PREFRONTAL CORTEX AND MANIPULATORY GO LEFT–GO RIGHT DIFFERENTIATION TO ACOUSTIC DIRECTIONAL CUES IN DOGS

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Abstract. In 20 dogs the manipulatory go left–go right differentiation to acoustic directional cues was elaborated. All dogs received total prefrontal, or dorsolateral (total or partial) or medial (total or partial) cortical ablations. All total ablations markedly affected performance of the task, whereas the partial removals produced moderate or no impairment. Thus, both the dorsolateral and medial prefrontal cortex are involved in this type of differentiation.

INTRODUCTION

Our previous experiments (8, 10) showed that removal of the medial prefrontal cortex in dogs produces considerable disturbance in postoperative retention of locomotor go left–go right differentiation to acoustic directional cues (left–right) when spatial discontiguity between cue and reward is involved. Other selective lesions within the prefrontal cortex do not affect performance of this task. Waclawa Ławicka and J. Szczepkina (personal communication) also found that in dogs similar differentiation to up–down cues was impaired following removal of the medial prefrontal cortex.

In monkeys, impairment in performance of a task involving a spatial element was seen after ablation of the dorsolateral prefrontal cortex (2–7). Recently, it has been shown by Goldman and Rosvold (1) that a critical region for performance of go left–go right differentiation to
up–down cues is located in the arcuate cortex. In contrast are the findings in dogs of little, if any, effect of removal of prefrontal cortex on manipulatory left leg–right leg differentiation to left–right cues even when spatial discontiguity between cue and reward was involved (9).

The question is, then, what factor is inherent in go left–go right but not in left leg–right leg differentiation which is influenced by prefrontal cortical removals.

METHODS

Twenty experimentally naive mongrel dogs were trained in the manipulatory go left–go right differentiation to acoustic directional cues. Training was conducted in a soundproof conditioned response (CR) chamber equipped with a feeder, two rotating pedals and two speakers (Fig. 1). The feeder was located on the stand in front of the dog while the speakers and pedals were situated on the left and right of the stand, with one pedal and speaker on each side. Both pedals were kept in a vertical position until put into a horizontal position for the animal to press. The experimenter could present a stimulus and operate both pedals and the feeder by manipulating switches in the prechamber.

Fig. 1. Experimental setting. F, feeder; S, speaker; P, pedal.
Preoperative training consisted of a preliminary and an acquisition phase. Preliminary training involved three stages. Food was initially presented in the feeder every 30 or 45 sec whereupon the animal approached the feeder took the food from the foodwell. During the second stage, either the left or the right pedal (one at a time) was turned into the horizontal position every 30 or 45 sec. The animal was trained by the method of passive movements to press it with its right foreleg in order to obtain food. The first and second stages of preliminary training were continued until the animal responded without error in a 100 consecutive trials. The third stage followed, during which the tones were introduced. Presentation of each tone was accompanied by one of the pedals being put into the horizontal position. The food was given when the pedal was pressed with the animal’s right foreleg. The third stage of the preliminary training always consisted of 200 trials.

Acquisition training began after completion of the preliminary training. During presentation of each tone both pedals were turned into the horizontal position simultaneously, and in order to be rewarded, the animal had to choose and press the correct one. The training continued until the criterion of 90 correct responses in 100 consecutive trials was reached. A daily session consisted of 34 trials separated by intervals of 30–40 sec. A tone of 1000 cycle/sec presented either through the left or the right speaker was used as a cue. The tone was discontinued immediately after the animal performed the instrumental movement or lasted 5 sec if the instrumental response was not performed, after which it was discontinued. During a daily session 34 trials were applied each cue (the left or the right tone) being presented 17 times in random order. The noncorrection method was used.

In order to obtain a food reward the task required that the dog presses the right pedal in response to the left tone (L-R), and the left pedal in response to the right tone (R-L), using the right foreleg for both responses. Food was not presented when the animal did not perform an instrumental response or responded with an incorrect movement. After the training was completed, the dog was rested for 7 days, tested for retention to the same criterion, and then operated. The postoperative training was resumed 7 days after surgery and was continued until the animal reattained the criterion.

With the dog under Nembutal anesthesia (35 mg/kg) and using aseptic conditions one stage bilateral removals were performed by aspiration.

After completion of testing, the animals were anesthetized with an overdose of Nembutal and perfused intracardially with saline and
Fig. 2. Reconstructions of the lesions of representative dogs from each group and selected cross sections through the lesions. T, total prefrontal (A); DL, dorsolateral (B); M, medial (C, D); DLP, partial dorsolateral (E, F); MP, partial medial (G, H).
10% neutral formalin. Brains were embedded in paraffin, cut at 40 μm, and, alternate sections stained according to Nissl and Klüver-Barrera methods in order to identify and determine the extent of lesion.

**LESIONS**

The extent of the lesions of representative dogs from each group are shown in Fig. 2.

