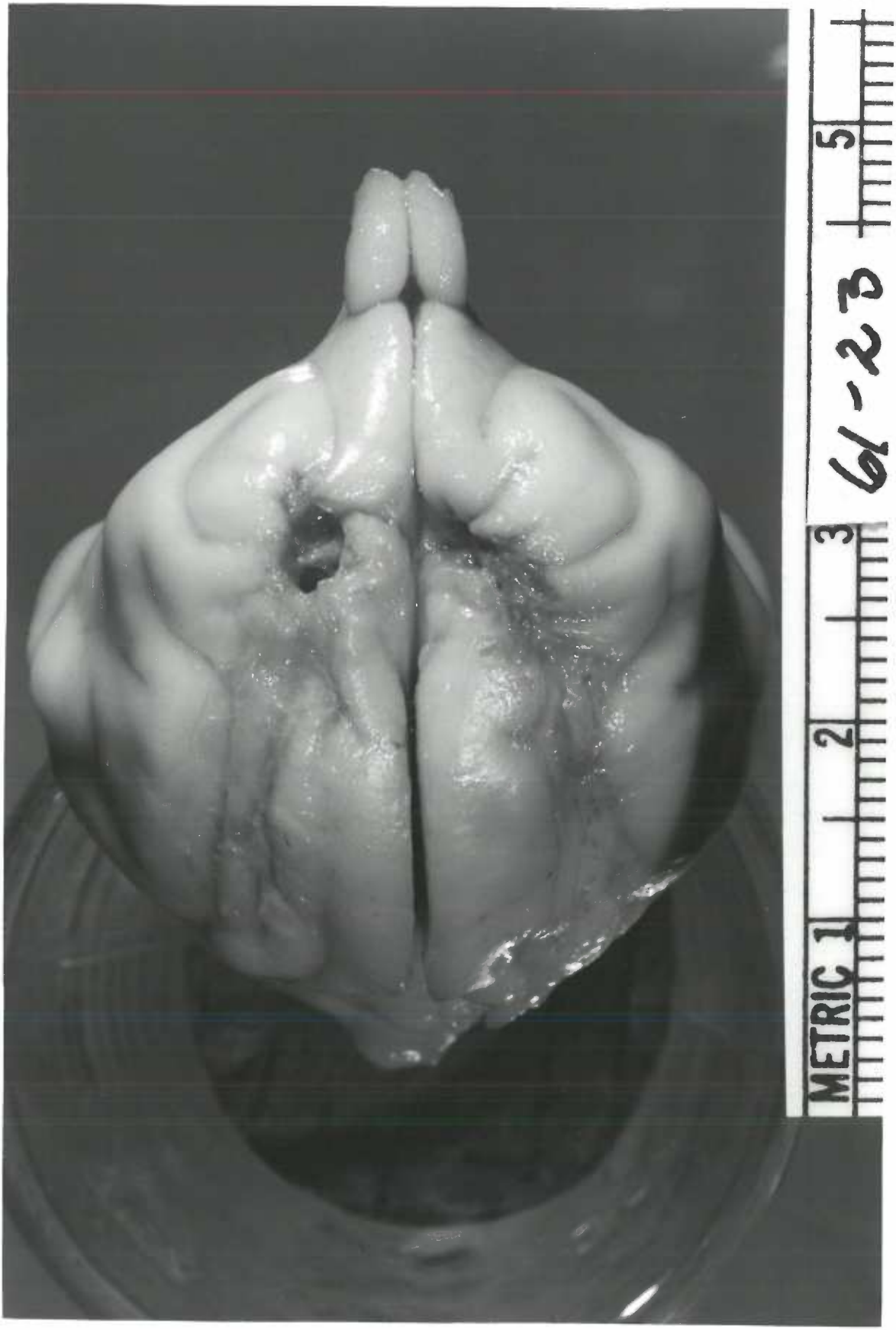

METRIC 1
2
3
5
61-23

FIGURE 11

Cat 61-32 (Large Lesion): Superior view of brain demonstrating lesion involving suprasylvian, anterior lateral and sigmoid gyri.

Compare to Figure 9.

