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ANNUAL REPORT

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Open Field Control of Dog Behavior by Remote Brain Stimulation

Contract # DA-49-193-MD-2288

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ABSTRACT

1. Preparing Institution: University of Maryland

2. Title of Report: Open field control of dog behavior by remote brain stimulation.

3. Principal Investigator: Stanley S. Pliskoff, Ph.D.

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This report is concerned with the development of two systems whereby the behavior of a dog may be controlled by remote electrical stimulation of certain brain structures. The first system employs multiple electrodes with control by elicited responses, i.e., for example, stimulation at one electrode site produces forced turning while stimulation at another electrode site produces walking or running.

The second system involves a single electrode implanted in a subcortical area at which electrical stimulation has behavioral reward properties. Stimulation at that site produces forward progression which can be "shaped". By employing the rewarding stimulation both to encourage progression and to differentially reward faster and faster progression, the dog can be trained to follow a "beam" of stimulation from any point in the open field to any other point. This system is versatile in the sense that the experimenter exerting control over the dog's behavior can at will redirect the dog to a target area different from the initial one. At present, the system is limited to line of sight control.

ANNUAL REPORT

I. Aims

The basic aim of contract # DA-49-193-MD-2288 is to examine the feasability of distance control over the behavior of a "free roaming" dog. Specifically, we are concerned with the problem of developing a procedure whereby a dog can be guided, through the use of electrical stimulation of the brain, from any arbitrary point in an open field to any other arbitrary point in that field. Stimulation is to be delivered to the dog by means of a portable stimulator-receiver unit on the dog which is controlled by a distant transmitter.

II. The Final Solution to Some Persistent Problems

Our previous annual report identified some problems, along with some solutions. A few of the problems proved to be illusory; solutions to some of the others were inadequate. We will very briefly review the present status of our work in terms of those problems.

A. The technique of mounting the electrode to the dog's skull, in conjunction with the cap designed to protect the entire assembly, has been abandoned. We experienced several instances of the electrodes being damaged or even torn loose while the dog was in his home cage. While the plastic cap served to prevent damage in the field, continuous use of the cap in the home cage was not practical because of the interference with the dog's normal movements. In addition, we had difficulty with infection around the electrode site, since the skin would not heal. While antibiotics were routinely used to control infection, oozing fluids would on occasion short the electrodes.

The system was abandoned and replaced with another that has proved to be entirely adequate. The electrode is implanted and the wires just below the pedestal are bent at a 90° angle so that the pedestal lies along the skull. The connector is secured to the pedestal, and the whole assembly is covered with dental cement. The skin is then drawn over the hardened cement and the incision is closed. Since the electrode is encased in cement, it is protected from shorting; since the incision is closed, healing occurs, and the possibility of infection is averted. The connector leads are passed subcutaneously along the dog's neck and brought out between the shoulder blades where they are fastened to a permanent dog harness. The entire system has proven to be quite satisfactory.

B. The social tendencies of the dog in general, and the response of the Beagle to punishment in particular, has not proven to be a problem of any consequence.

C. The electrode placement has continued to be reliable in providing positive reward effects upon stimulation. The coordinates (stereotaxic atlas by Lim, Liu, and Moffitt) are AP 20, L 2-2.5, V 7-8.

D. The portable stimulator-receiver unit and transmitter designed and built for us by HDL (formerly: DOFL) has been abandoned. As suspected previously, the units were never in satisfactory operating condition.

In order to obtain the necessary equipment, we contacted a local organization, Lewis Associates, Inc. of Bethesda, Maryland, representing Gulton Medical Instruments, Willow Grove, Pennsylvania. The unit was designed in accordance with our specifications. The stimulator output was a 100 cps sine wave, with adjustable peak-to-peak voltage, the maximum being 18 V. After delivery, a malfunction developed, and the unit was returned to the manufacturer. The malfunction was corrected, and, at the same time, the power output was increased to 50 V, peak-to-peak. The unit is presently functioning well, and it represents our first usable device.

