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THE EFFECT OF THE REMOVAL OF FRONTAL POLES OF THE CEREBRAL CORTEX ON MOTOR CONDITIONED REFLEXES

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The functions of the frontal lobes of the cerebral cortex studied by the ablation technique have been for many years subjected to extensive investigations, and many theories and assumptions have been put forward to account for the vast experimental material collected by numerous authors. Of course, there are differences in data obtained by various research workers depending chiefly on the animals used for experimentation and on the extent of ablations. Nevertheless, nearly all authors working in this field agree that frontal ablations do not produce any s p e c i f i c changes in cortical activity, such as disorders of either afferent or efferent functions, or impairment of learning ability. Even if there are some data pointing to such changes (e. g. autonomic disturbances caused by frontal ablations, cf. F u l t o n 1946, or specific impairment of olfactory discrimination, A l l e n 1940) the majority of authors do not consider these results as the most specific and essential for our understanding of the rôle played by frontal lobes. According to the overwhelming amount of evidence beginning from the classical works of F e r r i e r (1876), B i a n c h i (1895), H i tzig (1904), Bechterev (1907) etc., the frontal lobes are endowed with some more general and less concrete functions, and their ablations are usually described under such headings as „lack of ability to synthesis, impairment of intelligence, changes of personality", and so on. All such conclusions are drawn either on the basis of general observation of the behaviour of animals deprived of frontal lobes or on specific psychological tests in which the disability of operated animals to cope with some complicated experimental tasks was manifested. There are, however, only few works which approach the whole problem from the standpoint of the physiology of higher nervous activity and tend to formulate the results of ablations directly in physiological terms. (For references see Brutkowski et al. 1955).

The present work is an attempt to fill this gap and to show that such an approach, although certainly not unique in dealing with the problem, is fruitful and leads to a better understanding of the data obtained by other methods.

MATERIAL AND METHODS

The work was performed on dogs in an ordinary conditioned-reflex chamber. Six dogs were taken for these experiments, but as the work on this problem is still going on in our laboratory, the experiments reported here are fully confirmed on about ten other dogs.

In the present paper only experiments with motor alimentary conditioned reflexes are dealt with. These reflexes thoroughly studied by one of us in previous papers (Konorski and Miller 1933) have been called conditioned reflexes of the second type to distinguish them from classical Pavlovian conditioned reflexes. They are now called instrumental conditioned responses by the majority of American authors (cf. Hilgard and Marquis 1940). To put it briefly and quite generally, this type of reflexes consists in that the animal learns to perform a certain movement if its performance is reinforced by a positive unconditioned stimulus (as the food), or if an opposite movement is reinforced by a negative (noxious) unconditioned stimulus.

The course of experiments reported here is as follows.

First, a number of conditioned motor alimentary reflexes (both excitatory and inhibitory) were established, and after a more or less prolonged training one of the two cortical ablations was made in which either the frontal poles or parts of parietal lobes were bilaterally removed.

Following post-operative recovery which took usually from 2 to 6 days, the conditioner-reflex experiments were resumed and the status of the dog was thoroughly tested. After a lapse of time the second of the two operations was made (or the frontal ablation was enlarged), and the conditioned-reflex activity was studied again. The experiments on one dog lasted about 2—3 years.

Now we shall describe in more detail the conditioned-reflex training and the surgical procedure.

Conditioned reflex training

The dog was first habituated to the general experimental procedure and environment, in particular to stand quietly on the stand in the experimental chamber, to obtain food in small morsels from the foodtray placed before him, etc. Then the actual training began. The dog was urged to lift his right foreleg and to put it on the foodtray at the sound or sight of a given conditioned signal, the performance of this movement (passive or active) being reinforced by the presentation of food (one morsel of bread of about 8 cm³). After several days each application of the signal almost immediately elicited the learnt movement and was followed by the presentation of food. Thus, each trial lasted about 5 sec., and the intertrial intervals were 1—2 min. Then some other auditory or visual conditioned stimuli were also introduced.

The excitatory conditioned reflexes having been established, we proceeded to the formation of inhibitory reflexes. We made use of two kinds of internal inhibition, namely differentiation and conditioned inhibition.

In order to establish differentiation, a stimulus similar to the one applied as a conditioned stimulus was introduced and applied (among other stimuli) without reinforcement. Owing to the generalization this stimulus elicited at first the learnt movement but after a number of unreinforced trials differentiation developed and the conditioned response to the stimulus became inhibited.

The elaboration of conditioned inhibition was carried out as follows: A new stimulus differing from conditioned stimuli hitherto applied was chosen and it was applied just before a particular conditioned stimulus. The conditioned stimulus when preceded by the extra stimulus (conditioned inhibitor) was not reinforced. After a number of such trials the inhibitory reflex to this compound was elaborated and the conditioned stimulus applied after the conditioned inhibitor did not elicit the learnt movement. This being done, we have gradually prolonged the interval between both components of the compound until the dog was still capable to unfailingly inhibit the motor reaction to the conditioned stimulus following the conditioned inhibitor. The duration of this interval varied in different dogs, depending also on the strength of the conditioned inhibitor. Usually in our experiments it amounted to 10—15 seconds.