*Group T (n = 4): Total prefrontal ablation* (Fig. 2A). In three dogs the lesions were very similar. The proreal and precruciate cortex was completely removed while the orbital and presylvian areas were removed partially. The most caudally situated part of the orbital and presylvian cortex, as well as a lower part of the pregenual cortex, remained intact. On the other hand, small injuries mostly in the anterior part of the prefrontal region, were found in the underlying fibers. The lesion in dog T2 differed from the others only in that the whole presylvian cortex was left undamaged.

*Group DL (n = 4): Dorsolateral prefrontal ablation* (Fig. 2B). The lesions in this group were also very similar. In all dogs the proreal cortex was entirely damaged, but not the most caudally situated orbital and presylvian cortex. Small injuries in the gyrus coronalis were found.

*Group M (n = 4): Medial prefrontal ablation* (Fig. 2C and 2D). In dogs M1 and M2 the medial precruciate and pregenual cortex were almost completely removed while in M3 and M4 the pregenual cortex was injured only. Some damages were found in the proreal and anterior cingulate cortex in M2 and M3. The fibers underlying the pregenual cortex were injured in M1 and M2.

*Group DLP (n = 4): Partial dorsolateral prefrontal ablations* (Fig. 2E and 2F). This group consisted of two presylvian (DLP1, DLP2) and two orbito-proreal (DLP3, DLP4) dogs. The presylvian lesion was incomplete in both dogs, some cortex at the bottom of the fissure remaining intact. Orbito-proreal removal was also incomplete in both Ss. Here, the proreal cortex was entirely damaged, but a considerable part of the orbital cortex was left intact. Small injuries were found in underlying fibers in both dogs.

*Group MP (n = 4): Partial medial prefrontal ablations* (Fig. 2G and 2H). This group consisted of two medial precruciate (MP1, MP2) and two pregenual (MP3, MP4) dogs. In both precruciate Ss, a considerable part of the XM cortex remained. On the other hand, the medial proreal cortex was partly damaged in both dogs. The pregenual lesion was complete in both Ss. Additionally, the medial proreal cortex was damaged in the left hemisphere.
RESULTS

The effects of the prefrontal cortical removals are shown in Table I.

**Group T.** Following total prefrontal removal, a very marked deficit in the performance of the task was found in all dogs. They made a considerable number of errors before they re-attained the criterion. The number of errors in the first 100 postoperative trials varied from 51 to 100. They were more numerous than those performed in the first 100 acquisition trials and there was no overlap between them as the preoperative errors varied from 27 to 46. Those dogs that received a more extensive removal (all but T2) were performing the task at chance level for the next 400, 500 and 700 trials, following which they improved gradually. Dog T2 improved faster. The total number of postoperative

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errors in this group varied from 121 to 609. However, in all dogs except T2, there were at least 300 errors. They were more numerous than preoperative errors in T1, T2 and T4, and almost equal in T3.

New behavioral phenomenon, not shown in Table I, appeared during the postoperative retention test. While in acquisition training all errors performed by Ss of this group consisted in pressing the incorrect pedal with the correct foreleg, in the early postoperative period some other kinds of errors were observed. These consisted either in using the nose to press the pedal (5 times), placing the foreleg on the surface of the feeder by the foodwell (48 times), or the instrumental response was completely lacking (137 times). Later, all errors again consisted in pressing the incorrect pedal.

**Group DL.** Following removal of the proreal, orbital and presylvian cortex, all dogs showed a marked deficit in performing the task before the criterion was regained. During the first 100 postoperative trials, all Ss performed the task at chance level (50–55 errors). Two of them (DL2, DL3) continued working at this level for the next 300 and 100 trials, respectively, while two others (DL1, DL4) showed improvement in performance. The postoperative errors exceeded preoperative errors in all Ss of this group. The total number of postoperative errors varied from 88 to 334, with over 130 errors in three dogs; only DL3 scored as low as 88. The postoperative errors exceeded preoperative errors in DL1 and DL2: 134 and 334 to 48 and 186, while they were less numerous in DL3 and DL4: 175 and 88 to 281 and 569, respectively.

New kinds of errors did not appear in this group. However, in dogs DL1, DL2 and DL3 either placing the foreleg on the feeder or lack of the instrumental response was observed occasionally, both preoperatively and postoperatively. DL4, whose preoperative errors were confined to pressing the incorrect pedal, performed only this error postoperatively.

**Group M.** A pronounced deficit in the performance of the task was also observed following removal of the medial prefrontal cortex including the medial precruciate and the pregenual areas. However, all Ss improved gradually and re-attained the criterion. In the first 100 postoperative trials, the errors varied from 57 to 100, which surpassed the errors performed during the first 100 acquisition trials (23 to 54) with no overlap between them. M1, M2 and M3 continued to perform the task at chance level for the next 100 trials, while M4 showed faster improvement. The total number of postoperative errors varied from 151 to 216, which exceeded the preoperative errors made by M1 and M2, almost equalled those made by M3, and were less than those made by M4.

