SOME CHARACTERISTICS OF SELF-STIMULATION BEHAVIOR OF DOGS

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Abstract. Self-stimulation was studied in dogs chronically implanted with electrodes in different points within the basal forebrain. The animals exhibiting pure self-rewarding behavior were defined as “optimal” and “good self-stimulators”, whereas those with concomitant aversive phenomena were incorporated into the third category called “self-stimulation-withdrawal”. In “optimal self-stimulators” a remarkable resistance of the response to extinction was noted. A strong negative attitude toward food was found in four dogs upon stimulation of the self-rewarding loci. Penile erection accompanied self-stimulation in two animals. Sniffing at first always followed incentive brain stimulation, but later it appeared at the beginning of each experiment and/or preceded the bouts of pressing. A rise of hypothalamic temperature was noted in most of the animals. In some cases this was equal to or exceeded 1°C. The temperature increase was accompanied by intense panting between the bouts. Seizures appeared locally as contractions of masticatory muscles and sometimes developed into a generalized fit. Anatomically the “reward area” in the dog extends from the septum and the preoptic area to the mamillary bodies and reaches laterally to the internal capsule.

INTRODUCTION

The evidence for the motivational properties of self-stimulation comes mainly from experiments on rats. Some data have also been obtained with cats, monkeys and rabbits. They indicate that, though self-stimulation is a common phenomenon appearing in different animals, its properties, such as optimal stimulus parameters, mechanisms of induction and reduction of drive, behavioral effects, autonomic and neurohormonal correlates, anatomical distribution of loci and many other factors may differ from species to species.
In spite of a rapidly developing literature only a few papers deal with self-stimulation in dogs (15, 20). The patterns of self-rewarding in these animals thus remain practically unknown although this species provides a good opportunity to study emotional behavior elicited by electrical stimulation of the brain.

Several years ago we attempted to study behavior of unrestrained dogs upon stimulation of points distributed in forebrain and midbrain areas. With a particular position of the electrodes within the preoptic area the stimulation produced clear-cut effects indicating a strong positive-type emotional excitement. It was also possible to shape the animal's behavior toward performing an instrumental movement for brain stimulation as a reward. Starting with this observation we implanted more animals with electrodes aimed at different points within the preoptic area and the hypothalamus. The dogs were trained to self-stimulate in these regions by pressing a pedal.

METHODS AND INSTRUMENTATION

Our material is based on observation of self-rewarding behavior of 20 male mongrel dogs, each bearing four concentric stainless steel electrodes inserted by means of a stereotaxic instrument (Medicor, Budapest) under general anesthesia. Coordinates were taken from the atlas of Lim, Liu and Moffitt (9) with a correction for differences in skull dimensions. The electrodes consisted of a 0.5 mm tube (o.d.) enameled except for 0.5 mm at the end. Inside the tube there was a 0.1 mm wire covered with the same varnish. It protruded for a distance of about 1 mm beyond the end of the tube and its tip was uninsulated for a length of 0.5 mm. Both electrodes were soldered to pins of a connector placed in a Plexiglas socket. The latter was screwed into the partial bone and fastened additionally according to a technique similar to that of Sheatz (19). Several screws were placed in the skull in order to provide attachment for acrylic cement which kept the electrodes secure.

At least 2 weeks were allowed for recovery. The dogs were trained to self-stimulate either by means of a radio-operated telestimulation system or with the use of the conventional procedure. In the first situation the animal, carrying a miniature stimulator on his back, was permitted complete freedom of movement within a 5 × 3 m room. The stimulator generated 1 msec square pulses at a frequency of 200 cycles/sec. It was switched on by means of a radio transmitter operating a miniature receiver. The amplitude of the pulses was established before the experiment. In order to self-stimulate the dog had to press a pedal consisting of a 7 cm long and 4.5 cm wide lever placed 3 cm above the floor (Fig. 1). This
resulted in the closing of a switch connected to the transmitter through a timer so that for each press the animal obtained a train of pulses which stimulated the hypothalamus. The experimenter was able to change the duration of the trains within a range from 0.2 to 4 sec without approaching the dog. He could also switch on the transmitter at any time or switch it off in order to make the presses ineffective. The telestimulation technique was particularly suitable for studying motor effects accompanying self-stimulation or to detect withdrawal components. Extinction trials were made by disconnecting the pedal from the transmitter.

In the second situation the dog was partially restrained on a stand with free access to the pedal by means of which he could switch on a stimulator delivering a 250 cycles/sec sine wave during a period determined by a timer. The current was measured as the voltage drop across a resistor connected in series with the electrodes.