In some dogs we also used a kind of conditioned inhibition which we call „alternation“. In these experiments one and the same stimulus was applied throughout each session, alternatively reinforced and not reinforced by food. In special experiments it was shown that in this case the termination of the act of eating plays the rôle of the conditioned inhibitor conditioning the inhibitory reaction to the next stimulus.

Surgigal procedure

a. Frontal lobes ablations. After the incision of skin in the medial line and pushing aside the temporal muscles the frontal and partly the parietal bones were trephined and the sinus frontalis opened. The hiati to the sinuses were tightly packed with wax, the bones covering the frontal lobes were removed, the dura mater was divided and the cortex of the frontal lobes was destroyed by subpial suction. The lesion always included gyri prorei and greater parts of gyri orbitales. The posterior border of the lesion ran usually in sulci praesylvici, but in some operations the rostral parts of gyri sigmoidei anteriores (a few mm. before sulcus cruciatus) were also removed. The dura mater, the muscles, the subcutaneous tissue, and the skin were then sutured.

b. The parietal ablation. After the medial incision of the skin, the temporal muscles were pushed aside and the parietal bone was trephined without opening the sinus frontalis. After dividing the dura mater the cortex of gyri suprasplenia les, gyri entolaterales and the rostral parts of gyri ectolaterales, were bilaterally removed by subpial suction. The lesion situated about 20 mm behind the sulcus ansatus formed usually an irregular quadrangle 20 mm long and 11 mm wide.

At the end of the experiments the animals were sacrificed and the lesions carefully verified macroscopically. The microscopic study of the material will be given separately.

RESULTS

A detailed description of the results obtained on all six dogs used in this investigation is given elsewhere (Brutkowski et al., 1955). As the results obtained in each dog were very alike and fully confirmed by our further experimental material, we feel entitled to present here an extensive report of experiments performed on one dog, which may be considered as typical, supplementing it by some additional data obtained from experiments on other dogs.

A one-year-old mongrel weighing 12 kg. was kept in the laboratory from 1949. He accustomed himself to the experimental conditions very easily, and quickly developed all the excitatory and inhibitory conditioned reflexes. He was always very quiet and matter-of-fact and his conditioned-reflex activity was excellent.

In the preoperational training which lasted about one year alimentary conditioned reflexes to the sound of a Metronome, Bell and Bubbling of water were formed and firmly established. The differential inhibitory reflexes were formed to another timbre of the Bell and Bubbling. They were established after 12 and 4 repetitions of these stimuli, respectively. A rotating Propeller suspended before the dog was used as a conditioned inhibitor in combination with the Metronome. The inhibitory reflex to this compound was formed after 24 repetitions and then the interval between these stimuli was gradually prolonged to 10 seconds. The kymographic record of the last experiment before operation is given in Fig. 1a, its protocol in Table I.

First operation (frontal)

On October 26th, 1950, the first operation was performed during which the cortex and white matter of gyrus proreus were bilaterally removed. The ventral parts of the frontal poles lying on the tractus and bulbus olfactorius were spared. The posterior limit of the lesion was sulcus praesylvicus.

The recovery of the dog was uneventful.

A. General behaviour of the dog after operation. During the first two days the dog was quite apathetic, lay coiled and did not react to external stimuli. Then he recovered very quickly and after a few days it ways very difficult to find in his general behaviour any difference with the preoperative status. In particular no hypermotility reported by some authors after frontal ablations was seen, and the motor efficiency was quite normal. Only the act of eating was in the first days somewhat protracted.

B. Conditioned-reflex activity. The first experiment after operation was performed on October 31st. The protocol of this experiment (Table II) and the kymographic record (Fig. 1b) are presented. As we see the conditioned-reflex activity differs from normal in the following essential points:

1-o: the dog often lifts his leg and puts it on the foodtray in intertrial intervals. Such behaviour never occured before the operation (except, of course, at the very beginning of experiments, more than one year ago).

2-o: the inhibitory reflex to the differentiated Bell and to the Metronome following immediately after the Propeller is disinhibited; this also did not occur for many month.

3-o: contrarily, the excitatory conditioned reflexes do not differ in any regard from those before the operation.

