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Learning in Rats with Extensive Neocortical Damage

Abstract. Albino rats with as much as 99 percent damage to the cerebral cortex were trained on a position habit in a simple *T*-maze. The operated rats were found to learn the problem as efficiently as normal animals even when a 30-second delay was imposed between the response and the food.

Numerous experiments have demonstrated learning in mammals that have been surgically deprived of their neocortex (*1*). When the conditioning technique is used, the results of these studies indicate that there are only slight differences in the final performance of the conditioned response in comparison to that evoked in normal animals. Few studies exist which have examined the learning ability of decorticate animals in an unrestrained, "free-moving" situation, such as traversing a single-unit *T*-maze. According to the work of Lashley (*2*), removal of as much as 80 percent of the neocortex in rats only slightly impairs the mastery of a position habit. The present study showed that rats subjected to extreme neocortical damage not only learn a position habit as readily as normal ones but are equally efficient when a delay of 30 seconds is interposed between the response and the reward.

Twenty-seven experimentally naive adult rats of the Wistar strain were used. Of these, 12 were subjected to varying amounts of cortical damage by the suction method. All operations were performed in one stage with deep ether anesthesia. From 3 to 4 weeks after surgery, all rats were trained to choose their nonpreferred position in a *T*-maze in order to obtain food. After the conclusion of the experiment the brains were removed from the operated rats, and the lesions were reconstructed on standard diagrams. Brains showing extensive subcortical damage were sectioned and stained.

The alleys of the *T*-maze were 4 in. wide and 4 in. high. The stem consisted of a start box and a choice chamber, while each arm was composed of a delay chamber and an end box. These compartments, which were separated by guillotine doors, were 12 in. long. The floor and the top of the *T* were constructed of Plexiglas, the sides of plywood. Preliminary training involved giving each rat three trials per day in the maze for four consecutive days. The first two trials were "free," while on the third trial the rat was forced to the side it had avoided on the immediately preceding trial. Each end box contained a dish of wet mash from which the rat was allowed to eat for 10 seconds. No experimental delays were interposed during this period.

Determination of the nonpreferred side for each rat was made from the data on the last 2 days of preliminary training. On day 5, each rat was trained positively to the nonpreferred side, where food was present in the end box. No food was present in the end box on the preferred side. Eight control and five operated rats were trained without any delay. That is, as the animal made a choice of the left or right arm, the guillotine door separating the delay chamber from the end box was raised, allowing the animal to enter the end box. All of the remaining rats were delayed 30 seconds in the delay chamber following a correct or incorrect choice, after which the appropriate door was raised, allowing the animal access to the end box. The noncorrection method was used. Six trials were given daily with an intertrial interval of about 3 minutes. After early daily series of trials the rat was returned to its home cage and fed for 45 minutes. Training was continued until the animal made at least 10 correct responses on two consecutive days.

To reduce the operation of differential sensory cues coming from the delay chambers, the following precautions were taken. Visual cues were eliminated by enucleating the eyes of all animals. Olfactory cues were minimized by washing the floor of the maze after each trial and by placing a dish of food mash close to the incorrect end box. Auditory cues were reduced by the background noise of an air conditioner, and tactual cues were decreased by making the left arm identical with the right arm. Thus the development of secondary reinforcement from senses other than proprioceptive-kinesthetic was minimum.

For the no-delay groups, the differences between the controls and the operated rats were far from statistically significant. The controls required a mean of 11.4 trials and a mean of 3.7 errors to reach the criterion. The means for the operated animals, on the other hand, were 12.8 trials and 3.9 errors. The average percentage of cortex damaged was 71.5. There was no relationship between lesion size and ease of learning the position habit. Table 1 presents the indi-

