MIDBRAIN CENTRAL GRAY AND SWITCH-OFF BEHAVIOR IN CATS

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Electrical stimulation of the midbrain central gray is known to elicit a defensive or offensive response in cats and monkeys. In these experiments, there is some disagreement as to the subjective experience of the response and the exact sites from which the responses are elicited.

Ross et al. used conditioning methods in order to analyze the property of the response from the central gray. They reported the positive results. As for motivational aspects of the response on learning, OLDS and OLDS have studied both the positive and negative effects of 96 points in the rat brain, using the self-stimulation method. They have stimulated the midbrain central gray in one point and found the point to yield negative reinforcement. COOPER and TAYLOR also noted the same result in an electrode in the dorsal central gray. Recently, one of the present authors stimulated 366 points mainly in the periaqueductal areas of the midbrain and posterior diencephalon in cats, to determine whether they have a motivational effect on the switch-off behavior, an escape learning, and obtained 3 effective points in the midbrain central gray.

The purpose of this paper was to investigate further the midbrain central gray concerning the switch-off behavior.

METHODS

The experiment was carried out on 67 cats. Four to twelve electrodes were stereotaxically implanted in the midbrain central gray of cats under Nembutal anesthesia.

In 17 of them, electrodes were also implanted in the medial hypothalamic area to motivate the switch-off behavior, for investigating the transfer of learning between the hypothalamus and the midbrain central gray.

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Electrodes were constructed from stainless steel wire, 0.12 mm in diameter, insulated by insertion into a fine glass capillary, with only the cut cross section of the tips bared.

Brain stimulation was provided by an ordinary 60 cps current at 0.5-1.0 volt adjusted to elicit a clear-cut response. A wire which passed through the frontal sinus was used as an indifferent electrode for unipolar stimulation.

Switch-off behavior. This test has been described in detail elsewhere\(^5,6\). The animal was placed in the switch-off box which had two small windows in a wall. In front of one window was a plate, pushing of which broke the stimulating circuit and discontinued the stimulation. There was no plate at the other window. The animals were trained to push the plate to turn off the brain stimulation. Training continued until the cats pushed the plate with a short and stable response time, without coming to the other window. When an animal could reach this criterion, the stimulating site was regarded as a positive point for the switch-off behavior.

At the end of the experiments, the animals were sacrificed, their brains were perfused with 10% formalin and the sites of the electrode tips were histologically examined in serial sections cut in a coronal plane.

RESULTS

Switch-off behavior. Five hundreds and fourteen points in and around the midbrain central gray were stimulated for response on the observation stage and 412 of these were observed to induce inadequate responses to the switch-off behavior, such as motor responses, locomotion toward the stimulated side, circling and screeching.

Stimulating of the remaining 102 points in the central gray elicited a forward locomotion or locomotion somewhat toward the stimulated side.

Of these points tested in the switch-off box, 55 gave a positive result in a dependable fashion (open circle in Fig. 1), and 47 were negative (solid circle in Fig. 1). The positive points were in the region lateral to the Sylvian aqueduct in the middle and posterior portions of the central gray, between coronal planes A-3 and P-2. The area extended in the ventrolateral direction in the posterior portion of the central gray and one positive point was situated outside the central gray at the P-2 coronal plane (Fig. 1).

Fig. 2 shows one example of the response time histogenously constructed from 100 successive trials of the switch-off behavior.

Fig. 3 shows the average response time of every 10 successive trials in the test shown in Fig. 2. The figure indicates stability of the performance motivated from the central gray. These results coincided with those of the hypothalamically induced switch-off behavior reported before.

Transfer experiments were carried out between the hypothalamus and the midbrain central gray. Eight animals were trained to switch off hypothalamic stimulation in response to the stimulation. After the training was accomplished, the animals were tested in the same apparatus with electrical stimulation of the central gray instead of the hypothalamic stimulation which had
Fig. 1. Composite diagrams showing stimulated sites which elicited various responses.