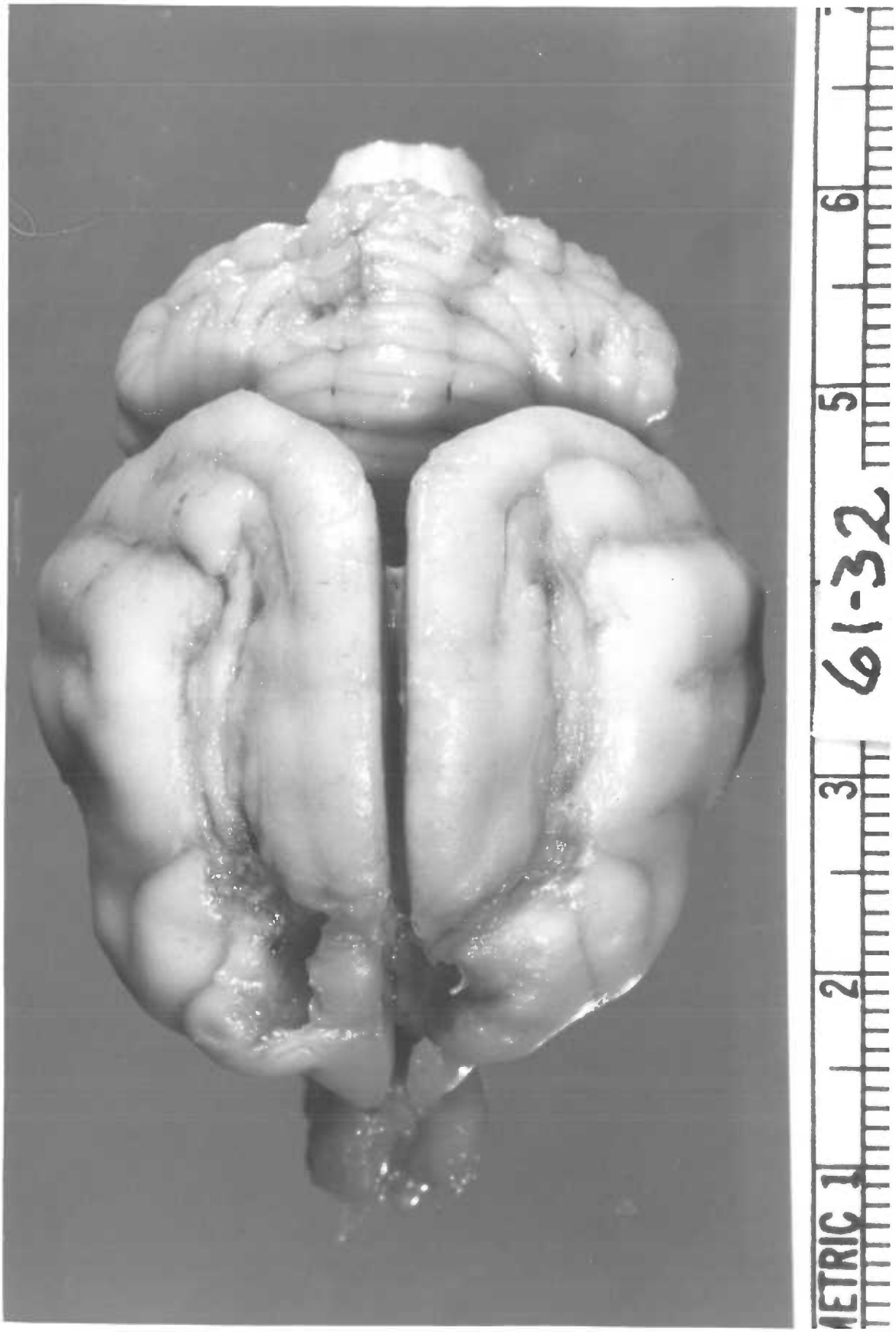