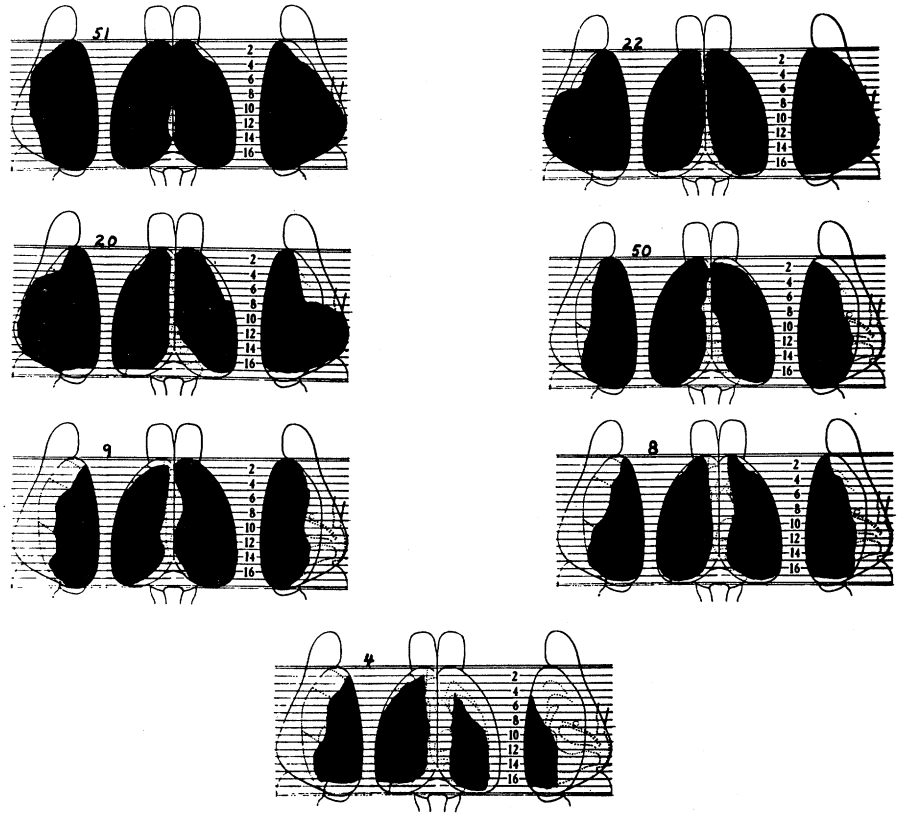

Fig. 1. Diagrams of the brains of those rats involved in the 30-second delay problem. Blackened areas indicate complete destruction of cortical surface.

vidual criterion scores for both the operated and control rats involved in the 30-second delay problem. Again, the mean differences did not approach statistical significance. Inspection of Fig. 1 reveals that two operated animals (22 and 51) were virtually decorticated. The scores of these rats were not appreciably different from those made by rats with considerably less damage or by the controls. Thus, no relationship between the size of the lesion and the ability to learn a position habit is indicated.

It is intriguing that the decorticate rats were not inferior to the controls in learning the position habit involving delayed reinforcement. The interpolation of a delay between the response and the reward is known to retard the acquisition of a position habit (*3*). In this experiment, both the cortical and control rats required more than twice as many trials to reach the criterion with a 30-second delay than they did with no delay. This reduction in learning speed is generally attributable to the decaying memory trace of the response. Apparently the neocortex is not necessary to mediate this function in the rat. The corpus striatum, septal area, hippocampus, pyriform cortex, and amygdaloid nuclei also do not appear to be specifically involved in this function, for these structures were bilaterally damaged in one or more of the operated rats of this experiment. It cannot be concluded, however, that the neocortex and its adjacent structures fail to have any influence upon the formation of the memory trace. Studies concerned with the perseverative trace (*4*), delayed response (*5*), retroactive inhibition (*6*), and multiple-unit mazes (*2*), indicate that the neocortex of the rat does function to facilitate the establishment of the memory trace. It would seem, however, that the strength of the memory trace left by a single position response is undiminished by the removal of the cerebral cortex.

Table 1. Individual criterion scores on the 30-second delay problem.

Rat No.	Cortical damage (%)	Trials	Errors
	Operated rats		
9	80	12	4
51	99	18	10
50	81	24	15
22	97	24	10
4	51	30	13
8	71	48	24
20	88	54	28
Mean	81.0	30.0	14.9
	Controls		
1		6	4
35		18	5
11		18	7
8		24	10
36		36	24
2		42	19
7		42	14
Mean		26.6	11.9

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Electrophysiology of the Elasmobranch Stomach

Abstract. A consequence of the recent study of the mechanism of gastric secretion has been the presumption, implicit (*1*) if not explicit (*2*), that the distinctive gastric transmucosal potential has a fundamental role in the formation of hydrochloric acid. The following report indicates that the isolated surviving elasmobranch gastric mucosa does secrete acid but, unlike that of other vertebrates, does so without developing a significant epithelial potential difference. The gastric transmembrane potential is neither necessary for hydrogen ion secretion nor is its generation a fundamental feature of the mechanism that leads to the formation of hydrochloric acid.