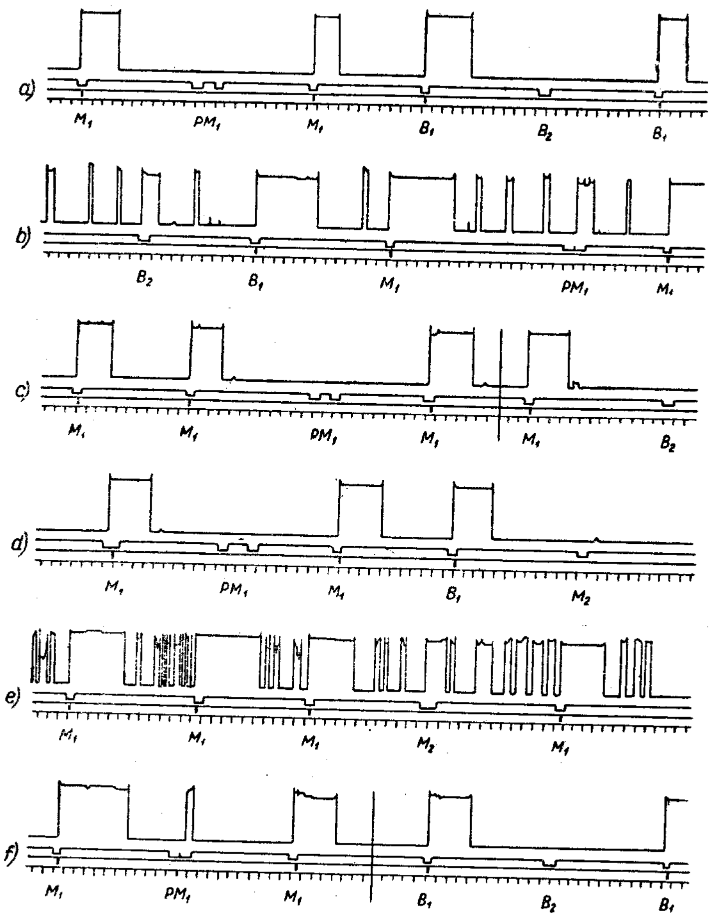

Fig. 1. Kymographic records of parts of some representative experiments in normal condition of the dog and in various periods after successive operations. Each record comprises from top to bottom: lifting the right foreleg and putting it on the foodtray; conditioned stimuli; the moment of food presentation; time (5 sec.); symbols of stimuli: M_1, Metronome, M_2, differential Metronome, B_1, Bell, B_2, differential Bell, PM_1, Propeller — Metronome (inhibitory compound). a — portion of the last experiment before first frontal ablation (No 90, 24.X.1950); b — portion of the first experiment after first frontal ablation (No 91/1, 31.X.1950); c — portion of an experiment 2½ months after first frontal ablation (No 136/46, 10.I.1951); d — portion of an experiment after parietal ablation (No 231/8, 21.VI. 1951); e — portion of an experiment shortly after second frontal ablation (No 264/5, 22.X.1951); f — portion of an experiment a month after second frontal ablation (No 284/25, 15.XI.1951).

In the following days the inhibitory capacity of the dog gradually improved (Fig. 2a): In the next experiment the intertrial responses disappeared, but the differentiated stimulus was still disinhibited; it became again inhibitory after 3 repetitions. As to the inhibitory reflexes to the combination of the Propeller and Metronome they failed to appear for a much longer period: even a month after operation the dog was not able to inhibit the response to the Metronome following immediately the Propeller. When he succeded at last to do so, it was sufficient to prolong the interval between the stimuli to 3 seconds to produce a dramatic disinhibition. When in the following days this task was mastered, another prolongation of

Table I

The protocol of the last experiment before first frontal ablation
24 th October 1950, No 90

No of trial	Time of successive trials	Conditioned stimulus	Its isolated period in sec	Latent period of conditioned reaction in sec	Reinforcement	Intertrial reactions
1	1 min	$Metronome_1$	2	1	reinforced	
2	2 min	$Metronome_1$	2	1	reinforced	—
3	3 min	Propeller	5	—		—
	3m 10 sec	$Metronome_1$	5	—	not reinforced	
4	4 min	$Metronome_1$	2	1	reinforced	—
5	5 min	$Bell_1$	2	1	reinforced	—
6	6 min	$Bell_2$	5	—	not reinforced	—
7	7 min	$Bell_1$	2	1	reinforced	—
8	8 min	$Metronome_1$	2	1	reinforced	—
9	9 min	Propeller	5	—		—
	9m 10 sec	$Metronome_1$	5	—	not reinforced	
10	10 min	$Metronome_1$	2	1	reinforced	—
11	11 min	$Metronome_1$	2	1	reinforced	—

the interval to 5 seconds again caused disinhibition. Only after two and a half months all the inhibitory reflexes returned to normal and the behaviour of the dog did not differ from his preoperative behaviour (Fig. 1c). The elaboration of a new differentiation (another timbre of Metronome) in this period was quite easy.

C. Neurotic disorders following the operation. Besides the above described disturbances of the inhibitory capacity of the dog, another type of disorder of his behaviour was also observed.

As we noticed before, this dog was before the operation exceedingly well-blanced and quiet, and his behaviour was always quite adequate and matter-of-fact. In the first experiments after operation, in spite of the disturbance of his inhibitory capacity, the general picture of the dog's behaviour was the same. But after

