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A selective spatial discrimination deficit following fornicotomy in the rat.

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A SELECTIVE SPATIAL DISCRIMINATION DEFICIT FOLLOWING FORNICOTOMY IN THE RAT

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The author would also like to thank Dr. E. E. Krieckhaus, for his assistance in the design and the conduct of this research.

Special thanks go to my wife, Charlotte, whose patience and tolerance have surpassed all reasonable expectations.

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de Castro, J. M. A selective spatial discrimination deficit following fornicotomy in the rat. Physiol. behav., The hypothesis that fornicotomy results in deficits specific to spatial discriminations was tested in two experiments. In experiment 1, 24 rats were trained under massed trial conditions in a plus (+) shaped maze to acquire, reverse, and extinguish a position, a turn, or a stimulus discrimination. There were no significant overall deficits attributable to the lesion. However, whereas the control animals improved in their performance of the position discrimination with previous experience in the maze, the lesioned animals failed to show improvement. In experiment 2, 30 rats were trained in the position or turn discrimination tasks. They were trained under spaced trials, ten trials per day, through acquisition and five successive reversals. Fornicotomy produced a selective impairment in the reversal of the position discrimination. The turn discrimination was not affected by the lesion. The results were interpreted to indicate that the hippocampal-fornix system is implicated in the long-term storage of the spatio-temporal relationships of stimuli in the environment.

Hippocampus Fornix Maze learning

Spatial discriminations Stimulus discriminations

Response discriminations Reversal training

The fornix is the major afferent and efferent pathway of the hippocampus. However, it is not the only pathway. The hippocampus receives afferents from (11, 12, 29) and sends efferents to (10) the entorhinal cortex. Thus the hippocampus has two anatomically distinct afferent and efferent systems. There is accumulating evidence that these two anatomical systems subserve different functions. Animals sustaining lesions in the entorhinal cortex are deficient in the acquisition of a passive avoidance response (5, 36) while fornix lesioned animals are not deficient (3, 6, 35, 36). Animals with lesions of the fornix acquire a two-way active avoidance response faster than control animals (19, 35, 36) while animals with entorhinal lesions do not differ from control animals (36). Finally, animals are deficient at the acquisition of one-way active avoidance following fornix lesions (3, 19) but not following entorhinal lesions (34). Thus these two systems appear to be not only anatomically distinct but also functionally distinct.

When the cellular areas of the hippocampal formation are damaged, there is a consequent severing of fibers from both of these anatomical systems. It is thus possible that the behavioral effects of hippocampal destruction are the sum of the effects attributable to damage of each of these systems. In fact, hippocampal lesions produce a set of deficits compatible with this notion. Animals with destruction of the hippocampus are deficient in the acquisition of a passive avoidance task (7, 15), are superior in the acquisition of a two-way active avoidance task (8, 28), and are deficient in the acquisition of a one-way active avoidance task (2, 23).

It is unfortunate that, in comparison to the vast literature on the effects of hippocampal lesions on behavior (see 4, 13, 16 for review), there is a paucity of studies on the effects of either fornix or entorhinal lesions. It is impossible to discriminate from the effects of hippocampal lesions which deficits are attributable to which anatomical system. It thus is impossible to formulate or evaluate a theoretical interpretation of the role of the hippocampus in behavior from the data on hippocampal lesions. Thus there is a great need to study the effects of destruction of either the fornix or the entorhinal cortex. At the present time, it is impossible to disrupt the hippocampal-entorhinal connections without considerable damage to the entorhinal cortex. It would not be clear following destruction of the entorhinal cortex whether an effect resulted from the severing of the hippocampal-entorhinal connections or from damage to the cells of the entorhinal cortex. Lesions confined to the fornix-ventral hippocampal commissure-complex do not damage any structure other than hippocampal afferent and efferent fibers. It thus appears that knowledge of the function of the hippocampus can best be extended by studying the effects of fornix lesions.

In a previous paper (3), it was suggested that the known effects of fornicotomy could be interpreted as reflecting a deficiency in the animals' ability to perform spatial discriminations. The effect of fornicotomy on performance in avoidance tasks could result from an impaired ability to discriminate between the two compartments in the shuttle box. Fortunately,

there are more direct demonstrations of this impairment in spatial discrimination. Fornix lesions in monkeys result in deficient spatial reversal performance without affecting object reversal performance (21). Cats with fornicotomies have difficulty retracing a path to food (33). Finally, destruction of the fornix results in impairment in the reversal of a position habit in both the cat (6, 34) and the rat (9). All of these findings suggest that the animals are deficient in the performance of spatial discriminations.

Unfortunately, there is a major shortcoming with these studies. The particular tasks that have been used do not separate position from turn. An animal learning to go to a particular goal arm in a T-maze, or to respond to a particular position in a WGTA, is always required to go to the same side and make the same turn at the choice point. Impaired performance on these tasks could result from either a difficulty with spatial discriminations or a difficulty with turn discriminations. Furthermore, since most of the reported deficits occur with the reversal of the position habit, the data can also be interpreted as a deficit in response inhibition (4, 22). Thus there is a need to investigate the effect of fornicotomy on a task within which position and turn are separated.

A cross or plus shaped maze has been used to investigate spatial discriminations (31, 32). In this maze, position and turn can be separated. The maze has two goal arms and two start arms which are located 180^{o}

from each other. For a position discrimination, reinforcement is made available in only one goal arm. Depending upon the start arm from which the animal begins, either a right or a left turn may be required to receive reinforcement. In this way, position is made independent of turn. For a turn discrimination, reinforcement is made available in a goal box to the same side of the start arm. The animal is required to make the same turn regardless of the goal arm entered in order to receive reinforcement. Thus, turn can be made independent of position. With the addition of lights at the ends of the goal boxes, a light dark discrimination can also be run in the maze. If fornix lesions produce deficits specific to spatial discriminations, then the position task, but not either the turn or the stimulus tasks, should be affected by fornicotomy. The following experiment was performed to test that prediction.

EXPERIMENT 1

METHOD

The subjects consisted of 24 male Holtzman albino rats. They ranged in age from 60 to 100 days and weighed from 260 to 450 grams at the time of surgery. Prior to surgery, they were caged in groups of four. Following surgery, they were isolated in individual cages. Water was provided ad libitum throughout the course of the experiment. Purina lab chow was provided ad libitum prior to and for four days following surgery. The rats' weights were then reduced, over a four-day period, to 85% of their maximum preoperative ad libitum weight and were maintained at this level for the remainder of the experiment.

Electrodes were aimed at the fornix-ventral hippocampal commissure-complex. Twelve rats were lesioned and twelve received sham operations. The animals were anesthetized with sodium pentobarbital (40 mg/kg body weight) administered i. p. and 1 mg of atropine methyl nitrate in a 2 cc isotonic saline solution was administered i. p. to suppress mucosal secretion. The animals were placed in a Kopf stereotaxic instrument. A series of five lesions were produced with a Grass LM-4 Radio Frequency Lesion Maker. The current was passed between the ear bars and a size 00 stainless steel insect pin, insulated with teflon except for a . 5 mm tip. The lesion parameters were measured in terms of maximum power. During the first ten sec. of the 50 sec. current duration, the voltage was slowly increased from zero to a value which produced the desired power output. Lesions were

placed with lambda and bregma at equal height in reference to anterior bregma, the midsaggital sinus, and the skull height over the target with the following coordinates and parameters: 1.4 P, $\pm$ 1.7 L, 5.0 D with 100 mw power, 1.4 P, $\pm$ 0.7 L, 4.9 D with 80 mw power, and 1.4 P, 0 L, 4.9 D with 80 mw power. Sham operated animals went through the same procedure except that current was not passed.

The maze was plus (+) shaped and is depicted in Figure 1. It was constructed of 6 mm plywood painted flat gray. The walls were 15 cm high

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Insert Figure 1 about here

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and the alleys were covered with a 3 mm thick plexiglass lid. The two start boxes were separated from the remainder of their respective alleys by a manually operated guillotine door. Another guillotine door was located at the juncture between the start arm and the two goal arms. This was used to block off the entrance to the unused start arm during each trial. The two goal boxes were separated by a manually operated guillotine door from the remainder of the goal arm. The rear wall of each goal box was constructed of milk glass and a housing containing a 25 watt light bulb was positioned behind the glass.

