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EFFECTS OF CINGULATE CORTEX LESIONS ON EMOTIONAL BEHAVIOR AND DELAYED RESPONSES IN CATS

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Abstract. Bilateral thermocoagulation of the cingulate gyri produced an abolishment of fear reactions concomitantly with an exaggerated aggressiveness and a drastic impairment of delayed responses. The changes in emotionality subsided after several months but there was no recovery, even after prolonged post-operative training, of the dalayed responses with a 5 min delay. Only partial improvement of the responses with shorter delays (10 sec and 1 min) was observed. This memory deficit is discussed in terms of disruption of neuronal limbic circuits necessary for maintaining the impulse reverberation.

INTRODUCTION

The effects of the cingulate cortex lesions on general emotional behavior or on learning and retention were studied by several authors. The results of these experiments are not clear and sometimes contradictory. Thus, Bard and Mountcastle (1948) and Mirski et al. (1957) reported only negligible behavioral changes after cingulate ablations, whereas Glees et al. (1950) and Brutkowski et al. (1961) found a reduction of fear and an increase in aggressiveness. Smith (1945) and Ward (1948), on the other hand, described a decrease in emotionality after similar lesions.

Changes in learned behavior have also been investigated. Animals with lesions in the cingulate cortex exhibited a deficit in passive avoidance learning (McCleary 1961, Kaada et al. 1962, Thomas and Slotnick 1962, Ursin et al. 1969), although active avoidance responses remained unaffected (McCleary 1961, Thomas and Slotnick 1962).

The aim of the present paper was the elucidation of the effect of cingulate cortical lesions on emotional behavior and short-term memory in cats.

MATERIAL AND METHODS

Experiments were performed on 20 adult cats. Pre-operatively in all the animals delayed responses were trained and the general behavior was systematically observed during 1 month. Also the reactions to nociceptive stimulation and the amount of food consumed were investigated. The training of delayed responses was carried out in a special two-compartment cage (Fig. 1). The smaller compartment (40 cm × 30 cm)

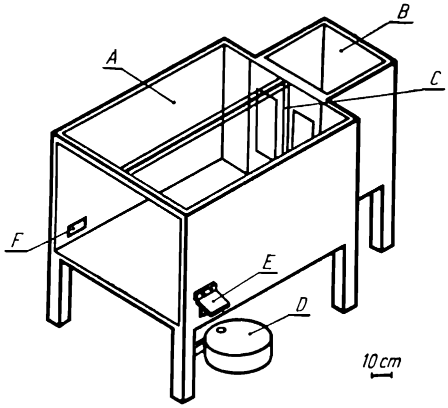

Fig. 1. A schematic view of the experimental cage. *A*, main section; *B*, starting box; *C*, gate separating the two compartments; *D*, feeder; *E*, platform where the food is delivered; *F*, window through which the food is taken by the animal.

served as a starting place (Fig. 1*B*). The adjacent large compartment (Fig. 1*A*) 100 cm long and 80 cm wide (the height of both compartments was 60 cm) had two small windows in the side-walls through which pieces of meat could be provided from the feeders. The two compartments were separated by a remotely operated gate through which the animal, waiting in the starting box, could observe the interior of the large compartment. Two conditioned stimuli, an electric bell and rhytmic clicks were applied close to the feeders. The training proceeded as follows. At first an approach conditioned reaction was established. 3–5 sec after the onset of the conditioned stimulus (CS) the door of the starting box was opened and the cat was allowed to enter the large compartment and take a piece of meat from the feeder. The CS was terminated as soon as the animal had received the reward. Using this procedure a discrimination between approaching the right or the left feeder was trained; the correct feeder could be determined by the quality (bell or clicks) and localization of the corresponding CS. 10–12 trials were presented during a session. When the discrimination reached 95–100% correct responses a delay between the termination of the CS and the opening of the gate was introduced. The CS served thus as a preparatory signal whereas the opening of the door constituted the triggering stimulus (*see* Konorski and Ławicka 1959*a*). The animals were trained to increasing delays and on each session delays of 0 sec, 10 sec, 1 min and 5 min were randomly presented. The number of errors did not exceed 10–15%, even with the longest delays.

Lesions in the cingulate gyrus were produced by thermocoagulation under Nembutal anesthesia (40 mg/kg). In the first group of the cats ($N = 15$) the cingulate gyrus was damaged partially (anterior, middle or posterior part) and in the second group ($N = 5$) total lesions were performed (Fig. 2). All lesions were bilateral.

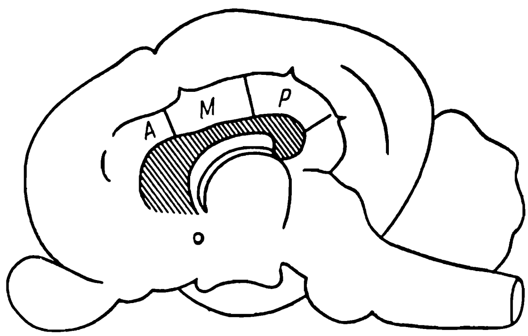

Fig. 2. The medial aspect of the feline brain hemisphere. Anterior (*A*), middle (*M*), and posterior (*P*), parts of the cingulate gyrus.