The gastric mucosae from dogfish (*Squalus acanthias* L.) caught in Frenchman's Bay and subsequently maintained in a "live-car" were isolated and bathed by oxygenated saline within 10 min after the fish was removed from water. One square centimeter of mucosa separated two chambers containing saline solutions having volumes of 6 ml and the following compositions (in millimoles per liter): (i) Serosal solution; NaCl, 220; $NaHCO_3$, 30; KCl, 10; $CaCl_2$, 5; Na_2HPO_4, 1; $MgCl_2$, 2; and glucose, 25. (ii) Mucosal solution; NaCl, 250; KCl, 10; $CaCl_2$, 5; $MgCl_2$, 2; and glucose, 25. Both solutions were gassed by 95 percent O_2 and 5 percent CO_2. No urea was incorporated in the bathing solutions, nor was it found to be necessary for the satisfactory maintenance of the isolated epithelium. The transmucosal potential was measured by a pair of agar-saline bridges and calomel cells, combined resistance 0.15 megohms, which fed into a Hewlett-Packard 130B oscilloscope. The experiments were conducted at a mean ambient temperature of 22°C, which was probably supraoptimal.

In ten experiments, the mean rate of hydrogen ion secretion was 0.65 ± 0.6 (standard deviation) $\mu eq\ cm^{-2}\ hr^{-1}$. The mucosae had a wet weight of 177 ± 33 mg. The transmucosal potential difference at 40 and 160 min after isolation was -1.3 ± 1.8 and -0.9 ± 0.9 mv, considering the mucosal solution to be ground. The mean initial and final bridge junction potentials were -0.4 mv. When the solution bathing the mucosal surface was replaced by one similar to that bathing the serosal surface, the potential difference became smaller by 0.5 ± 0.2 mv. The d-c conductance was estimated from the potential change that occurred after the passage of current, 100 $\mu a\ cm^{-2}$, for 1 min at 40 and 160 min after isolation. The conductance was 4.1 ± 1.8 and 5.6 ± 1.7 $mmho\ cm^{-2}$. A single experiment on a skate (*Raja erinacea*) yielded similar results. The mean potential difference developed across the entire thickness of the dogfish stomach was $+0.5$ mv in two experiments, and the conductance was somewhat lower than that cited above for the mucosa when it was separated from the serosa and muscle coat. In three experiments the mucosa did not spontaneously secrete hydrogen ion, presumably because of the higher ambient temperature (26°C). The electrical characteristics were the same except for a more rapid deterioration of membrane resistance.

The isolated gastric mucosae of marine and fresh-water teleosts (*Pollachius virens, Microgadus tomcod, Myxocephalus octodecimspinosus, Pseudopleuronectes americanus, Anguilla rostrata,* and *Ameiurus nebulosis*) were studied in the same fashion except for a reduction in concentration of NaCl of the bathing solutions by 50 mmole/lit. All of these mucosae spontaneously secreted acid and developed a potential difference of more than $+15$ mv. This potential difference is similar to that developed by the isolated mucosae of amphibia (*1*), dog (*2*), and man (*3*). Microscopic slides did not disclose any striking histological difference between the elasmobranch and teleost gastric epithelia (*4*). The dogfish gastric mucosa was found to have a high content of carbonic anhydrase (*5*).

These results imply that elasmobranchs secrete H^+ without generating a significant transmucosal electrical potential difference. The absence of a potential difference cannot be attributed to a higher membrane conductance. Though the membrane conductance is somewhat larger than that of amphibia (*1*), so is the wet weight of a comparable area of mucosa. The absence of a potential is not necessarily attributable to excessive H^+ transport. At the prevailing temperature the rate of H^+ secretion was less than that of the isolated amphibian gastric mucosa. At lower temperatures the