The animals were given preliminary training on the ninth postoperative day. A straight alley was used which consisted of the two goal arms of the plus maze. The guillotine doors were closed at the entrance to both start

arms. Ninety-five milligram Noyes pellets were present in the food cup of each goal box. The animals were allowed to freely explore the alley until the pellets were found and consumed in both goal boxes The animal was then removed and placed in a holding cage for 30 seconds. This procedure was repeated three times and was followed by training to traverse the straight alley for food. The rat was placed in one of the goal boxes with the food cup removed and the duillotine door down. After five sec. the door was raised. When the opposite goal box was entered, its guillotine door was gently lowered. After the pellet was consumed, the animal was removed and placed in the holding cage for 30 seconds. The goal box which served as the start box was alternated on each trial. Each animal was run for as many trials as were necessary to attain a criterion of two consecutive trials with a latency to traverse the alley of less than five seconds.

On the day following preliminary training each animal received acquisition, reversal, and extinction training. The next day, the second task was run, and the third task was run on the following day. There are six possible sequences of the three tasks, and two lesioned and two sham operated animals were run in each sequence. The six sequences are presented in Table 1. For

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Insert Table 1 about here

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the place discrimination, a single 95 mg pellet was always placed in the same goal arm. For the turn discrimination, the pellet was always placed to the same side of the start box. For the light-dark discrimination, the pellet was always placed in either the lighted or the dark goal box. Both the position and the turn discriminations were run with the room lights on and the stimulus lights off. The light-dark discrimination was run with the room lights off. The only illumination was provided by the stimulus light. An air conditioner provided considerable masking noise.

The start box and the stimulus position for each trial were determined prior to testing with a table of random numbers and the following constraints; each start box was used in five out of every ten trials, the stimulus light was on in each goal box five out of every ten trials, and the stimulus light was on the right of the start box ten out of every 20 trials. The position, turn, or stimulus which was reinforced in acquisition was opposite to the one chosen by the rat on the first trial of acquisition.

Prior to each trial, the entrance to the unused start arm was closed off, the guillotine doors at the entrance to the goal boxes were opened, and one food pellet was placed in the appropriate goal cup. The rat was then placed in the start box and, after a five-second delay, the guillotine door was raised. When the goal box was entered, the guillotine door was gently lowered. A non-correction procedure was used. The animal was then removed and placed in a holding cage for 30 seconds. If the rat did not enter a goal box within 90 seconds, it was removed from the alley and the trial was repeated. The experimenter recorded the goal box entered and the response latency.

The criterion used for both acquisition and reversal of all three tasks was nine correct choices out of ten consecutive trials. Massed trials were given until the acquisition criterion was attained. Following a ten-minute break, massed reversal training was carried out to criterion. After a final ten-minute break, extinction training began. Training continued without reinforcement to a criterion of three consecutive trials with a latency greater than 30 seconds. If neither goal arm was entered within 90 seconds, the animal was removed from the maze and placed in the holding cage to await the next trial. Up to a maximum of 100 extinction trials were run if criterion was not reached.

Following completion of the three tasks, the subjects were sacrificed with an overdose of sodium pentobarbital, perfused through the heart with 50 cc of isotonic saline followed by 50 cc of 10% neutral buffered formalin. The brains were removed, imbedded in gelatin, sectioned at 50 u on a freezing microtome, and alternate sections were stained with a modified Weigert procedure for unmounted sections (37). The lesions were rated for the percentage damage to the fornix on either side of the midline and any damage to surrounding structures was recorded.

Histology

Damage to the fornix ranged from 40% to 95% and is depicted in Figure 2.

Insert Figure 2 about here

The damage consistently occurred caudal to the septum and rostral to the hippocampus. Only the caudal extension of the triangular nucleus of the septum was consistently damaged. The most caudal aspect of the medial septal nucleus was damaged unilaterally in only one animal and the most rostral aspect of the dorsal hippocampus received unilateral damage in only one animal. The lesions frequently spread into the corpus callosum but never spread into the cingulum or the cingulate cortex. The cingulum consistently showed electrode damage. The most frequent extra-fornix damage occurred in the stria medullaris and the anterior thalamic nuclei. In two cases, the stria medullaris was completely severed bilaterally. Less than 50% destruction occurred in seven cases and the stria medullaris was spared in three cases. The anterior thalamic nuclei received up to 50% damage in nine out of the twelve lesions. The stria terminalis was unilaterally damaged in four rats and was bilaterally damaged in one animal. Damage outside of the fornix was not correlated with the behavioral results.

RESULTS AND DISCUSSION

Lesion of the fornix did not result in deficient performance on these tasks in comparison to sham operated control animals. There were no overall differences between groups as measured by either errors or trials to criterion. Neither the acquisition, reversal, or extinction of either the place, turn, or stimulus discrimination tasks was affected by the lesion. The mean performance for each group on each task in each stage are presented in Table 2. Although there were no overall deficiencies, an analysis

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Insert Table 2 about here

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of the group's performance on the place discrimination task alone revealed a significant Lesion X Order interaction for both trials to criterion ($F = 3.57$, $p < .05$) and for errors to criterion ($F = 4.59$, $p < .025$). This interaction term was not significant for either the turn or the stimulus discrimination tasks.

Figure 3 depicts the mean number of trials to attain the learning criterion in the place discrimination task for both groups at each position

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Insert Figure 3 about here

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of occurrence in the task sequence. When the place discrimination task was the first one encountered by the sham operated animals, they did significantly

worse than when it was the last task encountered. This improvement with experience occurred for the control animals in reversal ($t = 4.54$, $p < .005$) and in extinction ($t = 2.31$, $p < .05$). On the other hand, the fornix lesioned animals did not demonstrate a significant improvement with experience in the maze.

Analysis of variance of the response latencies revealed significant main effects due to task ($F = 3.99$, $P < .05$), to order ($F = 6.49$, $P < .01$), and to stage, either acquisition or reversal ($F = 6.27$, $P < .005$). The only significant effect attributable to lesion was a Lesion X Task X Stage interaction ($F = 3.90$, $P < .01$). The lesioned group responded significantly faster than the sham operated group during the acquisition of the position discrimination ($t = 2.47$, $P < .05$) but not during the reversal of the position discrimination ($t = .08$). The latencies for the lesion and control groups were not different in either the turn or the stimulus discriminations.

The fornix lesions did not produce deficient performance in the place discrimination task. In fact, none of the maze tasks were affected by the lesions. This is unusual since significant deficits in the reversal of maze tasks have been reported to occur following either fornicotomy (6, 9) or hippocampectomy (15, 18). However, the present experiment used a massed trial procedure. Liss (19) has found that fornix lesions do not produce deficits in avoidance tasks when massed trials are used while deficits do occur when spaced trials are used. Thus it is possible that the lack of an overall lesion effect in Experiment 1 resulted from the use of massed trials.

Thus Experiment 2 investigated the effect of fornix lesions on the performance of the place and turn discrimination tasks under spaced trial conditions.

The lesioned group in Experiment 1 did not improve in their performance on the place discrimination task with experience in the maze although the sham operated control animals did improve. This could be indicative of an inability to transfer relevant information from one task to the next. Thus Experiment 2 also investigated the effect of fornicotomy on serial reversal performance in the two maze tasks.

EXPERIMENT 2

METHOD

The subjects consisted of 30 male Holtzman albino rats. They were from 60 to 90 days of age and were from 240 to 400 grams in weight at the time of surgery. Fifteen rats were lesioned in the fornix-ventral hippocampal commissure-complex and 15 rats received sham operations. Surgical and histological procedures were the same as in Experiment 1 except for a .1 mm decrease in the vertical stereotaxic coordinate. The new coordinates and lesion parameters were as follows: 1.4 P, $\pm$ 1.7 L, 4.9 D with 100 mw power, 1.4 P, $\pm$ 0.7 L, 4.8 D with 80 mw power, and 1.4 P, 0 L, 4.8 D with 80 mw power. Recovery period, deprivation, preliminary training, start box schedule, and inter-trial interval were the same as used in Experiment 1.

