28 September 1967

Dear Dr.

While I'm not entirely settled in as yet, and am currently losing a stiff fight with a heavy cold, I am in residence, and we might plan another conversation so as to firm up our interests.

As you know, I spent about three years working in the research area of rewarding electrical stimulation of the brain - the "Olds effect," as it has sometimes been called. The work that we did involved both basic and applied aspects. In the laboratory, we performed a number of experiments with rats; in the open field, we employed dogs of several breeds. The culmination of our work was several publications that elucidated the nature of brain-stimulation reward, in addition to a demonstrated procedure for controlling the free-field behaviors of an unrestrained dog. Behavioral control was limited to distances of 100 to 200 yards, at most. Both kinds of work were described in detail in the final report for that project (Contract which, I believe, you have in your possession.

It was clear to me on the basis of our earlier talk that some of the work that we did was closely related to your current interests, although I must confess that that conversation was sufficiently non-directive that I came away with no clear idea of your precise research needs at the moment. Accordingly, the following are some thoughts regarding what we might be able to do.

We could establish an "under the roof" laboratory that would be equipped to study the basic parameters of the control procedure using a small animal such as the rat. I have in mind the construction of a sizable enclosure, a miniature representation of an open terrain. Basic experiments can be performed in that setting, once the job (and I think that it might be a difficult one) of objectifying the recording of the open field behavior is accomplished. An interesting possibility would be the development of an automated control procedure, i.e., instead of guiding the animal continuously by hand from point A to point B, the animal is guided by means of an automatic direction system. I can't imagine how this system might work, however. It does seem to be primarily an engineering task, rather than a problem in behavioral research.

On the other hand, you might be more immediately concerned with more practical matters and wish to forego problems in basic research, i.e., rat work. Work in the open field could employ a range of species; we've used dogs before, but I think that the same procedures could be employed with other species. A problem arises in that electrode implantation may be difficult if adequate atlases are unavailable. I don't know offhand the species for which stereotaxic atlases are available. Clearly the automatic guidance system that I mentioned above would be useful here. Again, I think that the problem is an engineering problem, since I can already specify the behavioral requirements of the system, but I can't specify the hardware.

There are behavioral problems that can be researched, however. If a small animal is to move from point A to point B, automatically controlled or under constant control by a human, what problems of competing rewards do we face? How easily is the animal distracted and by what? If control is lost, how may it be reestablished?

One of the problems with working with dogs is the absence of a suitable open field near, does own about 75 acres in and a facility, perhaps including surgery and laboratory, could be established for the purpose. It's likely to be expensive, however.

I really don't know what else to say at this point, which is why it's been so difficult to get this letter written. If you can suggest specifically the kinds of problems that interest you, perhaps I can be more constructive. I'll be looking forward to seeing you on 10 October.

Sincerely,

C00021825

Final Report

1 July 1962 - 30 Sept 1965

Remote Control of Behavior
with Rewarding Electrical
Stimulation of the Brain

Contract

Unclassified

C00021825

ABSTRACT

1.

2. Title of Report: Remote control of behavior with rewarding electrical stimulation of the brain.

3. Principal Investigator:

4. 69 pages, 8 figures, 30 September 1965.

5. Contract number:

6. Supported by:

This is a final report, and the results of our work are summarized. The specific aim of the research program was to examine the feasibility of controlling the behavior of a dog, in an open field, by means of remotely triggered electrical stimulation of the brain. The report describes such a system which depends for its effectiveness on two properties of electrical stimulation delivered to certain deep lying structures of the dog brain: the well-known reward effect, and a tendency for such stimulation to initiate and maintain locomotion in a direction which is accompanied by the continued delivery of stimulation. Experiments on the parameters of stimulation are described, in addition to an experiment on the ability of a conventional reinforcer, food, to disrupt ongoing, free field behavior under the control of rewarding brain stimulation. Finally, supporting research employing albino rats is summarized.

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FINAL REPORT

I. Aims

The aims of our work over the past three years were specific with respect to some research problems and general with respect to others.