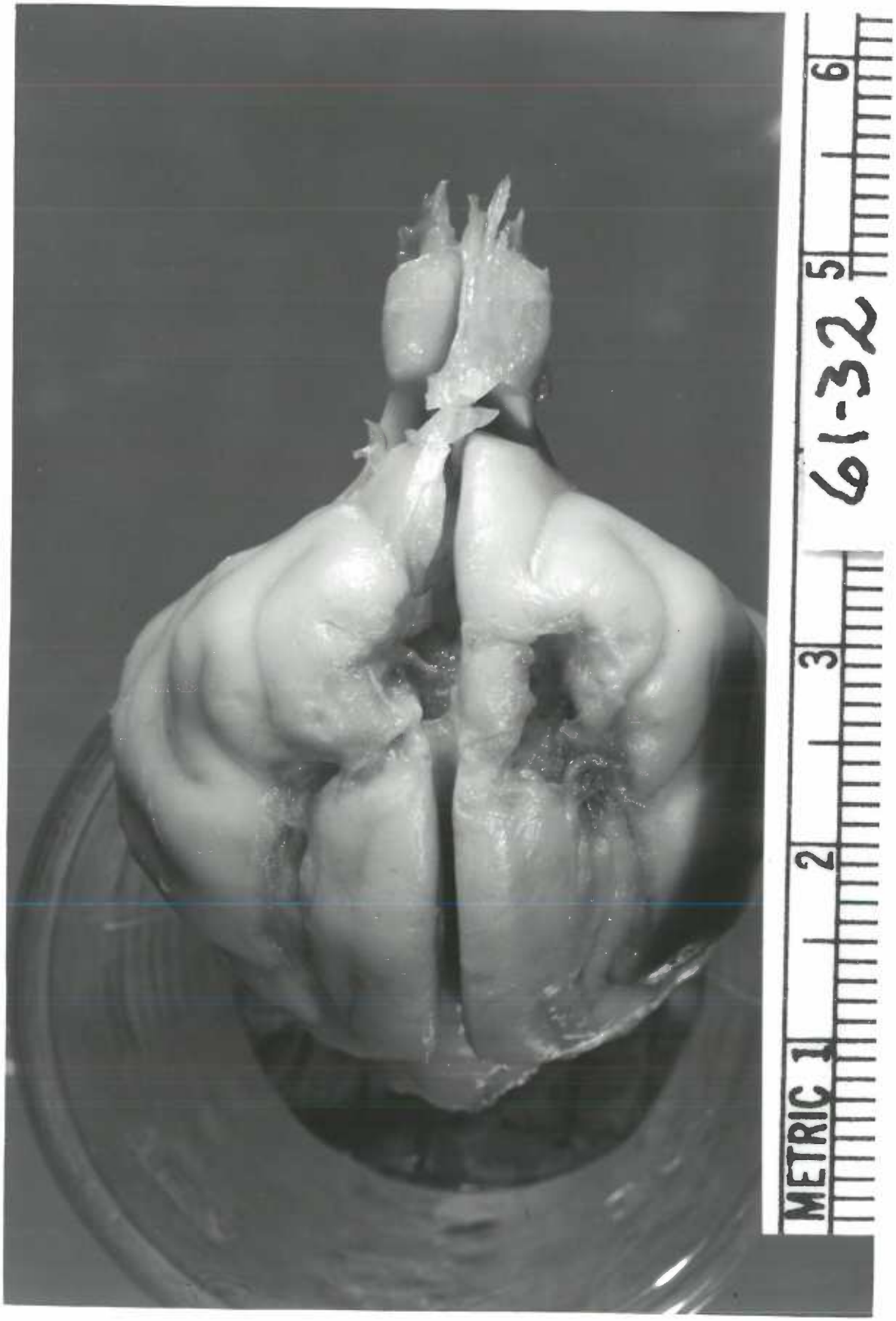