The animals were separated into four groups as follows: a fornix lesioned position group (n = 9), a sham operated position group (n = 9), a fornix

lesioned turn group (n = 6), and a sham operated turn group (n = 6). Each animal was trained for ten trials per day until a criterion was reached of nine correct trials in a single day. The animal was given acquisition training followed by five successive reversals. The light-dark discrimination was not run and the animals were not extinguished. All other aspects of the procedure were the same as in Experiment 1.

Histology

In general, the lesions were larger than in Experiment 1. The degree of fornix destruction ranged from 75% to 100% and is depicted for each animal in Figure 4. As occurred in Experiment 1, the major damage outside of the

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Insert Figure 4 about here

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fornix occurred in the stria medullaris and the anterior thalamic nuclei. Four animals incurred unilateral damage to the stria medullaris, and nine animals had bilateral damage ranging from 20% to 100%. The anterior thalamic nuclei were damaged bilaterally in ten animals. The stria terminalis received bilateral damage in four animals ranging from 75% to 100% destruction. The rostral tip of the dorsal hippocampus was damaged unilaterally in one animal. The septum, the caudate nucleus, the cingulate cortex, and the cingulum bundle were not damaged by the lesion. Electrode tract damage consistently occurred in the cingulum bundle.

RESULTS AND DISCUSSION

The results for errors to criterion and for sessions to criterion were very similar and thus only errors to criterion are reported. There was considerable heterogeneity of variance between the position and turn discrimination groups ($F_{max} = 22.36$, $P < .01$). Thus the overall analysis of variance was performed on logarithmically transformed data. For all other analyses transformed data were not used. The results for the number of errors incurred to reach criterion are depicted in Figure 5.

Insert Figure 5 about here

The place and turn discrimination tasks did not differ significantly in acquisition ($F = 1.22$, $P > .25$). However, in successive reversals, significantly more errors occurred in the turn discrimination than occurred in the position discrimination ($F = 31.26$, $P < .005$). Furthermore, performance across the successive reversals was strikingly different for the two tasks as indicated by a significant Task X Reversal interaction ($F = 8.92$, $P < .005$). As depicted in Figure 5, the position discrimination groups improved from the first to the last reversal ($t = 4.06$, $P < .01$). The turn discrimination groups, on the other hand, became worse but not significantly so from the first to the last reversal ($t = 1.08$, $P > .10$). This difference in successive reversal performance between the two tasks has implications for the theory

of serial reversal performance. In the turn discrimination, there are few, if any, relevant external stimuli. In the position discrimination there are abundant relevant external cues. If serial reversal improvement results at least in part from learning to attend to the relevant external cues, as has been suggested (20), then a task in which there were no relevant external cues should have little, if any, improvement over serial reversals. This occurred with the turn discrimination task. Serial reversal improvement did occur in the position task as would be predicted by the attentional model. Thus the behavioral results can be taken as evidence for an involvement of attention in serial reversal improvement.

Fornix lesions resulted in deficient reversal performance on the position but not on the turn discrimination. Analysis of variance of the errors to criterion measure revealed a significant Lesion X Task interaction ($F = 5.09$, $P < .05$). The lesioned animals made more errors than the control animals in the reversals of the place discrimination ($F = 61.27$, $p < .005$) but did not differ from the sham operated control animals in the reversals of the turn discrimination ($F = 0.01$, $p > .25$). The effect of the lesions was uniform across the successive reversals as indicated by the non-significant Lexion X Reversals X Task interaction ($F = 0.57$, $p > .25$). The percentage of the fornix destroyed correlated significantly with both the number of errors to criterion ($r = .66$, $p < .05$) and the number of trials to criterion ($r = .63$, $p < .05$) in the place discrimination task. Thus the fornix lesions produced a deficit in the successive reversals of the place discrimination task without

affecting performance on the turn discrimination task and the degree of the deficit was related to the degree of fornix destruction.

The number of errors occurring on each trial within sessions is depicted in Figure 6. Once again the lesioned animals' deficiency at the position dis-

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Insert Figure 6 about here

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crimination is evident ($F = 13.85$, $P < .005$). There was a significant improvement by both groups across trials ($F = 31.37$, $P < .005$). However, the Lesion X Trials interaction was not significant ($F = .87$). The lesioned animals improved as much as control animals during the daily ten trials.

The mean latency to traverse the maze for all groups is depicted in Figure 7. The animals' performance on the two tasks did not differ in the

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Insert Figure 7 about here

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latency to respond overall ($F = 1.39$, $P > .10$). However, there was a substantial difference between the two tasks over successive reversals as is evident in Figure 6 and indicated by a significant Task X Reversals interaction ($F = 2.56$, $P < .05$). The lesioned animals ran significantly faster than controls in both tasks ($F = 10.62$, $P < .005$). The Lesion X Task interaction was not significant ($F = 1.27$, $P < .10$) and thus, unlike the errors data, the two tasks were not affected differently. Within both tasks, the correlations

between latency to respond and either errors or trials to criterion were not significant. Furthermore, the mean response latency was not significantly correlated with the amount of damage to the fornix.

GENERAL DISCUSSION

The present experiments demonstrated that, under spaced trial conditions, fornix lesions result in deficient reversal performance of a place discrimination task while not affecting the reversal of a turn discrimination task. The task used separated turn from place. Thus the hypothesis that fornix lesions produce deficits specifically in tasks requiring spatial discriminations is supported, at least under spaced trial conditions.

The fornix lesioned animals demonstrated an ability, on a par with sham operated control animals, to reverse a previously reinforced response in the turn discrimination task. Thus they did not show response perseveration. This lack of perseverativeness in the turn discrimination task rules out a number of current models of hippocampal function as explanations for the effects of fornix lesions (4, 16, 22, 27). It is possible that the lesions resulted in a perseveration to a place rather than a perseveration of response. However, the fact that the lesioned animals improved as much as control animals did within the ten trial daily sessions would not be predicted by a place perseveration hypothesis.

If the lesioned animals were unable to attend to the relevant external stimulus dimension, they would be expected to show an impairment in tasks which require the utilization of external stimuli. Thus the place discrimination would be expected to be deficient while the turn discrimination would be unaffected. However, Experiment 1 and previous work (15, 18) have not found a deficiency in stimulus discriminations either with fornix or hippo-

campal destruction. Furthermore, an attentional impairment should affect behavior regardless of whether trials are massed or spaced. Thus a simple attentional impairment cannot account for the data.

A recent model of hippocampal function (13) postulates a motivational function for the hippocampus. The faster response latencies demonstrated by the lesioned groups in Experiment 2 could indicate an increased level of motivation for food. Furthermore, the faster running speed could affect the place discrimination while not affecting the turn discrimination. The lesioned animals could be running past the relevant cues in the place discrimination task. Since the cues in the turn discrimination task are mainly internal, this task would not necessarily be affected. However, the failure to find an overall change in the response latencies in the lesioned groups in Experiment 1 argues against this hypothesis. If there was a heightening of motivation resultant from the lesion, it should have affected the results under both massed and spaced trials. Furthermore, neither the degree of fornix damage nor the error rate correlated with the response latencies in Experiment 2. Thus fast runners did not necessarily make more errors than slow runners. Although the heightened motivation hypothesis cannot be rejected, the evidence does not appear to be strongly in favor of it.

The fornix lesioned animals improved within the ten trials of the place discrimination task sessions to the same extent as did the sham operated control animals. Furthermore, when the trials were massed

the fornix lesioned animals also did not differ from controls. Thus the important dimension of the spaced trial procedure would appear to be the 23+ hours between sessions. This could imply that the nature of the deficit was in the long-term memory storage and/or retrieval process. Spatial discrimination requires the discernment and storage of the spatio-temporal relationship of stimuli in the environment. Since the deficit appears to be specific to tasks requiring spatial discrimination, it follows that the deficit may be characterized as an impairment in the long-term storage or retrieval of the spatio-temporal relationships of stimuli in the environment.