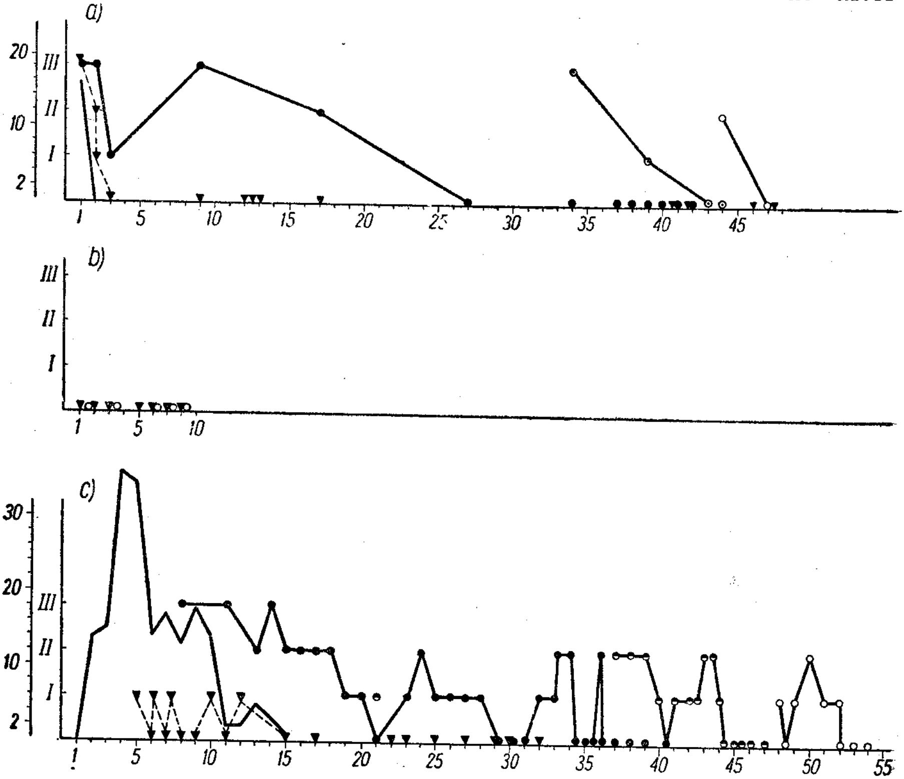

Fig. 2. The disturbances of the inhibitory capacity of the dog after successive operations. Abscissae denote the successive numbers of experiments after each operation. Ordinates denote number of intertrial reactions (Arabic numerals), and the degree of disinhibition of inhibitory reflexes (Roman numerals). I — weak disinhibition, the dog holds his leg on the foodtray for no more than 2 seconds, II — moderate disinhibition, the dog holds his leg on the foodtray for no more than 5 seconds; III — strong disinhibition, the dog holds his leg on the foodtray for more than 5 seconds. Dashed line — number of intertrial reactions. Triangles — differential inhibition. Circles — conditioned inhibition: full circles — interval between conditioned inhibitor and conditioned stimulus O seconds; half-filled circles — interval 2 seconds; dotted circles — interval 3 seconds; hollow circles — interval 5 seconds and more. a — disturbance of inhibitory reflexes after first frontal ablation, b — inhibitory reflexes after parietal ablation, c — disturbance of inhibitory reflexes after second frontal ablation.

a number of experiments in which inhibitory stimuli were repeatedly applied, the behaviour of the animal changed: he was reluctant to enter the experimental chamber, and when put on the stand he was restless, whined and tried to escape. Often he would leave some pieces of food untouched, what never happened previously.

Table II

The protocol of the first experiment after first frontal ablation
31 st October 1950, No 91/1

No of trial	Time	Conditioned stimulus	Its isolated period in sec	Latent period of conditioned reaction in sec	Reinforcement	Intertrial reactions
1	1 min	Metronome$_1$	2	1	reinforced	
2	2 min 30 sec	Metronome$_1$	2	1	reinforced	1
3	4 min 30 sec	Bell$_1$	2	1	reinforced	—
4	6 min	Bell$_1$	2	1	reinforced	3
5	8 min	Bell$_2$	5	2 (to 10)	not reinforced	3
6	9 min	Bell$_1$	2	1	reinforced	1
7	10 min	Metronome$_1$	2	1	reinforced	1
8	11 min 35 sec	Propeller	5	—		3
	11 min 40 sec	Metronome$_1$	5	1 (to 8)	not reinforced	
9	12 min 35 sec	Metronome$_1$	2	1	reinforced	1
10	14 min	Metronome$_1$	2	1	reinforced	2

All these disorders were unmistakenly symptomatic of experimental neurosis. The task required was now too difficult for the animal. When all inhibitory stimuli were excluded for several days the dog recovered rapidly and completely, while a renewal of too frequent applications of inhibitory stimuli led again to more or less express disorders.

For the sake of illustration we quote one of such incidents.

22nd November 1950. Only excitatory stimuli are applied. The dog behaves excellently and is quite calm.

24th November 1950. Condition unchanged.

25th November 1950. The differential Bell and the inhibitory compound of the Propeller with Metronome (in immediate sequence) are applied. The Metronome following the Propeller is disinhibited.

27th November 1950. The dog refuses to enter the experimental chamber. During the whole experiment he whines, is very excited, turns towards the door, leaves some pieces of food untouched. The experiment was shortened and only excitatory stimuli were applied.

28th November 1950. Is quieter but still whines after each trial. Only excitatory stimuli are applied.

30th November 1950. Condition unchanged.

2nd December 1950. More or less quiet but refuses to take food in last trials.

4th December 1950. Calm and matter-of-fact.

5th, 6th, 7th December 1950. Condition good. Only excitatory stimuli applied.

9th December 1950. At the beginning of the experiment the dog is quite calm. In the fifth trial the inhibitory compound was applied. The dog displayed a perfect inhibitory response. Nevertheless in the further course of the experiment he becomes excited, whines, gets entangled in the registration lines. The latent period of the motor reaction is protracted and in some trials the conditioned response fails to appear. This n e v e r occured in normal state.