After completion of post-operative testing the animals were sacrificed, the brain placed in a 10% formaline solution and the extent of the lesion checked macroscopically.

RESULTS

Changes in general behavior

Prior to the operation, all the cats manifested an emotional reaction of fear in the presence of dogs. The majority of them immediately escaped and hid. Some of them hissed and ran away when the dog approached. Painful stimulation of the skin elicited a fear reaction with avoidance. No aggressiveness was observed towards other cats of the experimenter.

The operated cats with partial or total lesions of the cingulate gyri recovered from anesthesia on the first post-operative day. During first several days the animals did not eat by themselves. Soon they were able to swallow, without chewing, food introduced into the mouth by means of a syringe or a forceps. After a week the animals began to eat spontaneously; they ate greedily but no hyperphagia was observed.

In cats with anterior cingulate lesions the emotional reaction of fear in the presence of dogs was during this period absent and the cats used to sit indifferently even when they were attacked. Painful stimulation elicited a rage response, a goal directed attack followed by a freezing reaction. After repetition of this experience the freezing reaction appeared in response to the painful stimulation itself.

The cats with bilateral middle cingulate lesions displayed hyperactivity and an increase of vocalization during the first two post-operative weeks. This behavior gradually disappeared.

Posterior cingulate lesions produced an insignificant and transient reactivity decrease.

Cats with bilateral total cingulate lesions showed an increased extensor tonus of the forelegs and clumsy walking; similar effects were also observed in the anterior cingulate cats. These disorders diminished with the lapse of time (6–8 days).

In competitive situations such as eating together with intact cats the operated subjects showed more aggressiveness than before the operation. They also attacked the experimenter in response to a painful stimulation of the tail. After several repetitions of this stimulation, however, they changed their behavior and fearfully ran away from the experimenter.

It is interesting to note, that the operated cats were not afraid of dogs, on the contrary, they attacked them and scratched their muzzles, the dogs escaping in fright. This apparent lack of fear and increased pugnacity continued for 3 months.

Thus, our experiments show that total bilateral cingulate lesions produced a depression of fear reactions and an increase of aggressiveness.

Changes in conditioned alimentary behavior and delayed reactions after total lesions

Before the operation the cats were trained to discriminate CSs and to choose the correct feeders. When a level of 100% correct performances had been reached the delays were introduced and extended up to 5–7 min. Figure 3 shows the course of the training of delayed responses in the intact (*A* and *B*) and operated (*C* and *D*) cats. Column A1 shows the perfect discrimination of the CSs without delay. The columns A2, A3 and A4 show the ratio of correct to incorrect choices with increasing delays (10 sec, 1 min and 5 min, respectively) during the first days of training. It is evident that whereas with a delay of 10 sec the animals exhibited a definite positive transfer from the discrimination training, longer delays produced only random choices with performances not exceeding the chance level. However, after 8–10 days of training the

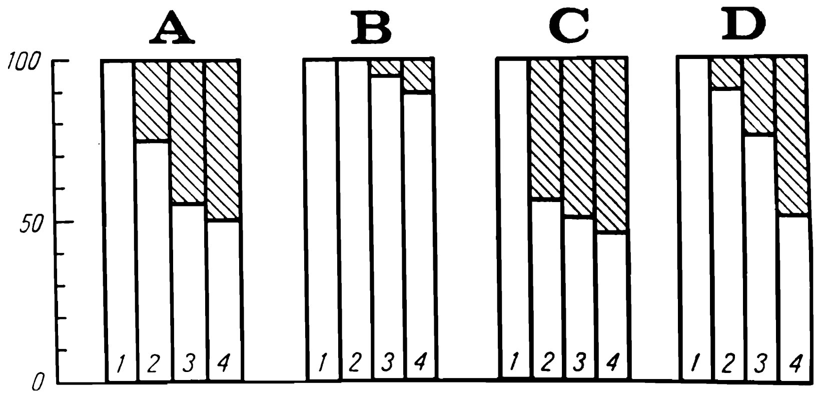

Fig. 3. Percentage of correct (white) and incorrect (hatched) responses in the go right–go left discrimination without (column 1) and with increasing delays: 10 sec (column 2), 1 min (column 3) and 5 min (column 4). *A* and *B*, the pre-operational training; *C*, the performance during the first month after the operation; *D*, the results obtained after 3 months of further training

performances rapidly improved and the average performance level was 100% of correct responses in trials with 0 and 10 sec delay, 95% with a 1 min delay and 90% with a 5 min delay (Fig. 3, columns B1, B2, B3 and B4).