Previous results on the effect of fornicotomy on the retention of a maze habit supports a hypothesis of impaired spatial memory. Significant retention deficits in complex maze habits have been reported to occur following fornicotomy (14, 30). Furthermore, some anomalous results from the hippocampal lesion literature could have resulted from an impaired retention of spatial information. Rats with total hippocampal ablations do not demonstrate latent learning (17). Hippocampally lesioned animals perseverate in reentering blind alleys in a maze (14). Also animals with hippocampal ablations show less flexibility than controls in the selection of routes through a Dashiel maze (26).

Hippocampal lesioned animals are deficient in their performance of successive but not simultaneous stimulus discriminations in a T-maze

(15, 18). Simultaneous discriminations can be learned with a strategy of turn toward the positive stimulus and/or turn away from the negative stimulus. A successive discrimination, on the other hand, requires the memory of the relationship between stimuli, that is, the memory of the relationship between one stimulus and one set of alley cues and the other stimulus and the other set of alley cues. Animals who are deficient at retaining the spatio-temporal relationship of stimuli in the environment would thus be expected to be deficient at the successive but not the simultaneous stimulus discrimination.

The spatial memory hypothesis is also supported by the effects of right temporal lobe damage in humans. Patients with damage to the hippocampus in the right hemisphere have difficulty learning both visually guided (24) and tactually guided (1) stylus mazes. These patients also have difficulty learning spatial sequences and reproducing the position of a cross on a line (25). Thus humans with damage to the right hippocampus appear to also be deficient at the retention of spatial information.

Thus the evidence from the present experiments suggest an involvement of the hippocampal-fornix system in spatial memory. This hypothesis is compatible with the literature on the effects of fornix lesions and is also compatible with the effects of hippocampal lesions in both humans and animals. Thus it is concluded that there is substantial evidence that the hippocampal-fornix system is involved in the memory of the spatio-temporal relationships of stimuli in the environment.

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TABLE 1

Task Sequences Used in Experiment 1

Group	Fornix	Sham	First	Second	Third
PRS	2	2	Position	Response	Stimulus
PSR	2	2	Position	Stimulus	Response
RSP	2	2	Response	Stimulus	Position
RPS	2	2	Response	Position	Stimulus
SPR	2	2	Stimulus	Position	Response
SRP	2	2	Stimulus	Response	Position

TABLE 2

Mean Number of Errors and Trials to Criterion for Each Group for Each Task for Each Stage Used in Experiment 1

		Position		Turn		Stimulus	
		TTC	ERR	TTC	ERR	TTC	ERR
FORNIX	ACQ	32.6	11.9	25.0	11.3	53.0	23.3
	REV	62.8	29.5	49.1	25.5	80.6	43.5
	EXT	42.2	--	66.1	--	58.8	--
SHAM	ACQ	50.0	22.3	23.8	8.3	51.8	24.1
	REV	57.9	28.1	46.6	25.7	87.4	46.0
	EXT	39.8	--	45.1	--	46.5	--

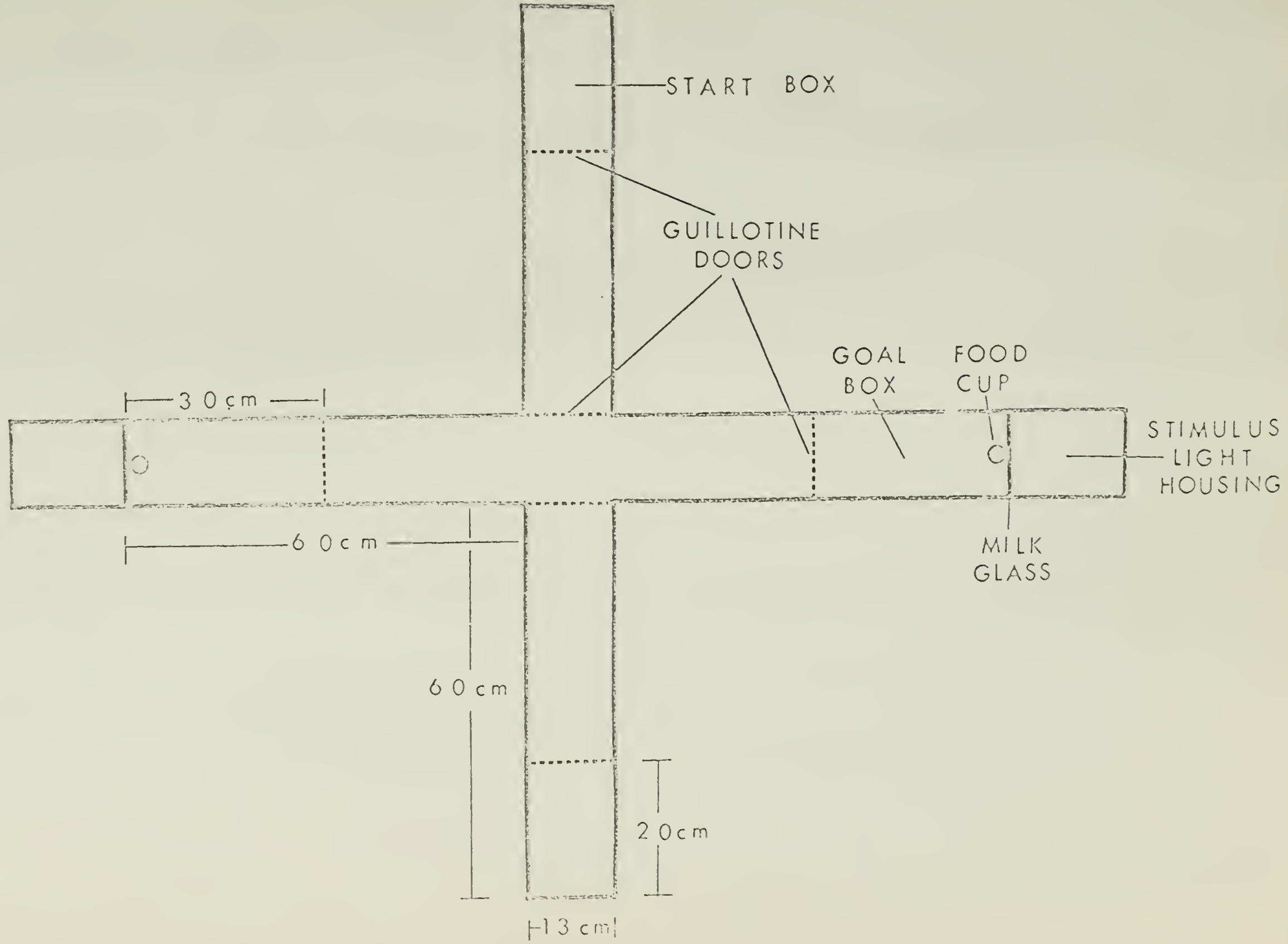


Figure 1: Diagram of the + shaped maze used in both experiment 1 and experiment 2.