The above most conspicuous intolerance to inhibitory stimuli, and chiefly to the inhibitory compound, compelled us not to apply these stimuli too often and to intersperse the experiments in which the inhibitory stimuli were used with purely excitatory experiments. After a lapse of time this state of „hypersensitivity" to inhibitory stimuli receded and it was possible to return to a quite normal experimental procedure.

S e c o n d o p e r a t i o n (p a r i e t a l)

On May 22nd 1951, when the general state of the animal did not differ from his preoperative state, the second operation was performed in which gyri entolaterales, suprasplenіales and ectolaterales were bilaterally removed. The frontal limit of the ablation ran ca. 3 cm behind the sulcus cruciatus. On the following day after operation the dog was able to run around the room without any sensory or motor deficiencies. On the sixth day after operation the experiments were resumed. It was found that the dog behaved in every respect quite normally and his inhibitory capacity was absolutely not disturbed: even the inhibitory response to the Metronome preceded by the Propeller with an interval of 10 seconds (the maximum interval used with this dog) was fully preserved (Fig. 1d and 2b).

Third operation (frontal)

On October 11th, 1951 the third operation was performed in which frontal poles were again exposed. It was found that the dura mater was much thickened and attached to the cortex. The rest of the gyri prorei, orbitales and the anterior parts of gyri sigmoidei anteriores were removed.

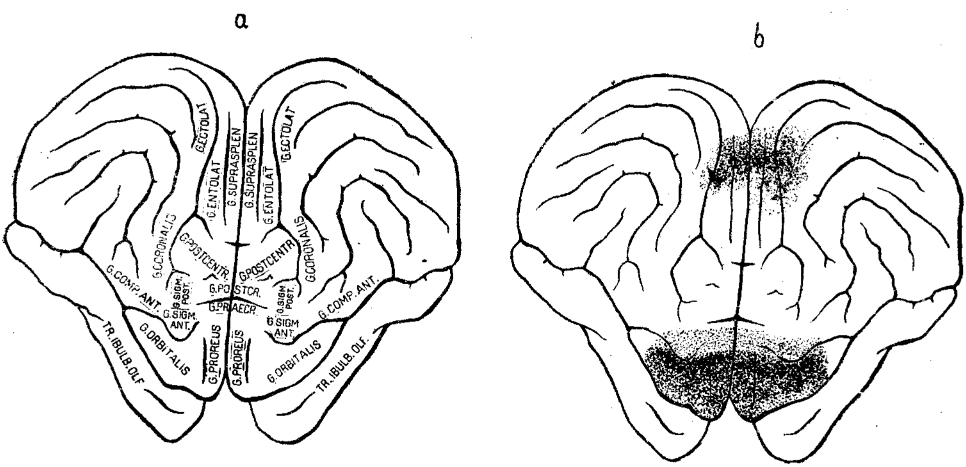

Fig. 3. a — cerebral cortex of dog, designations of gyri used in our laboratory. Both the superior and the lateral surface of the cortex are shown on one plane. b — the cortical lesions in the dog described in text; destroyed areas are marked by dots, the heavier the dotted surface, the deeper the lesion.

On the third day after operation the dog could stand and walk, but he was strongly disoriented in the familiar surroundings and failed even to find his way to the laboratory (he ran it through hundreds of times). This state gradually receded within 10 days.

In the conditioned reflex activity the same disorders as after the first operation were revealed, but this time they were much more pronounced and lasted longer. And so, in the first experiments, the dog put on the stand performed the learned movement incessantly, so that it was almost impossible to find a quiet moment to apply a conditioned stimulus (Fig. 1e). Such a state lasted through 9 experiments and then gradually subsided (Fig. 2c). In the same time the differential inhibition also became normal.

As to the conditioned inhibition, it was disturbed for a much longer time and did not recover fully up to the end of the experiments (Fig. 1f). The dog died on 31st January of 1952 after a severe epileptic attack.

The results of the autopsy are represented in fig. 3.

The data obtained in other dogs were so similar to those reported above that only a brief account of them is needed.

In some dogs the frontal ablation was limited and did not extend beyond the sulcus praesylvicus, in others it encroached more or less upon gyrus sigmoideus anterior. According to the extent of ablations the results were somewhat different and resembled respectively those obtained after the two ablations described above.

Thus after the more limited frontal lesions there was no impairment of excitatory conditioned reflexes and the only disturbance concerned the inhibitory reflexes, the degree of disinhibition and its duration being similar to that shown in fig. 2a.

The larger lesions, on the contrary, resulted in more severe disorders, namely: disorientation in the familiar surroundings, hypermotility consisting in incessant circling around the room, and entering all narrow corners without being able to get out of them. These symptoms lasted generally no more than one or two weeks. In this period the dogs, when put into the experimental situation, seemed also to be disoriented and often did not react to conditioned stimuli.

When this first period was over and the dog was again fit for conditioned-reflex experiments he performed the learnt movement incessantly hundreds of times, at first even without any attention to conditioned stimuli. Later these intertrial movements gradually subsided, but disinhibition of inhibitory reflexes was still visible and lasted for a long time.