61-32
METRIC 1
2
3
5
6

FIGURE 12

Cat 61-32 (Large Lesion): The anterior pole of the brain has been tilted up toward the viewer.

Compare to Figure 10.


METRIC 1
2
3
5
6
61-32

DISCUSSION

The large lesion animals were found to be inferior to the normal cats on several different measures. None of the large lesion group managed to reach criterion within the time taken by the slowest normal cat (45 days). Those large lesion animals which were run for 75 days still failed to reach criterion.

Nevertheless all cats eventually showed some differential response tendency. Such a tendency appeared also in the large lesion animals, but was not statistically significant between B and T until after the 30th day of training. The large lesion animals were slower learners, at least to the extent that discrimination learning can be measured by behavior in the wheel. This conclusion is supported by the data on cumulative responses to B in the first 30 days. The large lesion animals may have had difficulty learning to connect the warning stimulus with the subsequent occurence of the shock.

The large lesion animals made many of their errors by responding to tone. In fact, all animals made more responses to B than to T, and more responses to T than to L. At least two reasons may be suggested as an explanation for the greater tendency to respond to tone than to light. In the first place, the tone in this experiment represented a more nearly absolute increase in the intensity of sensory stimulation, since the box was soundproofed but dimly illuminated from within. Secondly,

unsophisticated observation of cats suggests that cats are "auditory animals". They seem to use their ears more than their eyes for the collection of alerting and warning stimuli (e.g. while dozing). Brogden (7) found tone to be a more potent stimulus than light in the conditioning of dogs.

One of the crucial problems in the interpretation of this study centers on the fact that the perceptual mechanism is not directly tapped. This is a problem in all studies in which a motor response is used as a measure of perceptual functioning. Perhaps the large lesion animals could not discriminate efficiently, on a perceptual basis, the tone alone from the simultaneous presentation of both tone and light. On the other hand, they might have been able to make the distinction perceptually but unable to inhibit response to the tone. An incidental observation in this experiment that may have a bearing on this problem is that the response to Tone was often qualitatively weaker than that to Both. For example, an animal might run for several revolutions of the cage after a presentation of Both, but only take a step or two in response to a Tone. Yet, both behaviors were tallied as a response. A study of training procedures in frequency discrimination experiments led Thompson to the conclusion that "removal of auditory cortex appears to interfere with the ability to inhibit responses to negative stimuli in frequency discrimination rather than to interfere with frequency

discrimination as such" (64).

If inhibition of a motor response is a factor in the present experiment, then the fact that the large lesion cats stood more than the normal animals may be an important point. It may well be more difficult to inhibit a motor response when standing than when lying. Sitting or lying, normal cats often startled as if to respond to a tone, and then settled down again. Perhaps such a start would have been consummated if it had occurred from a standing position. On the other hand, normal cats often stood between stimuli early in training, and then gradually assumed a more sedentary or recumbent position as they learned how to avoid the shock. Perhaps the standing posture of the large lesion cats was merely a symptom of anxiety based on an inability to successfully solve the problem of avoiding the shock. Furthermore, assuming a waiting posture of a sedentary type for several periods did not seem to appreciably improve the score of a large lesion cat. The preference for standing might have been an expression of the greater sensorimotor deficits suffered by the large lesion animals or of a mild frontal syndrome.

The results of this study would seem to indicate that the use of discriminations drawing on two modalities may have been too often neglected. The evidence from this study would also seem to emphasize the importance of the association area on the anterior sigmoid gyrus and in the depths

of the cruciate sulcus. Had only the small lesions been performed, not much difference would have been observed between operated and normal cats.

That the small lesion group lies between the large lesion and normal groups in the results of many of the analyses, as well as in the extent of brain damage, raises a question as to whether or not the results can be explained in terms of the principle of "mass action" (33). There is nothing in the results of this experiment to argue against the possibility that the principle of mass action is predictive of the effects of lesions within the feline association cortex. A further test of the applicability of the principle, however, would be to study the effects of a lesion confined to the pericruciate area. The behavioral effects of such a lesion might either prove comparable to the effects of the small lesion involving the three more posterior association areas, or perhaps even prove comparable to the effects of the large lesion performed in this study.

The somatosensory lesion animals, although subjected to a lesion which was more extensive than the small lesion, were comparable to the small lesion and normal groups in cumulative error scores and in the results of the sign tests of differential response tendency. It would seem unlikely, therefore, that the effects of the large lesions were non-specific brain damage effects. Conclusions about the somatosensory lesion group would be more satisfactory

if data for more training periods were available and if the group contained more animals.

Many areas of future investigation are suggested by this study. What would be the effect of submitting a cat to a large lesion after training? What would be the effect of a lesion of the pericruciate areas alone? Would the tone dominance disappear if a background tone were present? Would mapping several months after ablation of the four association fields disclose any new functioning areas of association response? Would the large lesion group show a deficit in a food reward problem, such as lever-pressing in an enlarged Skinner box? What effect does oestrus have on the performance of female cats in a conditioned avoidance problem? Are there specific individual differences, e.g., in "emotionality", that interfere with this type of study? Could a way be found to identify "emotionally abnormal" cats so that they might be excluded from studies in which they might be contaminants? What would be the result if a discrimination using all three modalities of sensation were employed?