Errors performed by M1 and M2 during acquisition training consist-
ed in pressing the incorrect pedal with the correct foreleg. During early postoperative retention, however, some errors consisted of placing the foreleg on the feeder (4 times), using the nose to press the pedal (25 times), or failing to perform the instrumental response (104 times). Dogs M3 and M4 performed the same kinds of errors both preoperatively and postoperatively. They consisted in pressing the incorrect pedal or occasionally either placing the foreleg on the feeder or withholding the instrumental response. These two Ss performed no other kinds of errors during postoperative retention.

**Group DLP.** Much less impairment was produced by the partial dorsolateral lesions. Removal of either the presylvian or orbito-proreal cortex was followed by short lasting impairment in performing the task. Performance at chance level in the first 100 postoperative trials was observed only in one dog of this group (DLP1, errors 56), the subject with the presylvian lesion. The number of errors made by other dogs of this group varied from 17 to 39. The number of errors performed in this period of testing was similar to that in the respective period of acquisition. The total number of postoperative errors varied from 39 to 79 while preoperative errors varied from 102 to 385. Thus, impairment in

![Fig. 3. Vincentized postoperative retention curves.](image-url)
this group was much less pronounced than that in group T, DL or M. Further more all Ss of group DLP improved rapidly. The postoperative errors were of the same kind as before operation.

**Group MP.** Dogs MP1 and MP2 with the precruciate lesions showed only slight and short lasting impairment: they made 24 and 30 errors, respectively, during the first 100 postoperative trials. In MP2 they were less numerous than the number of errors in the respective acquisition trials and slightly exceeded them in MP1. Both dogs reattained the criterion in the second 100 postoperative trials. The preoperative and postoperative errors were of the same kind, with no new kinds of errors appearing postoperatively. Both pregenual Ss performed the task at the criterion level from the very beginning.

Comparison of postoperative performance of the task among the groups is shown in Fig. 3. Vincentized postoperative retention curves indicate that there are no significant differences between Group DL and Group M as well as between Group DLP and Group MP. Such differences, however, do appear in comparision between each of these groups and Group T. Significant differences in performance of the task are also seen between groups D1 and M, on the one hand, and groups DLP and MP, on the other (p < 0.01, analysis of variance).

**DISCUSSION**

Our results show that in dogs bilateral removal of the total prefrontal cortex, or its dorsolateral or medial part, produce a pronounced deficit in the performance of the manipulatory go left–go right differentiation to acoustic directional cues. The deficit in performance of the task, which resulted from total prefrontal removal, was significantly greater than that produced either by the dorsolateral or the medial removal. The number of postoperative errors performed by dogs with total prefrontal lesion (Group T, excluding T2 in which the presylvian cortex remained intact) exceeded the number of errors performed by all dogs with dorsolateral (except DL3) or medial lesions. Similarly there was no difference between dorsolateral Ss and those with medial lesions. Further, Ss with total prefrontal removal (Group T, except T2) were also worse than those with dorsolateral or medial lesions when the number of postoperative trials in which the task was performed at chance level were considered. Those trials varied from 500 to 800 in Group T, 100 to 400 in Group D1 and 100 to 200 in Group M. Dogs from groups D1 and M did not differ from each other along this index.

However, two other factors seem to indicate that there may exists some difference between the deficit produced by the dorsolateral and
that by the medial lesion. First, the appearance of new kinds of errors not seen in acquisition training appeared in postoperative retention. These included placing the foreleg on the feeder by the foodwell, pressing the pedal with the nose, or withholding performance of the instrumental response. These new types of errors seem to be produced only by extensive medial removal. They were seen in two dogs in Group M whose lesions included the medial precruciate as well as a large part of the pregenual cortex (M1, M2), and also in all Ss of Group T in which the medial prefrontal cortex was radically damaged. Further, these new type errors were not observed following lesions in either the medial precruciate, the pregenual, or the medial precruciate together with a small part of the pregenual cortex. They were also not found in those Ss in which the dorsolateral prefrontal cortex was partially or completely removed.

Secondly, the number of errors in the first 100 postoperative trials provide a measure of differences in the effects of dorsolateral and medial cortex ablations. The number of errors for Ss in Group M significantly exceeded those in Group DL (57–100 and 50–55). Performance similar to that of Group M was also observed in Group T (51–100 errors in the first postoperative 100 trials) but not in other groups. Thus a large number of errors, significantly surpassing 50%, was characteristic only of medial prefrontal lesions, involving mainly damage to the medial precruciate cortex. Such a large error score may be due to the “magnet reaction” described in our earlier papers (8,10), and shown to be a consequence of bilateral removal of the medial precruciate cortex.

In contrast to the results presented here were those obtained earlier (9) in which the left leg–right leg differentiation to acoustic directional cues was used. Only total cortical removal of the prefrontal area produced impairment in the performance of that task and even that was slight and short lasting (48 postoperative errors). In both series of experiments the animals were trained in the same CR chamber and the same cues were used. The only apparent difference between the experiments was that in the go left–go right differentiation Ss were required to differentiate the direction of the instrumental response in space, while in the left leg–right leg differentiation the dog had to differentiate the side of the body and then place the correct foreleg forward on the feeder. Thus, spatial differentiation of the instrumental response seems to be the factor which is selectively influenced by prefrontal cortical ablations.

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