The sequence of the recovery of inhibitory processes was usually the same as described above. Thus, the occurence of the learnt movements in intertrial intervals would disappear earliest. Then the differential inhibition returned usually to normal and finally, conditioned inhibition gradually improved, first with the immediate or overlapping sequence of both components of the inhibitory compound, and afterwards with the more and more protracted interval

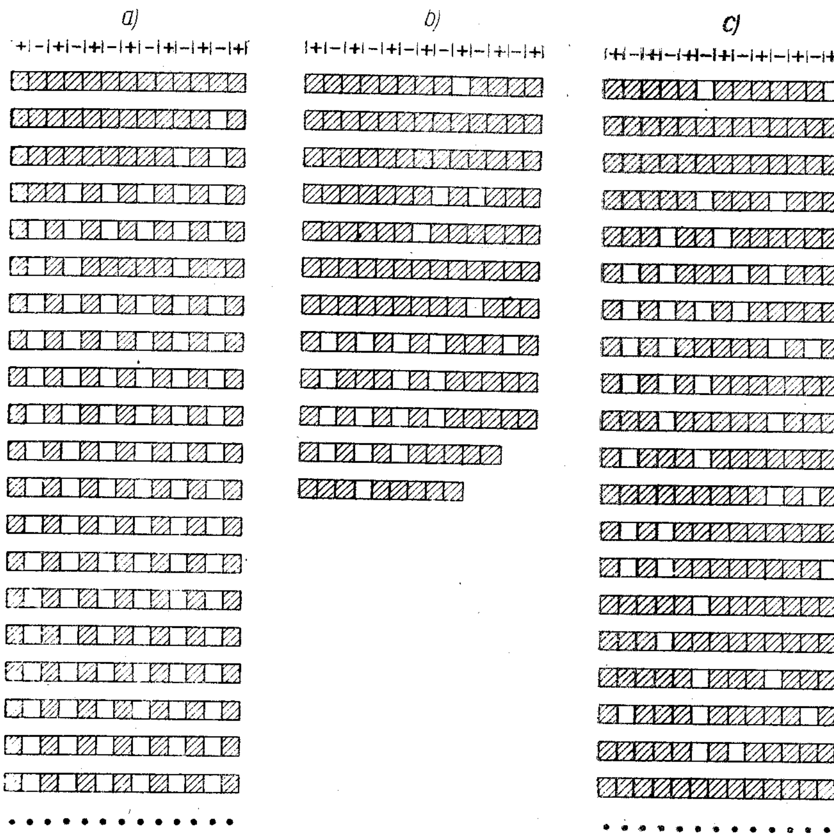

Fig. 4. The elaboration of „alternation" before operation (a), and after two successive frontal ablations (b and c). Only the first 20 experiments in series a and c are given. Series b was discontinued because of experimental neurosis. Black squares denote the positive reaction to the conditioned stimulus, hollow squares denote inhibitory reaction to the conditioned stimulus. + denotes reinforced trials, — unreinforced trials.

between them. But it must be noted that in one dog in which conditioned inhibition was very firmly established before the operation and differentiation was relatively difficult and not well fixed, the latter form of inhibition was more disturbed than the former one.

As to the conditioned inhibitor itself, it did not, as a rule, produce a positive response, except in some dogs in the first experiments after operation, when the animal performed the learnt movement almost incesantly without the least attention to the applied stimuli.

In one dog „alternation" was elaborated, the same stimulus being reinforced only on its every second application. After frontal operation the ability to perform this task was totally lost and in spite of prolonged training it was not recovered (Fig. 4). As the dog became very excited and developed symptoms of experimental neurosis, these experiments had to be abandoned.

As far as the parietal ablation is concerned, irrespectively of whether it was performed before or after frontal ablation, in none of the dogs even the slightest disturbance of inhibitory reflexes occured.

DISCUSSION

When we start to train a dog to perform a given movement in response to a given stimulus by means of food reinforcement, he ordinarily begins with performing this movement immediately he is put on the stand, quite independently of the stimulus applied. Only gradually, as these interval movements are not reinforced, they become inhibited, and the dog stands quietly performing the movement at the conditioned signal exclusively. The same happens when a stimulus similar to that evoking the movement is applied without reinforcement. Owing to the existence of generalization, the dog performs initially the learnt movement to this stimulus, and stops doing so only after a number of its unreinforced repetitions. The same applies to the unreinforced conditioned stimulus succeeding the so-called conditioned inhibitor. On the contrary, the conditioned inhibitor itself, which is not similar to any of the conditioned stimuli, does not evoke a trained movement even at the beginning of its application. We have called such a stimulus a „primarily" or „purely" inhibitory stimulus in contradistinction to the differentiated stimuli, or conditioned stimuli succeeding the conditioned inhibitor; such stimuli always contain some excitatory elements alongside with the inhibitory ones (Konorski and Szwejkowska 1952).

Putting this in terms of conditioned connections we would say that the „centre" of a primarily inhibitory stimulus is linked up with the „centre" of the unconditioned stimulus only by means of inhibitory connections, while the „centre" of a „mixed" excitatory-inhibitory stimulus is linked up with it both by excitatory and inhibitory connections.