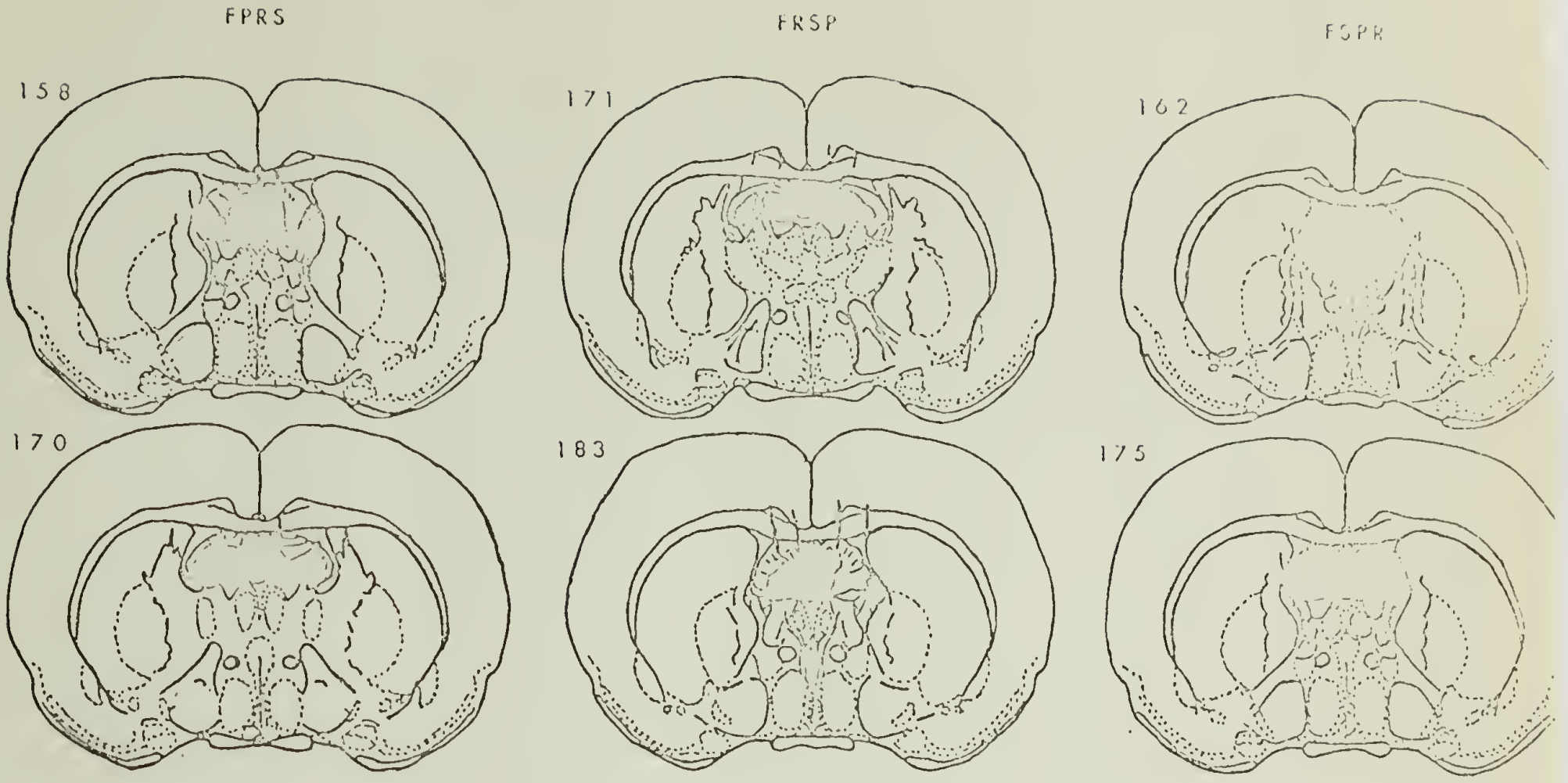


Figure 2: Reconstructions of the maximum extent of the damage to the fornix for all lesioned animals in experiment 1.