A. Specific

Since 1954, it has been known that electrical stimulation of certain deep lying structures in the brain could serve as an instrumental reinforcer, i.e., a reward in the sense that an organism would perform some specific behavior which produced or was followed by such stimulation. It was known, further, that the effect could be obtained in several species of laboratory animal: rat, cat, monkey, guinea pig. Research work centered on determining specific loci and systems in the brain which produced reward effects upon stimulation; determining interactions among systems, particularly those maintaining rewarded and escape behaviors; developing an integrated, conceptual account of many findings on rewarding electrical stimulation of the brain.

It is not difficult to conceive of some practical applications of reinforcing brain stimulation. The work undertaken in these laboratories was concerned with the exploration and development of one such application, i.e., the control of open field behavior by rewarding brain stimulation triggered from a point remote from the behaving organism. The experimental animal chosen for this work was the dog, and that choice dictated some of the specific problems investigated during the course of our work.

1. A stereotaxic atlas of the dog brain was available and an electrode placement providing reliable reward effects upon stimulation had to be located.

2. A small, portable stimulator which could be attached to a dog harness and connected to its electrodes was needed. The stimulator had to be reliable and capable of sufficient voltage output to be usable in the face of expected impedance variation across individual dogs.

3. The precise method of controlling open field behavior had to be determined. The control of free-field behavior may be conceptualized, in general, as moving the dog from one arbitrary point in the field to any other arbitrary point. There are potentially a number of procedures whereby this may be accomplished, ranging from the stimulus control of discrete movements to "homing on a beam."

4. Given solutions to the above questions, the parameters of the control technique should be explored. The degree of distractability of a dog actively under control is a question of importance with regard to any potential application of the control system.

B. General

Subsidiary to the specific aims of the contract research, we undertook to explore some general questions regarding the nature of rewarding electrical stimulation of the brain. Much of this research was performed with the albino rat as the experimental subject.

1. There have been suggestions in the research literature that brain stimulation as a reinforcer may have properties different from conventional reinforcers such as food and water. We undertook to explore this question, with particular emphasis on the ability of rewarding brain stimulation to maintain in strength performances of an order of complexity equal to those maintained by conventional reinforcers. A satisfactory solution to this problem had relevance to the field work with the dog.

2. Experiments reported in the literature which deal with comparisons between rewarding brain stimulation and the conventional reinforcers are, in our opinion, unsatisfactory in that the baseline performances for the two reinforcers have not been equated. We undertook to develop an experimental procedure which would permit not only the equation of the performances maintained by the two reinforcers, but also permit an inequality defined and controlled by the experimenter.

II. Facilities

The several phases of the contract work were housed in a new research building The building, 3000 sq. ft. under the roof, provided office space, an electronics shop, rooms for programming equipment, separate rooms for experimental animal chambers, animal holding facilities for several species, and a surgery. Histology facilities, maintained in another building, were provided were generously available to us. Machine shop facilities were also available.

Finally, our main laboratory building was located in a relatively secluded area on a fenced plot of land one acre in size. Those accomodations permitted the private conduct of field work. The above facilities became available in the early summer of 1963.

III. Research Activities

The research activities undertaken during the term of the contract may be divided conveniently into: research directly related to the specific goals of the contract, and supporting research. Substantial portions of both research efforts have been described in detail in previous reports. When it is necessary to refer to those aspects of our work, we will do so briefly and reference the previous report in which details may be found.

A. Work Related to Specific Goals of the Contract.

1. Electrode placement in the dog.

The work on electrode placement began when we entered the new research building that was provided Initial electrode placements that we examined proved to be unsatisfactory in that lever pressing could not be maintained in a lever-press dog box. The difficulties encountered were described in our report