The present experiments have shown that after frontal bilateral ablations the cortical inhibitory process is greatly impaired while the excitatory process remains more or less unchanged. And so the dog put in the experimental situation performs without any difficulty the learnt movement, proving thus that the conditioned excitatory connections formed between the „centre" of this situation and the respective motor centre are left intact. As to the inhibitory connections they are destroyed, and leave the field to the action of excitatory connections only. As a result of this the dog performs the learnt movement not only to the conditioned excitatory stimuli, but also to those stimuli which have a mixed character possessing both the excitatory and inhibitory elements. Such a stimulus is first of all represented by the experimental situation itself, which— as we have just said — elicited a conditioned response at the beginning of the training and afterwards lost this power only by way of inhibition. That the repetitive performance of the trained movement is not due to general overactivity of the dog but to the specific connections established between respective cortical „centres" is best proved by the fact that the dog performs this movement o n l y in the experimental situation and n e v e r in other circumstances. Furthermore in other experiments carried out by one of us (Ł a w i c ka 1956), in which the dogs were trained to perform two different movements in two distinct experimental situations, the frontal ablations led to a strong disinhibition of both these responses but the dog never performed in one of these situations the movement proper to the other one.

As the experiments proceed, the inhibitory power of the dog is gradually restored. The conditioned reactions displayed in the intertrial intervals disappear first inasmuch as owing to the prolonged training the experimental situation itself has become a strong inhibitory stimulus with a rather poor admixture of excitatory elements; then the inhibition to differential stimuli returns to normal, the more subtle the differentiation, the more retarded is the recovery. Usually the restitution of the conditioned inhibition comes last, especially when the interval between the two components of the inhibitory compound attains a dozen or so seconds. This is easily explained by the fact that here the conditioned stimulus itself is turned inhibitory when preceded by the conditioned inhibitor, and so the excitatory process called forth by this stimulus is not easily overcome. However, the conditioned inhibitor itself very rarely calls forth the conditioned response; this fact is again easily explicable as this stimulus not being similar to any of the conditioned stimuli is a „pure" inhibitor and has a very poor excitatory admixture if any.

The problem is bound to arise as to whether the recovery of the inhibitory cortical process progresses „spontaneously" after some time, or whether it is due to the post-operative training. Being unable to answer this question definitely, we are nevertheless inclined to favour the latter of these alternatives. This view is substantiated by Ławicka's experiments in two experimental situations: after frontal ablation the retraining of the inhibitory reflexes in one situation had scarcely any effect on the disturbed inhibitory reflexes in the other.

Further experiments of this series (to be published elsewhere) proved that disinhibition of inhibitory conditioned reflexes takes place not only when the dog is trained to put his leg on the foodtray (this movement might be considered as closely connected with the very act of eating) but also with any other learnt movements, such as barking, standing up on hind legs, etc. (Ławicka). Disinhibition occurs also in quite the same form if instead of motor reflexes classical salivary reflexes are used (Brutkowski). And so we are compelled to conclude that frontal ablations produce a general impairment of cortical inhibitory processes, while excitatory processes are left undisturbed.

As in some of our dogs the posterior border of the ablation involved rostral parts of gyrus sigmoideus anterior, the disorders ensuing from these lesions should be briefly commented upon.

We saw that these dogs differ from those with the more limited frontal lesions in two respects. First, just after the operation they display a great deal of general disorientation connected with more or less complete disappearance of conditioned reflexes. Secondly, they are much more disinhibited than the dogs with limited frontal lesions.

The first of these disorders was very clearly shown in I. Stępień's experiments on cats, performed in this laboratory. In these experiments the animals were trained to find their way in a simple maze, and then they were subjected to large frontal ablations extending to sulcus cruciatus. After the operation the cats were fully disoriented and had to be trained in the maze from the very beginning. The symptom is now subjected to more thorough experimental analysis.

The second disorder (a very strong disinhibition) also deserves a more careful consideration. As previously noticed, the dogs, after a short period of disappearance of conditioned reflexes, show an opposite disorder consisting in the incessant performance of the trained movement. Besides, these dogs reveal a general tendency to stereotyped, repeated movements, such as: going to and from an empty bowl, climbing the foodtray, persistent gnawing the edge of the foodtray, and so on. We think that incessant pacing often observed after large frontal ablations belongs to the same set of symptoms.

What sort of lesions is responsible for these symptoms (nucleus caudatus?), and whether or not they should be considered as a disturbance sui generis not reducible to the impairment of conditioned inhibitory reflexes is a matter demanding further elucidation.

In order to ascertain whether the syndrome of disinhibition described here may have resulted from any cortical lesion as an expression of „general weakening of cortical processes", a control lesion in the parietal region was carried out in each dog either before or after the frontal operation. The fact that after this operation even the most „strained" inhibitory reflexes i. e. those with the greatest admixture of excitatory elements were fully preserved, refutes this supposition and confirms the view that disinhibition obtained in our experiments is closely bound with the frontal ablations. This does not, however, exclude the possibility that lesions in some other regions of the cerebral cortex may lead to the same or similar disorders.

The problem arises what may be the mechanism of the above described disorders.