The large lesion in this study is unfortunately "impure" because of the necessity of removing motor and somatic sensory cortex, even against the general frame of reference of lesion studies. But in light of recent microelectrode and mapping studies (e.g. 12 and 65) the problem appears unlikely to become simple. Perhaps future research

may help sort out effect from side-effect in the results of lesions aimed at the association response field in the motor area. Until further definition, the results of this study stand as showing that a complete bilateral ablation of all the known cortical areas where "association" evoked responses are found produces a deficit in the ability of cats to function in a conditional discrimination problem employing input in both the auditory and visual modalities.

SUMMARY

On the cat cerebral cortex, four bilateral "association" fields have been defined electrophysiologically: one on the anterior lateral gyrus, one on the anterior sigmoid gyrus, and two on the middle suprasylvian gyrus. The present experiment was directed toward the study of some of the behavioral effects of lesions in these areas. Four groups of animals were compared: 1) normal cats; 2) cats with extensive lesions in the middle suprasylvian and anterior lateral gyri (small lesions); 3) cats with extensive lesions in the anterior and posterior sigmoid, the middle suprasylvian and the anterior lateral gyri (large lesions); and 4) cats with control lesions in the posterior sigmoid, anterior suprasylvian and anterior ectosylvian gyri (somatosensory lesions).

Postoperatively, the lesion and normal animals were trained on a shock-avoidance conditional discrimination problem employing stimuli in both the visual and auditory modalities. After 45 days of training all normal cats, one-half of the small lesion cats and none of the large lesion cats had reached criterion. Several statistical analyses of the response data pointed to significant differences between the large lesion cats and the normal cats. The small lesion animals were found not to be significantly different from normal cats with respect to the measures analyzed. Incomplete data suggested that the somatosensory control lesion animals were not significantly different from the

normal cats in their performance in the discrimination problem.

The data would seem to suggest that further studies of discriminations employing stimuli in more than one primary sensory modality might be fruitful. It would also seem that in the future, lesions of the cat "association cortex" cannot be considered "complete" if the anterior sigmoid field is left intact.

The principle conclution is that bilateral lesions involving all four of the known foci of electrophysiologically defined "association" responses in the cat cerebral cortex result in impaired performance in a conditional discrimination problem designed to require the utilization of information from two separate sensory modalities for successful solution.

BIBLIOGRAPHY

1. Ades, H. W., & Brookhart, J. M. The central auditory pathway. J. Neurophysiol., 1950, 13, 187-205.

2. Amassian, V. E. Microelectrode studies of the cerebral cortex. Intern. Rev. Neurobiol., 1961, 3, 67-136.

3. Bard, P. & Macht, M. B. The behaviour of chronically decerebrate cats. In Wolstenholme, G. E. W., & O'Connor, C. M. (Eds.) CIBA foundation symposium on the neurological basis of behaviour. London: J. & A. Churchill, Ltd., 1958, pp 55-75.

4. Benjamin, R. M., & Thompson, R. F. Differential effects of cortical lesions in infant and adult cats on roughness discrimination. Exper. Neurol., 1959, 1, 305-321.

5. Billett, H., & Warren, J. M. Umweg behavior in normal and brain operated cats after prolonged postoperative recovery. Am. Psychologist, 1956, 11, 440. (Abstract)

6. Brogden, W. J. Sensory pre-conditioning. J. Exp. Psychol., 1939, 25, 323-332.

7. Brogden, W. J. Acquisition and extinction of a conditioned avoidance response in dogs. J. Comp. Physiol. Psychol., 1949, 42, 296-302.

8. Brogden, W. J., & Culler, E. Device for the motor conditioning of small animals. Science, 1936, 83, 269-270.

9. Brookhart, J. M., Arduini, A., Mancia, M., & Moruzzi, G. Thalamocortical relations as revealed by induced slow potential changes. J. Neurophysiol., 1958, 21, 499-525.