E. In our previous report, we stated: "Since the control of behavior can be resolved in large measure to the problem of stimulus control, we are undertaking a series of stimulus generalization and discrimination studies,..." That work, predicated on the assumption that free field control of the dog's behavior would involve a series of stimulus commands, each cuing a response such as walking, stopping, turning, etc., was begun. The setting for that work was standard dog chambers fitted with paw-press manipulanda.

III. Research and Accomplishments

A. Simultaneous with the work on stimulus control in the dog, we began to explore a different procedure for guiding the free roaming organism. Instead of discrete stimuli (such as tone, clicker, quiet) exerting control over discrete responses (such as stop and stand, turn, walk) we conceived of a "homing beam" technique in which a given clicker frequency was correlated with the experimenter-chosen tracking path. Deviation from the path by the dog would result in a change in clicker frequency. The dog would then have to return to the path by altering direction of locomotion so as to reinstate the true-path clicker frequency. The correlation between the administration of rewarding brain stimulation and the series of clicker frequencies was open to conjecture, and the best solution was to be empirically determined. We began by constructing a rat analogue to the homing beam system.

B. An open field, approximately 8 x 4 feet, was constructed. An overhead pulley and spring system was devised so that electrode leads could be attached to a rat while permitting him free access to all parts of the field. A speaker, by means of which several clicker frequencies could be presented to the rat, was installed over the open field. A target consisting of concentric rings and a bull's eye was projected onto a mirror in which the experimenter could see the open field. Each ring of the target was correlated with a preset clicker frequency, lowest in the outermost ring and highest in the bull's eye. As a first approximation to a correlation between performance in the open field and rewarding brain stimulation, we arranged for bursts of rewarding stimulation to be delivered to the rat at the same frequency as the clicker. Thus, if the rat were located, say, in a ring which was identified by a clicker frequency of one per sec, then it would receive one burst per sec of stimulation. The outermost ring produced a clicker and stimulation frequency of one per 2.5 sec. Beyond that ring, the frequency was zero. In order to obtain a more favorable frequency of stimulation, the rat had to find the direction along which locomotion would bring him closer to the experimenter's bull's eye. The target, and, hence, the location of the bull's eye could be changed from trial to trial.

During the course of training a rat in this situation, we manipulated some of the parameters of stimulation in order to explore their effects. We discovered that by setting each burst at about 200 msec and providing for a frequency of three bursts per sec, an intensity of stimulation could be found for each rat that would produce forward progression. When the stimulation was turned off, progression ceased. The rat would then move his head from side to side in what we would characterize as "seeking" behavior. When the stimulation was turned on again, progression would begin anew in the direction in which the rat's head was pointing at the onset of stimulation. Thus, the clicker was disconnected, and we developed the new technique. With each rat that we tested, all of which had positively rewarding electrodes, we were able to guide the rat from any point in the open field to any other by the procedure which will now be stated explicitly:

1. In the absence of stimulation, the rat stands still and moves his head (and, sometimes, the forward part of his body) from side to side "seeking" the direction.

2. When the rat is facing in the direction of the target point in the open field, the stimulation is turned on and delivered in the form of 200 msec trains, three such trains per sec. The invariable response of the rat is to locomote in the direction in which it was facing when stimulation was turned on.

3. If, during the course of locomotion, the rat strays from the path, or if the direction was not precisely on target, the stimulation is turned off, and step 2 is

repeated, followed, if necessary, by step 3.

The next step was to determine if the rat could be guided over obstacles in the field. The field was divided into nine areas by lengths of 2 x 2 wood placed on the floor. There were no difficulties encountered, and guidance was positive. Finally, the barriers were removed, and the field was flooded with water to a depth of 6 in. maximum. A platform was installed in one corner of the field. By the use of the above procedure, it was possible to move the rat off the platform and "swim" it to any point in the field. The control over swimming is important in two respects:

1. Swimming is not a "rat-like" behavior. Thus, the field control exerted by positively reinforcing brain stimulation is adequate to maintain behavior unusual for the species.
2. Swimming involves movements different from running. Thus, the progression obtained on a dry surface cannot be considered to be elicited muscle movements. It appears to be, rather, a genuine "approach' behavior under the control of a positive reinforcer. The word approach is in quotes, since the reinforcer is not "out there" but the animal behaves as though it were.