There is now a growing body of evidence to show that the process of inhibition evoked in a neurone by impulses impinging from another neurone do not depend on the form or location of synapses but on the transmitter produced by the first of these neurones (cf. Eccles, Fatt and Landgren, 1954; Eccles, Fatt and Koketsu, 1954; Florey and Mc Lennan, 1955 and others). In keeping with this fact is the evidence that here and there in the central nervous system there are some definite groups of neurones with an overt inhibitory action, such as the inhibitory respiratory centre in the medulla (cf. Pitts, 1947), the inhibitory alimentary centre in the hypothalamus (cf. Brobeck, 1946, 1955), the central gray inhibitory system in the midbrain (cf. Magoun, 1950), etc. Whether or not the well-known and much disputed supressor areas in the cortex belong to such inhibitory centres is a matter for discussion.

Consequently we may assume that all acquired inhibitory reflexes also operate through certain intermediary inhibitory centres, one of which is situated somewhere in the frontal lobes. When such a centre is destroyed, the inhibitory conditioned reflexes become much impaired while excitatory conditioned reflexes remain unchanged. This impairment is gradually more or less compensated as other inhibitory centres take over the function of the destroyed one. It is easy to conceive that this compensation must occur by way of additional inhibitory training in order that the new inhibitory connections in place of the destroyed ones might be established. It is also obvious that the more „strained" is the given inhibitory reflex, i. e. the stronger excitatory reflex it must oppose, the less successful will be the compensation.

Future researches will prove whether the line of explantation of the described phenomena is, or is not true. Meanwhile we should like to show that, irrespectively of this, many experimental and clinical data concerning the effects of frontal ablations on the behaviour of animals and man can be easily interpreted as symptoms of the more or less manifest impairment of the conditioned inhibitory reflexes. Such a view had been put forward long ago by Kalischer (1911) and Afanasjew (1913). Recently it has been amply documented in Stanley and Jaynes's paper concerning animal experiments (1949) and Jarvie's paper on clinical material (1954). Stanley and Jaynes have shown that such frontal symptoms as hypermotility, difficulty in habit reversal, the impairment of the performance of seriatim problems, etc. can be explained as ensuing from disinhibition. In the same way may be explained the results of Shumilina's experiments from Anochin's laboratory with double reinforcement (1949) and Shustin's experiments with trace conditioned reflexes (1953). I. Stępień (1956) in our laboratory has convincingly shown on cats that some forms of hypermotility as well as the difficulty of reversal learning reported by some authors (Harlow and Dagnon, 1943; Harlow and Settlage 1948) are also easily explained by the impairment of inhibitory processes.

Concluding this discussion we should like to comment briefly on the experimental neuroses often observed in animals after frontal ablations and caused by such experimental procedures which were for the animal quite harmless before the operation. Two factors may be responsible for this. First, it must be noted that owing to the impairment of inhibitory processes the task, which before the operation was quite easy for the animal, now becomes very difficult or even impossible to solve. We know very well from experimental practice that in quite normal animals endowed with the great prevalence of excitatory processes and relative weakness of inhibition all inhibitory tasks (such as difficult differentiations, conditioned inhibitions, etc.) are performed with great difficulties and very often lead to neurosis. And so the „organic" impairment of inhibitory processes by destruction of frontal poles makes a previously quite well-balanced animal overexcitable and more prone than before to experimental neurosis. Secondly, it may be possible that a gross damage to cortical tissue may generally impair the higher nervous activity of a dog and lower his ability to cope with difficult tasks. Irrespectively of which of these factors plays a major rôle in producing experimental neurosis in our dogs, it must be stressed that the detection and proper evaluation of neurotic functional states in such experiments as described in the present paper is of paramount importance lest we should confuse two quite different sets of symptoms and mistake one of them for the other.

SUMMARY

1. The present paper is concerned with the effect of the removal of frontal lobes of the cerebral cortex on the excitatory and inhibitory instrumental conditioned reflexes.

2. It has been found that after bilateral frontal ablations limited to gyrus proreus and gyrus orbitalis excitatory conditioned reflexes are unimpaired while inhibitory reflexes are disinhibited: in consequence the dog performs the learnt movement not only to the excitatory conditioned stimuli but also in intertrial intervals, to

differentiated stimuli and to the conditioned stimulus preceded by conditioned inhibitor.

3. The inhibitory capacity of the dog returns to normal gradually in the following sequence: a) disappearance of intertrial conditioned reactions, b) inhibition of reactions to differential stimuli, c) inhibition of reactions to the conditioned stimulus immediately preceded by conditioned inhibitor, d) inhibition of reactions to the conditioned stimulus preceded by conditioned inhibitor with an interval of a few seconds.

4. When frontal ablations are more extensive, encroaching upon gyrus sigmoideus anterior, the following disorders of animals behaviour are found: a) early symptoms: disorientation in familiar surrounding, incessant pacing or running, partial or total disappearance of conditioned reflexes; b) later symptoms: great tendency to perseverative movements, strong impairment of inhibitory reflexes.

5. After frontal ablations the dogs are more prone to develop experimental neuroses than dogs with intact cortex.

6. After control parietal ablations involving gyrus entolateralis and suparsplenialis no disturbance of either excitatory or inhibitory conditioned reflexes is observed.

7. The physiological mechanism of the impairment of inhibitory processes after frontal ablations is discussed.

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