10. Bruner, J. S. Neural mechanisms in perception. Psychol. Rev., 1957, 44, 340-358.

11. Brush, F. R. The effects of shock intensity on the acquisition and extinction of an avoidance response in dogs. J. Comp. Physiol. Psychol., 1957, 50, 547-552.

12. Buser, P., & Imbert, M. Donnees sur l'organisation des projection afferentes au niveau du cortex moteur du chat. Anales fac. med., Montevido, 1959, 44, 220-228.

13. Chow, K. L. Conditions influencing the recovery of visual discriminative habits in monkeys following temporal neocortical ablations. J. Comp. Physiol. Psychol., 1952, 45, 430-437.

14. Chow, K. L. Further studies on selective ablation of associative cortex in relation to visually mediated behavior. J. Comp. Physiol. Psychol., 1952, 45, 109-118.

15. Chow, K. L., Blum, J. S., & Blum, R. A. Effects of combined destruction of frontal and posterior "associative areas" in monkeys. J. Neurophysiol., 1951, 14, 59-71.

16. Doty, R. W., & Rutledge, L. T. "Generalization" between cortically and peripherally applied stimuli eliciting conditioned reflexes. J. Neurophysiol., 1959, 22, 428-435.

17. Doty, R. W., Rutledge, L. T., & Larsen, R. M. Conditioned reflexes established to electrical stimulation of cat cerebral cortex. J. Neurophysiol., 1956, 19, 401-415.

18. Eccles, J. C. The neurophysiological basis of mind. London: Oxford University Press, 1953.

19. Evarts, E. V. Effect of ablation of prestriate cortex on auditory-visual association in monkey. J. Neurophysiol., 1952, 15, 191-200.

20. Evarts, E. V. Effect of auditory cortex ablation on auditory-visual association in monkey. J. Neurophysiol., 1952, 15, 435-441.

21. Evarts, E. V. Effect of auditory cortex ablation on frequency discrimination in monkey. J. Neurophysiol., 1952, 15, 443-448.

22. Field, J., Magoun, H. W., & Hall, V. E. Handbook of physiology: Vols. I-III, Neurophysiology. Washington, D. C.: Am. Physiol. Soc., 1959-1960.

23. Galambos, R. Microelectrode studies on medial geniculate body of cat. III. Response to pure tones. J. Neurophysiol., 1952, 15, 381-400.

24. Galambos, R., Rose, J. E., Bromiley, R. B., & Hughes, J. R. Microelectrode studies on medial geniculate body of cat. II. Response to clicks. J. Neurophysiol., 1952, 15, 359-380.

25. Gastaut, H. Some aspects of the neurophysiological basis of conditioned reflexes and behaviour. In Wolstenholme, G. E. W., & O'Connor, C. M. (Eds.). CIBA foundation symposium on the neurological basis of behaviour. London: J. & A. Churchill, Ltd., 1958, pp 255-276.

26. Hara, K., & Warren, J. M. Equivalence reactions by normal and brain-injured cats. J. Comp. Physiol. Psychol., 1961, 54, 91-93.

27. Hara, K., & Warren, J. M. Stimulus additivity and dominance in discrimination performance by cats. J. Comp. Physiol. Psychol., 1961, 54, 86-90.

28. Harlow, H. F., Davis, R. T., Settlage, P. H., & Meyer, D. R. Analysis of frontal and posterior association syndromes in brain-damaged monkeys. J. Comp. Physiol. Psychol., 1952, 45, 419-429.

29. Hebb, D. O. The organization of behavior. New York: John Wiley & Sons, 1949.

30. Hoffeld, D. R., Thompson, R. F., & Brogden, W. J. Effect of stimuli time relations during preconditioning training upon the magnitude of sensory preconditioning. J. Exp. Psychol., 1958, 56, 437-442.

31. Kennard, M. A., & Kessler, M. M. Studies of motor performance after parietal ablations in monkeys. J. Neurophysiol., 1940, 3, 248-257.

32. Kluver, H. "The temporal lobe syndrome" produced by bilateral ablations. In Wolstenholme, G. E. W., & O'Connor, C. M. (Eds.). CIBA foundation symposium on the neurological basis of behaviour. London: J. & A. Churchill, Ltd., 1958, pp 175-186.