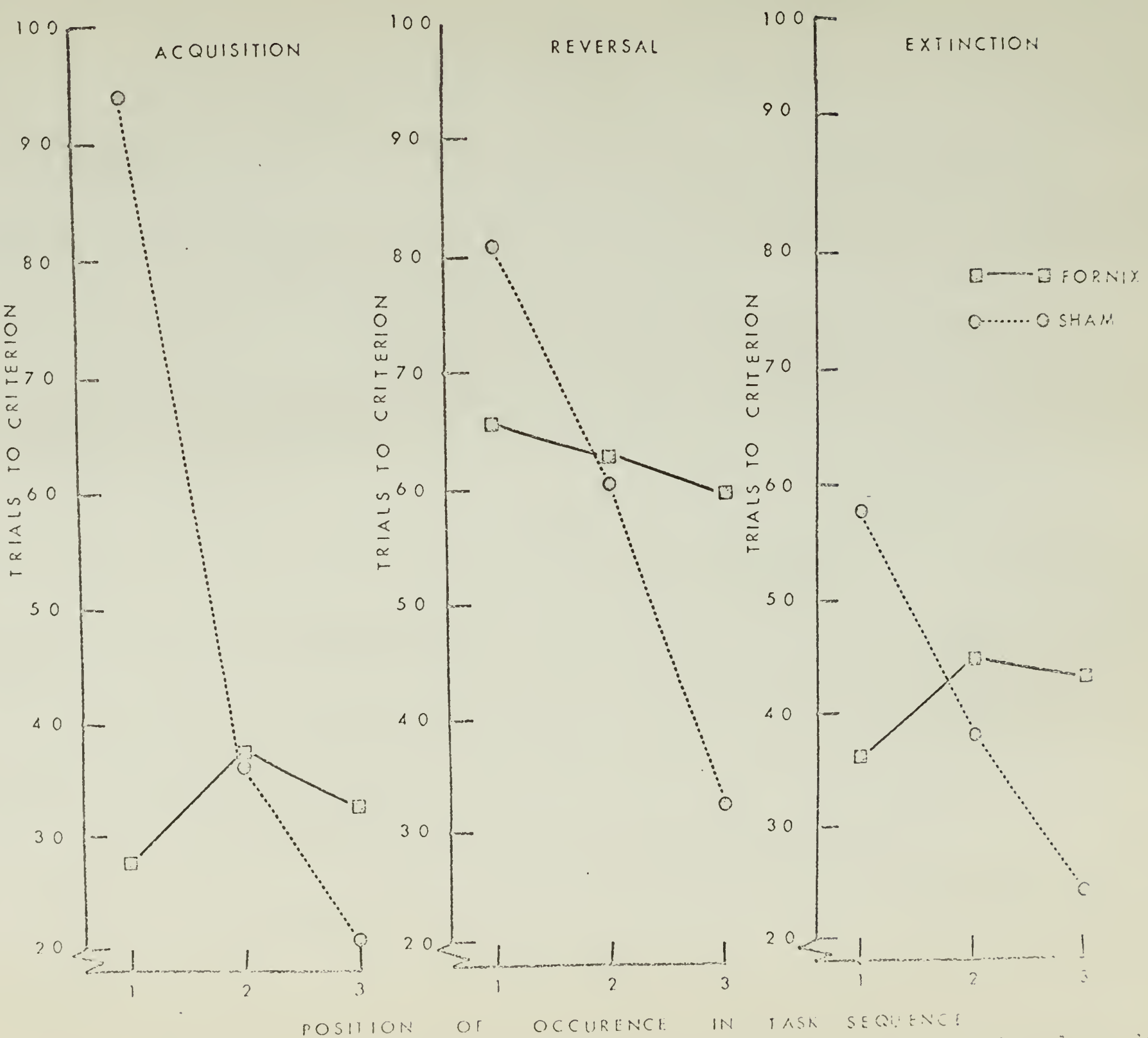
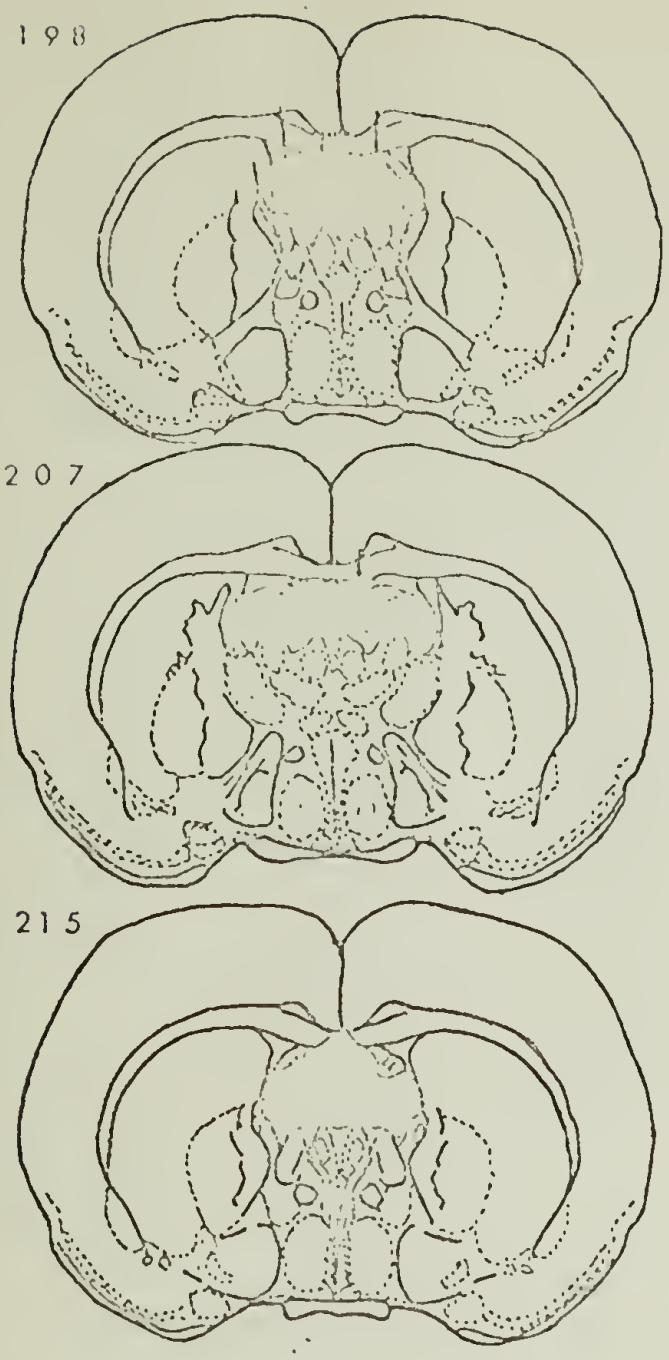
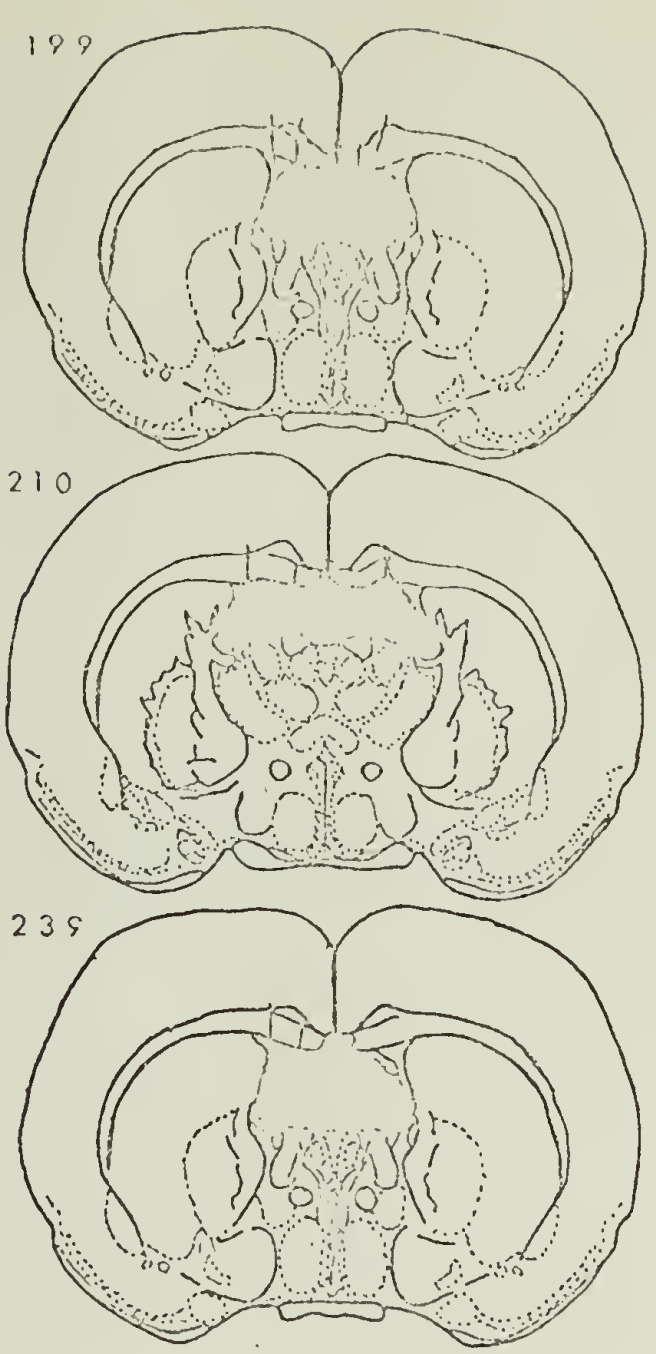
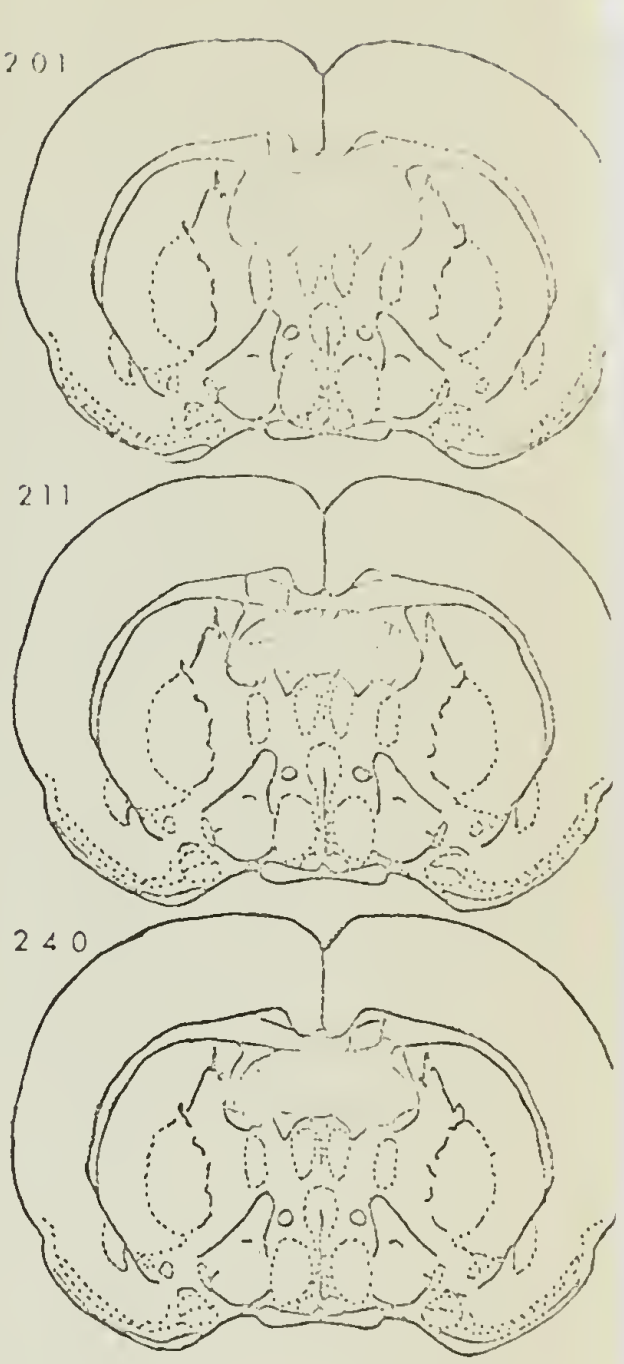


Figure 3: Trials to criterion for the acquisition, reversal and extinction of the place discrimination task for each position in the sequence of tasks for lesion and control groups.