C. We applied the procedure developed with rats to our dogs. Because our distance stimulator was still being manufactured, it was necessary to employ a "direct line" arrangement. With that imposed restriction, we constructed a fenced area, about 15 x [illegible] feet, in the field adjoining the laboratory. An overhead system permitted direct connection of a dog's electrodes with a stimulator inside the laboratory. Stimulation was delivered to the dog by the experimenter who occupied a place alongside the enclosure. Two important results were obtained with this procedure:

1. Employing a dog with a single, positive reinforcing electrode, we observed "approach" behavior on stimulation. This dog, Sam, did not, however, move as rapidly as our rats did. Rather, halting paw extensions were the rule. By judiciously applying brief (0.5 sec) trains of stimulation, it was possible to move Sam from one point in the field to another. Progression was characterized, however, by partial paw movements and step by part step walking.

Once received, the portable stimulator was substituted for "direct line". All work since then employing positively rewarding electrodes has been done with the portable stimulator-receiver and transmitter units. Sam was trained in the fenced enclosure to increase his speed of locomotion. This was accomplished by varying the parameters of stimulation (intensity of the 100 cps sine wave, train duration per stimulation and frequency of stimulation). Intensity and frequency were found to be quite critical. Too high an intensity produced a "disorganized" response consisting mainly of a backing movement. At the proper intensity (800 microamperes), Sam moved forward on stimulation. Frequency, or how often stimulation was delivered to the dog, was an essential variable in overcoming the hesitant, step by step progression. Stimulating the dog less often increased the rate of locomotion.

2. Employing dogs with several electrodes implanted per dog, some aimed at positive reinforcement sites and others aimed at negative (or aversive) reinforcement sites, in conjunction with "direct line" connection to the stimulators, we devised a second method of control. This method cannot be used with our portable stimulator inasmuch as more than a single channel of stimulation is required. In addition, somewhat higher intensities of stimulation are required for this method than is available with the portable stimulator.

This second method involves elicited responses. Some, but not all dogs with several electrodes have a combination of electrodes such that by stimulating through them in an appropriate sequence, the dog may be moved from any point in the field to any other point in the field. The responses produced by stimulation are such as head and torso turning, running, stopping, etc. These responses to stimulation, in contrast to those produced by lower level stimulation through a rewarding electrode, have the character of involuntary, reflexive behavior. Some are difficult to characterize, however; running sometimes seems to be escape behavior, perhaps voluntary.

D. A comparison of the two methods may be made as follows:

1. The single, positive electrode is a one-electrode system, whereas the elicited behavior technique requires more than one electrode.
2. Lower levels of stimulation can be used with the positive electrode system. It may be possible to reduce the required level of stimulation for the multiple electrode system by using other electrode placements.
3. The human observer would characterize the behaviors obtained with the two systems in very different terms. The system employing a single, positive electrode produces "voluntary" behavior of a tracking sort. The animal literally keeps his nose to the ground as though sniffing out the reward. The system employing multiple electrodes often produces "involuntary" behavior reflexive head turning and, sometimes, backing up are examples In the former system, the animal seems drawn forward; in the latter, pushed forward.
4. The single electrod , positive reward system seems to produce a greater homogeneity in the final performance than the multiple electrode technique. In the several

dogs trained with either of the two techniques, the dogs with the single electrode are virtually identical in their tracking performances. With the multiple electrode technique, the several dogs are remarkably different inasmuch as different reflexive responses are used to move and guide the dogs.

5. To date, the second method employing reflex elicitation, moves the dog from the starting to the finish point in less time. Whether or not the second method can be improved in this respect is an experimental question.