33. Lashley, K. S. Brain mechanisms and intelligence. Chicago: University of Chicago Press, 1929.

34. Lashley, K. S. The mechanism of vision: XVI. The functioning of small remnants of the visual cortex. J. Comp. Neurol., 1939, 70, 45-67.

35. Lashley, K. S. The mechanism of vision: XVIII. Effects of destroying the visual "associative areas" of the monkey. Genet. Psychol. Monographs, 1948, 37, 107-166.

36. Leary, R. W. Serial discriminations in monkeys with extensive brain damage. Am. Psychologist. 1955, 10, 398. (Abstract)

37. Leary, R. W., Harlow, H. F., Settlage, P. H., & Greenwood, D. D. Performance on double-alternation problems by normal and brain-injured monkeys. J. Comp. Physiol. Psychol., 1952, 45, 576-584.

38. Meyer, D. R. Some psychological determinants of sparing and loss following damage to the brain. In H. F. Harlow & C. N. Woolsey (Eds.) Biological and biochemical bases of behavior. Madison: University of Wisconsin Press, 1958, pp 173-192.

39. Meyer, D. R., & Woolsey, C. N. Effects of localized cortical destruction on auditory discriminative conditioning in cat. J. Neurophysiol., 1952, 15, 149-162.

40. Milner, P. M. The cell assembly: Mark II. Psychol. Rev., 1957, 64, 242-252.

41. Nakahama, H. Functional organization of somatic areas of the cerebral cortex. Intern. Rev. Neurobiol., 1961, 3, 187-250.

42. Neff, W. D., & Diamond, I. T. The neural basis of auditory discrimination. In H. F. Harlow & C. N. Woolsey (Eds.) Biological and biochemical bases of behavior. Madison: University of Wisconsin Press, 1958, pp 101-126.

43. Neff, W. D., Fisher, J. F., Diamond, I. T., & Yela, M. Role of auditory cortex in discrimination requiring localization of sound in space. J. Neurophysiol., 1956, 19, 500-512.

44. Orbach, J., & Frantz, R. L. Differential effects of temporal neo-cortical resections on over-trained and non-overtrained visual habits in monkeys. J. Comp. Physiol. Psychol., 1958, 51, 126-129.

45. Pasik, P., Pasik, T., Battersby, W. S., & Bender, M. B. Visual and tactual discriminations by macaques with serial temporal and parietal lesions. J. Comp. physiol. Psychol., 1958, 51, 427-436.

46. Peele, T. L. Acute and chronic parietal lobe ablations in monkeys. J. Neurophysiol., 1944, 7, 269-286.

47. Poljak, S. An experimental study of the association callosal, and projection fibers of the cerebral cortex of the cat. J. Comp. Neurol., 1927, 44, 197-258.

48. Pribram, H. B., & Barry, J. Further behavioral analysis of parieto-temporo-preoccipital cortex. J. Neurophysiol., 1956, 19, 99-106.

49. Pribram, K. H. Neocortical function in behavior. In H. F. Harlow & C. N. Woolsey (Eds.) Biological and biochemical bases of behavior. Madison: University of Wisconsin Press, 1958, pp 151-172.

50. Pribram, K. H., Mishkin, M., Rosvold, H. E., & Kaplan, S. J. Effects on delayed-response performance of lesions of dorsolateral and ventromedial frontal cortex of baboons. J. Comp. Physiol. Psychol., 1952, 45, 565-575.

51. Restle, F. A theory of discrimination learning. Psychol. Rev., 1955, 62, 11-19.

52. Riopelle, A. J., & Churukian, G. A. The effect of varying the intertrial interval in discrimination learning by normal and brain-operated monkeys. J. Comp. Physiol. Psychol., 1958, 51, 119-125.

53. Riss, W. Effect of bilateral temporal cortical ablation on discrimination of sound direction. J. Neurophysiol., 1959, 22, 374-384.

54. Rose, J. E., & Galambos, R. Microelectrode studies on medial geniculate body of cat. I. Thalamic region activated by click stimuli. J. Neurophysiol., 1952, 15, 343-357.