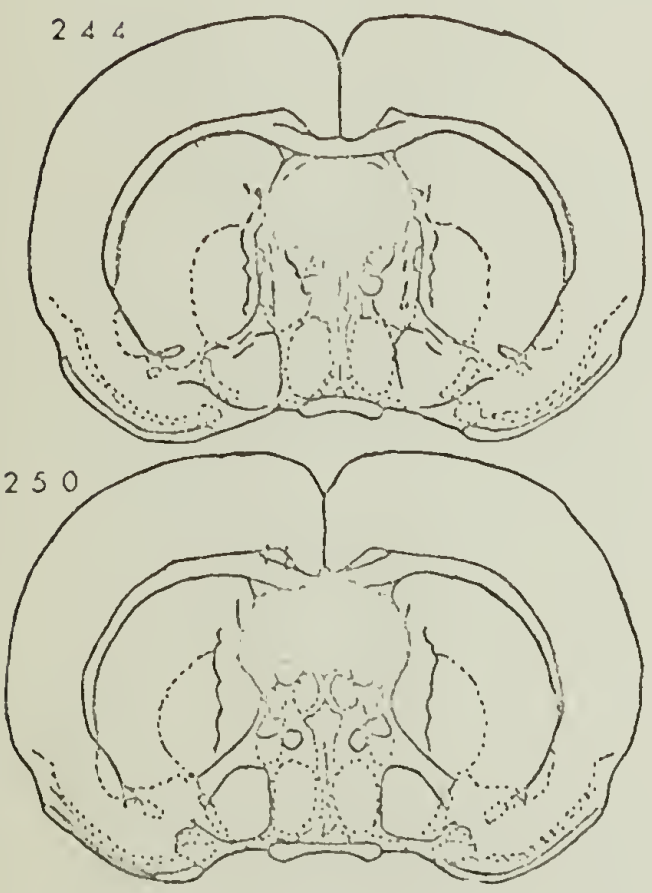
POSITION TASK

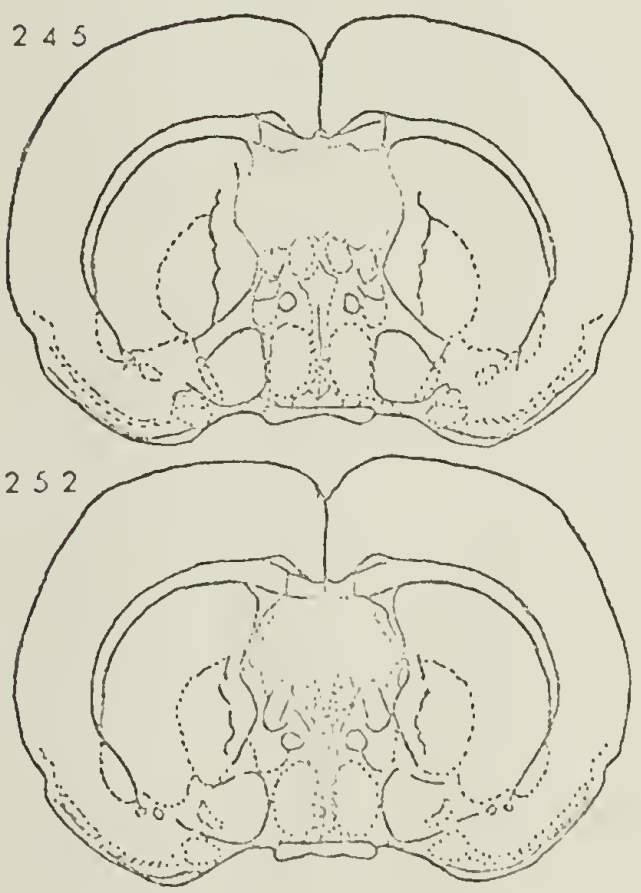






RESPONSE TASK





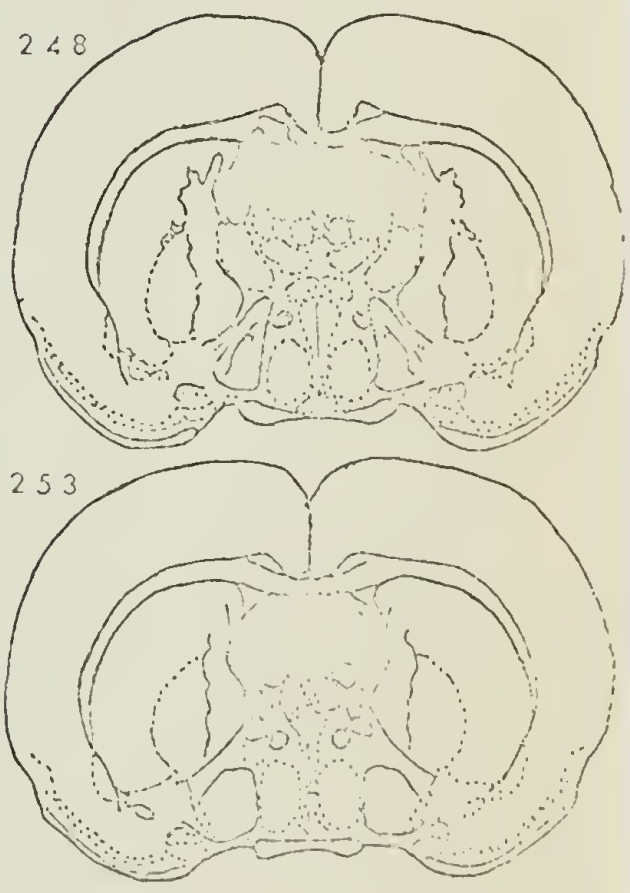


Figure 4: Reconstructions of the maximum extent of the damage to the fornix for all animals in experiment 2.

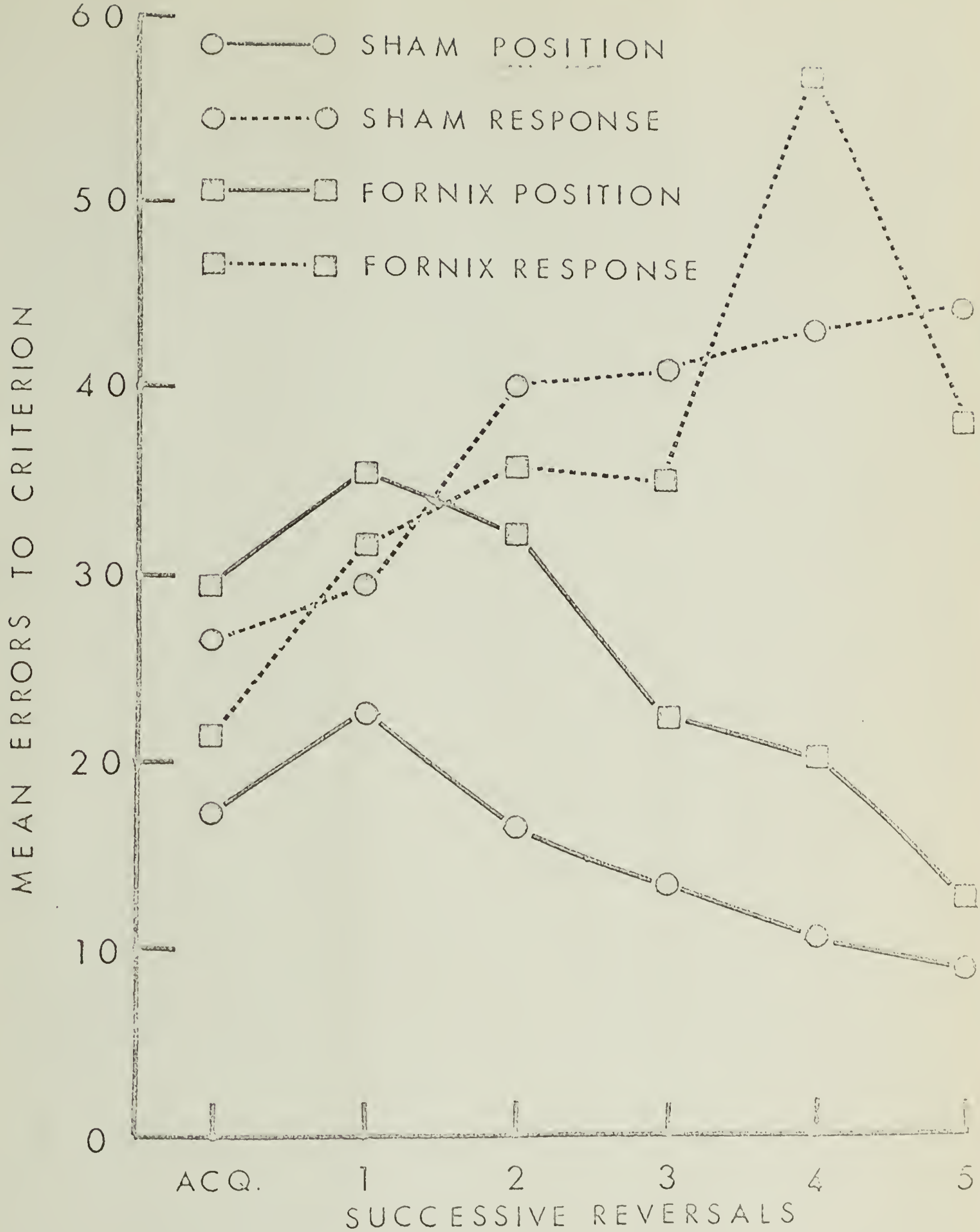


Figure 5: Errors incurred in attaining criterion performance in the place and turn discriminations for the initial acquisition and for the five successive reversals for the lesion and control groups.