Fig. 2. Distribution of the response time of the switch-off behavior induced by midbrain central gray stimulation: abscissae, response time; ordinates, number of trials.
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FIG. 3. Average response time of every ten trials of the switch-off behavior: abscissae, successive trials; ordinates, response time. Data were taken from the test shown in Fig. 2.

FIG. 4. The switch-off behavior originally learned to hypothalamic stimulation transferred to central gray stimulation.

FIG. 5. The switch-off behavior trained with central gray stimulation transferred to hypothalamic stimulation.

been used during the original training. The animals switched off the stimulation from the first trial as shown in Fig. 4. Thus, the habit of switch-off transferred from the hypothalamic stimulation to the stimulation of the central gray. Exactly the same result was obtained when the hypothalamus was stimulated in 7 animals originally trained with the electrodes in the midbrain central gray. One example is given in Fig. 5.

Attack response. An attack response was seldom seen in comparison with a flight response. Only 2 of 319 points stimulated in the central gray elicited an attack response, whereas 55 points were obtained for a flight response as proved in the switch-off behavior test.

Behavioral manifestations of the response consisted of flattening of the
ears, arching of the back, piloerection of the back and tail, pupillary dilatation, growling and urination. When a stick was offered during stimulation, the cat launched a well directed attack. These general characteristics resembled those of the attack response elicited by ventromedial hypothalamic stimulation.

Histological examination revealed that the electrode tips were in the central part of the central gray at the A-1 and 0 coronal planes (cross in Fig. 1) away from the positive area of the switch-off behavior.

**Locomotion.** Locomotive responses were evoked by stimulation of almost all parts of the central gray except its lower part.

Forward locomotion (vertical line in Fig. 1): The animals walked or ran, forward or to either side, and none hissed or screeched. Some of them had a marked frightened expression which resembled the hypothalamically-induced flight response. Stimulation of most points motivated the switch-off behavior.

Locomotion toward the stimulated side (slant line in Fig. 1): A walking or a running toward the stimulated side were induced in a stereotyped fashion from the central part of the central gray. In some cases, the response was accompanied by an inclination of the foretrunk to the stimulated side, or vocalization, or both. The switch-off behavior could not be motivated by these responses.

Circling (semicircle in Fig. 1): A turning movement was elicited from the dorsal boundary of the middle and posterior central gray (A-2—P-1 in Fig. 1). The locomotion was smooth and the direction was clockwise on left-sided stimulation. The response was inadequate for the training of the switch-behavior.

**Motor response.** Rotation: The head rotated clockwise in the coronal plane when the stimulated side was the left. The rotation was confined almost solely to the head. In some cases the rotation spread to the whole of the foretrunk or extended to the whole body, eliciting a rolling motion. Finally, there were cases in which the whole body inclined to the stimulated side with or without a rotation of the head and extension of the contralateral foreleg. The points lay widely dispersed in the lower part of the central gray and the tegmentum.

Lowering of the head and foretrunk: Immediately following the stimulation, the head was lowered until the nose struck the table. This response was obtained from the posterior commissure above the central gray at the A-5 and A-4 plane in Fig. 1. At the A-5 plane, lowering of the trunk and raising of the head were observed.

**Vocalization.** Four kinds of vocalization were produced by electrical stimulation of the central area of the central gray (Fig. 6). This area overlapped
the area of locomotion toward the stimulated side.

As shown in Fig. 6, the points of each vocalization intermingled to some extent, but, in general, screeching was obtained from the central and lateral parts, growling from the medial parts, hissing from the dorsal and medial parts, and mewing from the ventral part of the central gray. In most instances the screeching and growling were accompanied by locomotion or motor responses.

The positive points of the switch-off behavior and the pain-inducing points mingle in some degree as shown in the composite diagrams of Fig. 1, but these effects were found separately in each individual animal.