55. Rose, J. E. & Woolsey, C. N. Cortical connections and functional organization of the thalamic auditory system of the cat. In H. F. Harlow & C. N. Woolsey (Eds.) Biological and biochemical bases of behavior. Madison: University of Wisconsin Press, 1958, pp 127-150.

56. Rosvold, H. E., Szwarcbart, M. K., Mirsky, A. F., & Mishkin, M. The effect of frontal-lobe damage on delayed-response performance in chimpanzees. J. Comp. Physiol. Psychol., 1961, 54, 368-374.

57. Ruch, T. C. Sensory mechanisms. In S. S. Stevens (Ed.) Handbook of experimental psychology. New York: John Wiley & Sons, 1951, pp 121-153.

58. Ruch, T. C., Fulton, J. F., & German, W. J. Sensory discriminations in monkey, chimpanzee and man after lesions of the parietal lobe. Arch. Neurol. Psychiat., 1938, 39, 919-937.

59. Rutledge, L. T., & Kennedy, T. T. Extracallosal delayed responses to cortical stimulation in chloralosed cat. J. Neurophysiol., 1960, 23, 188-196.

60. Siegel, S. Nonparametric statistics for the behavioral sciences. New York: McGraw-Hill, 1956.

61. Starzl, T. E., & Magoun, H. W. Organization of the thalamic projection system. J. Neurophysiol., 1951, 14, 133-146.

62. Starzl, T. E. & Whitlock, D. G. Diffuse thalamic projection system in monkey. J. Neurophysiol., 1952, 15, 449-468.

63. Thompson, R. F. Effect of acquisition level upon the magnitude of stimulus generalization across sensory modality. J. Comp. Physiol. Psychol., 1959, 52, 183-185.

64. Thompson, R. F. Function of auditory cortex of cat in frequency discrimination. J. Neurophysiol., 1960, 23, 321-334.

65. Thompson, R. F., & Johnson, R. H. Organization of auditory, somatic and visual projection to association fields of cerebral cortex in cat., 1962. (In preparation).

66. Thompson, R. F., & Sindberg, R. M. Auditory response fields in association and motor cortex of cat. J. Neurophysiol., 1960, 23, 87-105.

67. Thompson, R. F., Voss, J. F., & Brogden, W. J. Effect of brightness of simultaneous visual stimulation on absolute auditory sensitivity. J. Exp. Psychol., 1958, 55, 45-50.

68. Thompson, R. L. Effects of lesions in the caudate nuclei and dorsofrontal cortex on conditioned avoidance behavior in cats. J. Comp. Physiol. Psychol., 1959, 52, 650-659.

69. Towe, A. L., & Ruch, T. C. Association areas and the cerebral cortex in general. In T. C. Ruch & J. F. Fulton (Eds.) Medical physiology and biophysics. Philadelphia: W. B. Saunders, 1960, pp 464-482.

70. Warren, J. M., & Harlow, H. F. Learned discrimination performance by monkeys after prolonged post-operative recovery from large cortical lesions. J. Comp. Physiol. Psychol., 1952, 45, 119-126.

71. Warren, J. M., Leary, R. W., Harlow, H. F, & French, G. M. Function of association cortex in monkeys. Brit. J. Anim. Behav., 1957, 5, 131-138.

72. Warren, J. M., & Sinha, M. M. Effect of differential reinforcement on size preferences in cats. Percept. Mot, Skills, 1957, 7, 17-22.

73. Warren, J.M., Warren, H. B., & Akert, K. Umweg learning by cats with lesions in the prestriate cortex. J. Comp. Physiol. Psychol., 1961, 54, 629-632.

74. Welch, W. K., & Kennard, M. A. Relation of cerebral cortex to spasticity and flaccidity. J. Neurophysiol., 1944, 7, 255-268.

75. Woolsey, C. N. Organization of somatic sensory and motor areas of the cerebral cortex. In H. F. Harlow & C. N. Woolsey (Eds.) Biological and biochemical bases of behavior. Madison: University of Wisconsin Press, 1958, pp 63-81.

76. Zubek, J. P. Studies in somesthesis. II. Role of somatic sensory areas I and II in roughness discrimination in cat. J. Neurophysiol., 1952, 15, 401-408.