In 7 out 10 operated cats with a bilateral ablation of the cingulate gyri the discrimination of the CSs (without delay) was normal. In the three remaining animals there was a temporary impairment of discrimination. If, however, the gate from the starting box was opened after the termination of the CS, the animals made errors. Inspection of Fig. 3 reveals how serious was this impairment of delayed responses. Columns C show that 1 month after the operation the number of correct responses was still on the chance level (i.e., nearly 50%) with 1 and 5 min delays and hardly exceeded this level with a 10 sec dalay. Long post-operative training resulted in some improvement in trials with shorter delay but even 3 months after the operation the cats reached only the level of 75% of correct performance with 1 min delays (Fig. 3, column D3), which being still unable to cope with 5 min delays (Fig. 3, column D4). The pre-operative level of correct responses was not restored after 5–6 months of the post-operative training.

DISCUSSION

It is generally accepted that the limbic system is an integrative center of emotional behavior (Papez 1937, Brady 1958). Since Klüver and Bucy's (1937) classical work much evidence has been accumulated showing that the removal of archi- and paleo-cortical structures produces changes in general and conditioned animal behavior (Grastyan and Karmos 1962, Gavrilova and Obuhova 1963, Douglas and Pribram 1966, Tartygin 1966, Semenova 1967, Oniani et al. 1968). Although the cingulate gyrus in considered to be an important structure of the limbic system, its role in the organization of emotional reactions and short-term memory is still poorly understood.

Our experiments with lesions in different parts of the cingulate gyrus provide evidence of a topographic functional differentiation and show that this structure plays an important role in the organization of emotional behavior. This conclusion was confirmed by the experiment with electrical stimulation of different parts of the cingulate gyrus (Koridze 1967).

The cingulate gyrus seems to play an especially important role in the regulation of fear and aggressive reactions (Fangel and Kaada 1960, Koridze 1967, Lagutina and Fufacheva 1968). In spite of this evidence Ursin (1969) questioned recently this opinion and presented his experimental data on flight and defensive behavior in feral cats before and after cingulate lesions, suggesting, thus, that this cortex is not essential for emotional behavior.

Our results indicate that the cingulate gyrus does indeed play an important role in the regulation of fear and aggressive behavior. Considering, that the coordinating centers for emotional discharges are located preferentially in the hypothalamus (Hess 1956, Nakao 1958, Yasukochi 1960, Wasman and Flynn 1962, Romaniuk 1965), it may be assumed that the cingulate cortex exerts a facilitatory as well as inhibitory influence on these centers. Both the facilitatory and inhibitatory mechanisms must be localized mainly in the anterior part of the cingulate gyrus. This is ascertained by the fact that electrical stimulation of this part elicits a fear reaction (Fangel and Kaada 1960, Koridze 1967), whereas a lesion of the anterior cingulate produces a disappearance of fear reactions and an increase of aggressiveness.

Our experiments have also shown that cats with total cingulate lesions are more aggressive than cats with lessions of the anterior part of the cingulate gyrus and that this behavioral change continues longer in the former case. These facts seem to indicate that although partial lesions in the middle part of the cingulate gyrus produce only negligible behavioral alterations, the removal of this cortex adds to the offect of the lesion in the anterior cingulate. It is probable that the compensation after isolated anterior cingulate lesions proceeds due to the remaining parts of this gyrus; this would explain a faster recovery after a partial anterior lesion as compared to the total cingulectomy.

It was postulated that the neurophysiological basis of delayed reactions consists in the reverberation of excitation and posttetanic potentiation of synaptic conduction in the nervous circuits of the brain (Eccles 1953, Hebb 1957, Konorski and Ławicka 1959*b*, Beritashvili 1968) and particularly in the limbic system (Oniani 1969, Oniani et al. 1969). The authors suggest that the cingulate gyrus, being one of the main parts of the limbic system, is also directly involved in the maintenance of recent memory traces.

Another structure related to the performance of delayed responses is the prefrontal cortex (Jacobsen 1936). This finding was a subject of many studies on various animals (Jacobsen and Nissen 1937, Mishkin and Pribram 1955, 1956, Konorski and Ławicka 1959*b*, Ławicka and Konorski 1961, 1962, Warren et al. 1962, Beritashvili et al. 1964). It is of utmost interest, in this context, that the existence of bilateral connections between cingulate gyrus and prefrontal lobes was established by means of the method of terminal degeneration (Nauta 1964, Cragg 1965, Kiknadze 1969).

The present study allows the authors to conclude that the cingulate gyri participate in the organization of short-term memory. This view is based on the observation that delayed responses are impaired by the lesions of the cingulate gyri (Koridze 1968). This deficit is severe since and a long post-operative training does not improve the performance of this short-term memory task with delays of 5 min, and even with shorter delays the improvement is incomplete. It is feasible to interprete these effects of cingulate lesions as the disturbance of the integrity of the limbic neural circuits. In other words, the impairment of delayed responses after cingulate lesions would be caused by a decrease in duration and intensity of the impulse reverberations both within the limbic system and between the limbic and neocortical regions.

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