Behavior of the dogs was noted in the protocol and photographed. Motion pictures were occasionally taken. In some dogs a copper-constantan thermocouple was implanted for measuring hypothalamic temperature.

After termination of the experiments the dogs were sacrificed and their brains were submitted to a routine histological procedure involving staining 50-100 μm frontal sections according to the Nissl and Weil methods.

RESULTS

The stimulated area of the brain was believed to belong to a rewarding system if upon stimulation the dog performed sniffing and searching movements. In telestimulation experiments the animal stopped walking, sniffed and explored nearby objects. With repeated stimulations he tried to touch them with his nose or foreleg.
The shaping of the dog's behavior toward self-stimulation consisted of stimulating the rewarding area each time the animal approached and/or touched the pedal. This was followed by more and more intense attempts to explore the manipulandum. Once the animal fortuitously pressed the lever, it was rewarded only for correct responses even if they were not strong enough to close the switch. Finally the animal learned to make adequate presses and from that time on proper self-stimulation began. Usually one or two training sessions were needed to achieve a stable rate of responding.

For pressing the pedal the dog used the nose, the forelegs or both alternately. One animal performed the response by licking the lever. The presses were grouped in bouts with intervals between them. Salivation, micturition and defecation were the commonly observed autonomic effects. Penile erection appeared in two dogs. Most of the animals licked or bit the pedal. One dog tried to catch the manipulandum with his teeth and to transport it to another place.

During the action of the current a certain degree of sedation was noted, i.e. the dog did not perform presses and stood motionless. In two animals slow contralateral turning of the head appeared, with a tendency to circling. This effect was evident with long trains. When the current was off, the animals became excited and performed the subsequent pressing.

All the dogs could be included in one of three categories according to their self-rewarding characteristics. The first category comprising "optimal self-stimulators" was characterized by the following properties:

1. The rate of presses was stable during many weeks or months.
2. The responses continued at any train length (from 0.2 to 3 sec).
3. No withdrawal was observed regardless of the length of the trains or amplitude of the pulses.
4. No priming was needed, i.e. the dogs undertook self-stimulation immediately when presented with the experimental situation.
5. The response was highly resistant to extinction, i.e. during extinction trials the dogs performed a great number of non-reinforced presses.

Figure 2 summarizes the experiments performed on a dog included in the first category. With the same intensity of current the rate of presses decreased when the length of the trains increased. Figure 2B summarizes this situation, indicating that there was no preference toward any train length. Resistance to extinction in the same dog is presented in Fig. 3. The dog performed 82 non-reinforced presses in the course of 15 min, however, as shown in A the highest rate of responding occurred within the 1 min. In B the animal was allowed to self-stimulate for 1 min and then the stimulator was off during the next minute. A high rate of responding is visible at the beginning of the extinction procedure. A simi-
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Fig. 2. Response patterns of an "optimal self-stimulator". A, the rate of responding depending on the train length as indicated for each curve; B, total time when the current was on during 20 min of self-stimulation with the same train lengths as in A; C, the pulse shape and current intensity.

Fig. 3. Extinction curves in an "optimal self-stimulator". Filled circles, rewarded presses; open circles, extinction. A–D, different experimental procedures as-explained in the text.

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lar situation is shown in C except that the manipulandum was not available for 1 min following 1 min of responding. Withdrawing the pedal did not affect the number of ineffective presses during the subsequent extinction period. Finally in D the extinction curve following 20 min of self-stimulation does not differ essentially from those in other situations.

The self-rewarding patterns of "good self-stimulators" belonging to the second category according to our classification consist of: (i) stable responses and no withdrawal with changing of the parameters of the current, (ii) preference toward a particular length of the trains, (iii) priming occasionally needed, and (iv) low resistance of the response to extinction.

Figure 4 shows a typical series of experiments. The highest rate of responding occurs with a train length of 0.4 sec. With this length there is also the longest summed time of all periods when the stimulus is on.

![Figure 4](image)

According to the data presented in Fig. 5 extinction proceeds rapidly under all circumstances and develops after a few nonreinforced presses.

The third category of self-rewarding behavior may be called "self-stimulation–withdrawal". It is characterized by unstable responses. This means that their rate may vary from session to session. With increasing
current intensity or train length, withdrawal phenomena appeared consisting of running away from the pedal. Priming was always needed, both at the beginning and sometimes in the course of the session. The extinction of the response developed immediately after one or two ineffective presses.