DISCUSSION

Skultety\textsuperscript{11} has described responses of flight and rage evoked from the midbrain central gray but imputed no emotional significance to the responses. Furthermore, he has definitely rejected the idea that he can know anything about the emotions of an experimental animal. We can agree with his idea when the experimental method is merely an observation of an animal’s behavior, as seen in his and others\textsuperscript{6,7} experiments. The present study has used a learning method to analyze the responses evoked and it has been clearly shown that the locomotive response from the central gray has motivational property for an escape learning.
Ross et al.\textsuperscript{10} reported that the aversive drive of the midbrain including the central gray cannot be ascribed to any sensory input, such as pain, but to the direct activation of the central mechanisms of emotion. One of the bases of their opinion is the result of electrode placing far from the classical primary sensory pathway. But pain-suggestive reactions are easily induced by central gray stimulation\textsuperscript{9,18}. Delgado\textsuperscript{2} concluded that the central gray stimulation activates sensory pathways and thus evoked defensive responses. There still remains a possibility that the negative reinforcement obtained in the present study may be due to noxious sensation produced by the central gray stimulation.

However, the most constant pain-suggestive reaction is a typical high-pitched screeching and we avoided the utilization of electrodes which evoked screeching. Histological work also showed that the sites of screeching are concentrated in a certain area away from the “switch-off” region. Our conclusion is that the area of screeching and the “switch-off” region in the central gray belong to different functional systems, respectively, and the flight-resembling locomotion accompanied by negative reinforcement is a fear-flight response in the sense of an emotional experience. In this respect, the effect of the central gray stimulation was very similar to that of the hypothalamic stimulation. Transfer experiments were performed between the central gray and the hypothalamus to compare the effects of these two structures. The results confirmed that bi-directional transfer of the switch-off behavior was possible.

As described before, a fear-flight region, the “switch-off” region, localizes in the medial hypothalamus with a relatively wide area in the rostral portion\textsuperscript{8}. According to Hunspurger\textsuperscript{4}, the “peripheral zone” related to the escape pattern has topographic continuity extending from the preoptic area to the caudal portion of the midbrain central gray. Skultety\textsuperscript{11} reported that a flight response was not obtained from the rostral portion of the central gray but from the caudal portion. Our results confirmed that the “switch-off” regions in the hypothalamus and the central gray were disconnected at the rostral midbrain level while they have the same motivational effect as proved in transfer experiments. The topographical findings in our study would tend to support Skultety’s report on the central gray.

Topographical discrepancy is also found as to a rage response. Hunspurger\textsuperscript{4} obtained the affective defense reaction from the “central zone” in the middle portion of the midbrain central gray. Similarly, Skultety\textsuperscript{11} found a rage response from a fairly wide area in the central gray beneath the superior colliculus. In contrast, we have obtained a rage response from two points in a central area between the aqueduct and the lateral margin of the central gray in its middle portion. Characteristics of the rage response were similar to those of the hypothalamically elicited rage-attack response. These
were only two among more than 350 points tested in the central gray, indicating that the area of rage in our study is very small. No explanation can be offered for these discrepancies.

The stimulation which elicited locomotion toward the stimulated side, circling or motor responses did not motivate the animals to learn the switch-off behavior.

SUMMARY

The aim of this investigation has been to study whether electrical stimulation of the midbrain central gray could produce negative reinforcement. Sixty seven adult cats were tested. The test learning was the switch-off behavior, an escape learning.

The positive points for the test were found in an area located laterally to the Sylvian aqueduct to the middle and caudal portion and an area extending ventro-laterally from the above described area in the caudal portion of the midbrain central gray.

These areas were situated very close to an area which elicited pain-suggestive screeching in the central gray. We did not use these screeching-yielding sites for the test and assumed that the negative reinforcement obtained in the present study was not due to pain but to fear in the sense of a subjective experience. Transfer experiments of the switch-off behavior proved that central gray stimulation could induce the same motivational effect as hypothalamic stimulation did.

A well-directed attack response was induced by stimulation in the central region of the middle portion of the central gray, but an attack response was rarely obtained in comparison with a flight response.

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REFERENCES