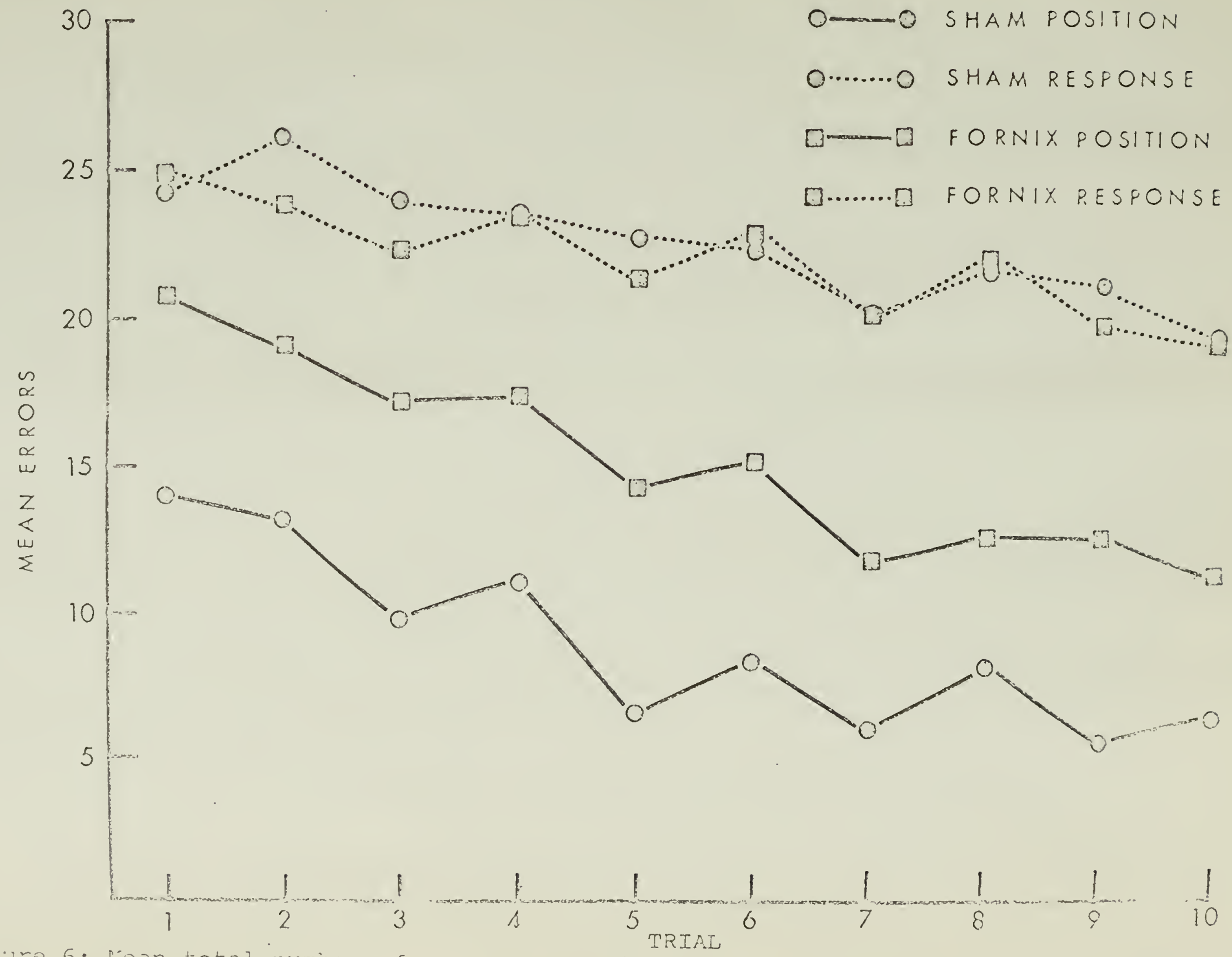


Figure 6: Mean total number of errors occurring on each trial of the ten trial session, summed across acquisition and the five successive reversals for lesion and control groups.

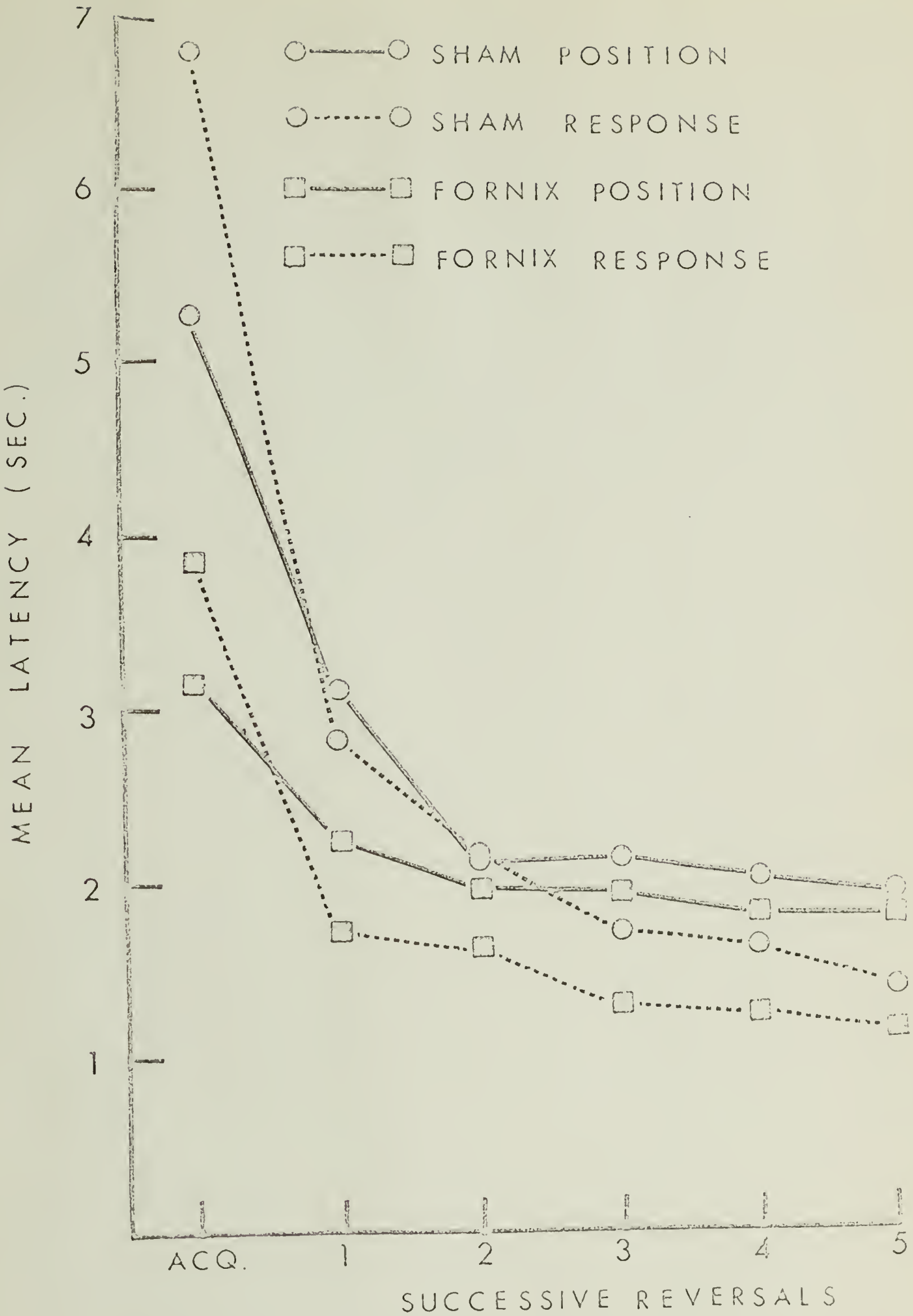


Figure 7: Mean latency to traverse the maze in the place and turn discriminations for acquisition and five successive reversals for lesion and control groups.