In an attempt to understand the motivational basis of self-stimulation the attitude toward food was studied in some dogs. Four animals exhibited strong inhibition of food intake in the course of self-stimulation. They did not take a piece of meat placed in front of them or even on the manipulandum and rejected food when stimulated passively in the rewarding area by the experimenter. In three animals food ejection was observed when stimulation started with meat already in the mouth.

Changes of respiration were prominent and consisted of: (i) sniffing, (ii) decrease of the amplitude and frequency of respiratory movements, and (iii) panting.

Sniffing always followed incentive brain stimulations in the preliminary learning period. On the other hand, during self-stimulation it usually preceded the presses. When the stimulus was on, the dog closed its mouth and breathed less deeply. Panting with a frequency exceeding 300/min was evident during intervals between the bouts of pressing. Its intensity increased as self-stimulation proceeded. The panting seemed to be of a thermal rather than emotional origin. Direct measurements of hypothalamic and rectal temperature justified this assumption. Figure 6 shows
Self-stimulation caused a rise of hypothalamic temperature by 1°C during 30 min of self-stimulation. Drinking of water was never observed during self-stimulation. It appeared only in animals with a marked hyperthermia at the end of the experiment.

Anatomical distribution of points from which self-stimulation was obtained is shown in Fig. 7. They cover a widespread region involving the preoptic area and the lateral hypothalamus and reach caudally to the mammilary bodies. Some points are also located in forebrain structures rostrally to the preoptic area. The tip of one electrode yielding a good rewarding effect was found in the internal capsule. Particular locations of electrodes in some dogs are shown in Fig. 8.

Epileptic seizures appeared often in the course of self-stimulation. In most cases they were limited to masticatory muscles and thus resembled chewing movements with a pronounced salivation. Sometimes, however, they developed into a generalized fit with tonic and clonic contractions of trunk and leg muscles. In spite of the severity of the seizures the dogs usually resumed pressing within a few minutes following the fit.

**DISCUSSION**

All students of self-stimulation emphasize a dual role for hypothalamic stimulation; it acts as an incentive and as a reinforcement. In dogs this duality is particularly evident in the first period of training. In order to teach the dog to self-stimulate it is necessary to induce a motivational state which compels the animal to perform manipulatory movements which result finally in correct presses on the pedal. This can be achieved
Fig. 8. Some typical positions of stimulating electrodes. Photographs of frontal sections through the septum (A), anterior portion of the hypothalamus (B and C) and the mammillary bodies (D). Arrows indicate the sites yielding: a, pure self-rewarding, b, self-stimulation — withdrawal and c, withdrawal. Staining after Weil.
Fig. 7. Frontal sections through dog's forebrain showing self-stimulation anatomy. The data have been collected from 14 animals. Filled circles, pure rewarding; triangles, withdrawal; triangles in open circles, ambivalent sites (self-stimulation–withdrawal); e, penile erection; f, inhibition of food intake; h, hyperthermia. Abbreviations: AH, anterior hypothalamus; APr, preoptic area; CA, anterior commissure; CGM, corpus geniculatum mediale; ChO, optic chiasma; CI, internal capsule; CM, centrum medianum; CMM, mammillary bodies; DH, dorsal hypothalamus; DMH, dorsomedial nucleus of the hypothalamus; Fx, fornix; H, field H of Forel; LH, lateral hypothalamus; MD, mediodorsal nucleus of the thalamus; NAc, nucleus accumbens septi; NC, caudate nucleus; NCA, nucleus of the anterior commissure; NCM, nucleus centralis medialis; NEnt, nucleus entopeduncularis; NO, optic nerve; Ped, peduncle; Pf, nucleus parafascicularis; PH, paraventricular nucleus; Ret, nucleus reticularis; Rhe, nucleus reuniens; SO, supraoptic nucleus; TD, taenia diagonalis; TMT, mammillothalamic tract; VL, ventrolateral nucleus; VM, ventromedial nucleus of the thalamus; VMH, ventromedial nucleus of the hypothalamus; VPL, nucleus ventralis posterolateralis; VPM, nucleus ventralis posteromedialis; ZI, zona incerta.
by applying brief brain stimulation which through its incentive action provokes exploratory object-directed movements as well as reinforces the manipulations just performed. It is of extreme importance to make the dog perform the desired movement while under a stimulation-induced drive and to reward this response with a subsequent adequately applied stimulus. All other procedures, e.g. passive placing of the animal's foreleg on the lever, are according to our experience ineffective in establishing self-rewarding behavior.