E. The single, positively rewarding electrode system has been used in the large, open field. After initial adaptation to and training in the procedure, the dogs have been permitted to track in a large open space. The experimenter stands near the transmitter with the operate switch in his hand. The dog is placed in the field with the portable stimulator-receiver on his back. The experimenter then chooses some arbitrary point in the field as his target point. By stimulating the dog with short bursts, locomotion is produced. If the dog deviates from the desired path, stimulation is stopped until the dog is facing the target point, at which time stimulation is recommenced. We have been able to move S_s from any point in the field, through a predetermined path, to any other point in the field. The predetermined path may be on a direct line or a zig-zag with intermediate subtargets.

A second dog, Leroy, has received the same training as Sam and has also been tested in the large, open field. We have obtained the same results. Leroy will track from any given point in the field to any other point in the field. Control is positive, and the topography of his behavior, as indicated above, is very close to that of Sam. A third dog, Hubie, is finishing the preliminary stages of training in the small enclocure, and his performance to date indicates that he will perform essentially as do Sam and Leroy. A fourth dog, Runt, is beginning preliminary training in the fenced area.

F. Data

Until now, we have been concerned with qualitative considerations. Our successes and failures have been measured in terms of clear Yes and No answers to straightforward questions. With the development of the control system, and the success in its use, we are devising a quantitative system in order to evaluate performance among the several dogs and the results of the manipulation of technique parameters within the single dog. A quantitative technique, even one as crude as running time in feet per second from starting point to finishing point, would permit finer discriminations among the performances of our dogs than we have been called upon to make until now.

The research described above has been documented by means of photographs and moving pictures. Those data will be included in our final report.

IV. Summary and Conclusions

This report describes the development of two techniques for the control of dog behavior in the field through the use of remotely controlled brain stimulation. The first stage of the research focused on the development of open field behavior control with a lower and experimentally more convenient organism, the rat. Several early methods for the control of movement in the rat, using auditory stimuli as cues for correct and incorrect movements in the field, were unpromising. However, we discovered that at certain intensities and frequencies of brain stimulation "automatic walking" occurred. This walking behavior was shown to be other than simple reflexive or elicited walking, since the animals would climb over barriers or swim through water during the application of brain stimulation. By judicious application of the brain stimulation, movement from one point in the field to any other point was rapidly achieved.

Using the techniques developed with the rats, we turned our efforts toward the control of dog behavior in the field. Two methods were developed. The first method (using direct line stimulation) involves alternate stimulation of two electrode sites. Stimulation of each electrode produces an elicited motor effect, e.g., turning of the body or forward movement. By selectively stimulating one electrode or the other, producing turning movements or forward movement, we are able to move the dogs from one point in the field to any other. The development of the second method coincided with the delivery of our first usable distance stimulator. (Operation of a transmitter triggers a small stimulator carried by the dog in the field.) In this method, we use the positive rewarding effects of brain stimulation. A single electrode in this case is aimed at the median forebrain bundle. When the animal walks in the correct direction (toward the target) rewarding brain stimulation is given. When the animal walks in the wrong direction (away from the target) brain stimulation is withheld. By careful delivery or withholding of brain stimulation, delivered remotely, we can control the movement of the dog from one point in the open field to another. We are currently working on the development of quantitative methods for measurement of performance in the field. This will permit us to compare the effectiveness of different electrode sites and different training methods.

These results demonstrate the feasibility of controlling the movement of dogs in an open field by the use of remotely controlled brain stimulation. Future work might center about 1) the development of control methods where the animal is out of the line of sight of the experimenter; 2) the development of a repertoire of behaviors in addition to walking; for example, fighting, digging, vocalization, etc., with each separate behavior under the control of the experimenter by means of remotely controlled brain stimulation.

Some applications of the methods of control demonstrated here can be suggested: 1) inspection of areas dangerous to man; 2) rescue work, where an animal carrying supplies can be guided to survivors in inaccessible or dangerous areas; 3) with the development of microminiaturized equipment that can be buried beneath the skin or in the body cavities, dogs carrying microphones, radiation detectors, or other electronic sensors, might be used for certain limited types of reconnaissance; 4) carrying exposed TV cameras these animals might be used for surveillance of forward combat areas, or detection of ambush, etc.

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