There is good reason to believe that later when the animal has learned the procedure, the induction of drive is not necessarily connected with a priming incentive stimulation, but depends rather on the experimental situation acting as a complex conditional drive stimulus. This is particularly evident in “optimal self-stimulators” (first category of self-rewarding according to our classification). The level of motivation in these animals is so high that when being prepared for the self-stimulation session they whimper. Perhaps with this pattern of self-rewarding it would be possible to condition the motivational state in the same way as was done by Perez-Cruet, McIntire and Pliskoff (15) in dogs and Bindra and Campbell (1) in rats using a sporadic conditional stimulus. Such an assumption is further supported by our observations of sniffing which was very similar to the same phenomenon described by Clarke and Trowill (3) in rats. According to these authors sniffing may be regarded as an index of motivation in self-rewarding behavior. Our dogs defined as “optimal self-stimulators” exhibited intense sniffing just as they were introduced into the experimental room. Sniffing also preceded bouts of presses and was evident at the beginning of extinction.

A high resistance of the response to extinction in “optimal self-stimulators” permits one to claim the concept of a rapid decay of drive after the last reinforcement (7) is not applicable to these dogs. Neither was the decay of drive evident when the manipulandum had been withdrawn prior to the beginning of extinction (see Fig. 3C). On the other hand, extinction was immediate when the stimulated site had ambivalent properties from a motivational point of view. This finding is consistent with the observation of Wasden, Reid and Porter (22) in rats that overnight decrements in performance of self-stimulation are due to stimulating ambivalent sites and, that such decrement is absent when a purely rewarding area is stimulated. According to these authors a conflict resulting from a concomitant reward and punishment may be the reason for more rapid extinction.

On the basis of direct observation of behavior in dogs one might suspect that the drive underlying self-stimulation possesses some patterns of alimentary and/or perhaps sexual motivation. A strong negative at-
titude of four dogs toward food in the course of self-stimulation needs more detailed discussion. It should not be regarded as a kind of aversive effect, because two of these animals were classified as “optimal” and one as a “good self-stimulator” and only in the fourth one was a clear approach-avoidance conflict evident. Our observation is contradictory to the data reported in the literature. Hoebel and Teitelbaum (6) and Margules and Olds (10) postulated identity of self-rewarding points and those increasing feeding behavior upon stimulation. Similarly Fonberg (4, 5) found in dogs that food reinforcement in instrumental conditioning could be successfully replaced by electric stimulation of the lateral hypotalamus. Stimulation of the same area in the presence of food induced eating in previously satiated animals. This discrepancy may be understood in the light of recent investigations in which minute probes and extremely weak currents were used to stimulate the rat’s hypotalamus (12). The three effects, i.e. self-stimulation, induction of hunger (or thirst) drive and disruption of consummatory responses may be dissociated with this procedure. It can be thus admitted that the difference between our results and those reported in the literature may depend on location of electrodes and/or some peculiarities of the stimulation technique.

Food rejection and ejection may be regarded as phenomena of satiation, which could provide a motivational basis for self-stimulation. In terms of Konorski’s (8) theory they might appear in response to excitation of hypothetical off-units within the alimentary center. Furthermore, a subsequent activation of on-units could be responsible for an increase of drive after termination of the stimulus. More data are needed to prove this suggestion. Robinson and Mishkin (16) demonstrated in a thorough study on monkeys that negativism toward food may be produced by stimulating different points within a widespread area of the basal forebrain, not necessarily limited to the classical satiety center in the ventromedial hypotalamus.

The hyperthermic effect which is consistent with the data obtained in rats (2) may depend on two factors. The first one appeared clearly in our study. It consisted of closing the mouth and slowing of respiratory movements when the current was on. This necessarily affected the heat loss mechanism which in dogs involves evaporation from the surface of the tongue and the upper respiratory pathways. The other factor may be an increased production of heat in the body. Such assumption is justified by the results of neuroendocrinological studies on rats (14, 18, 21) and monkeys (11) demonstrating an elevated corticosteroid and catecholamine output during self-stimulation. The increased body temperature may secondarily affect the drive and pattern of self-stimulation in a given animal.
The anatomical distribution of loci belonging to the "reward system" corresponds in its general features to the area depicted by Olds and Olds (13) for rats. It is worth noting that one electrode track was identified in the internal capsule. This finding is similar to the same observation made by Routtenberg, Gardner and Huang (17) in monkeys.

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REFERENCES

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