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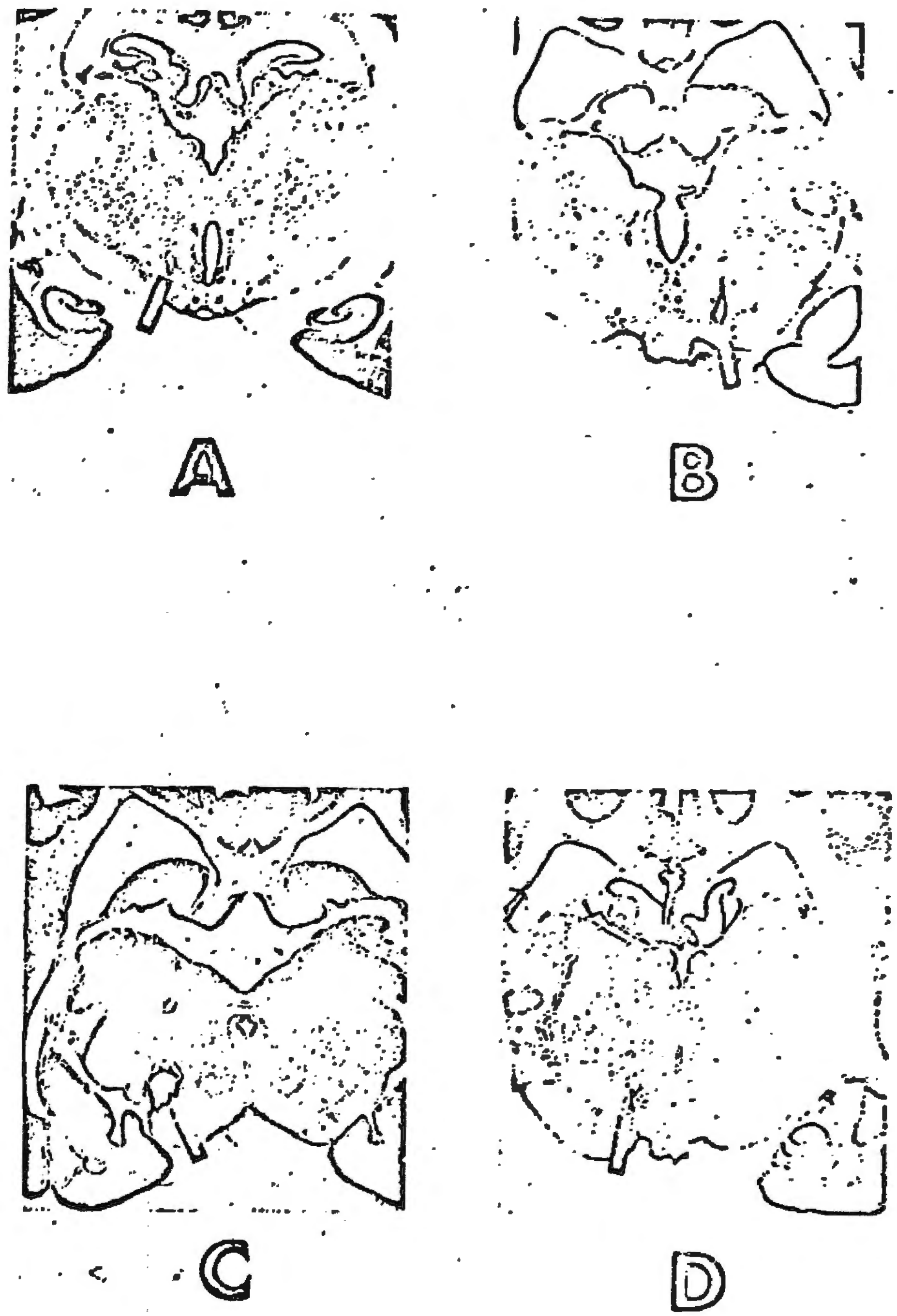
of 1 January 1964. In addition, it became apparent at that time that the electrode preparation itself offered some special problems with a dog that are not ordinarily faced with the rat as an experimental subject. Those problems were (a) protecting the electrode from damage, and (b) infection at the electrode site due to a failure of the surgical wound to heal. The plastic helmet that was devised to protect the electrode from damage was described in our report of 1 January 1964. A better technique that we developed involves embedding the electrode entirely within a mound of dental cement on the skull and running the leads subcutaneously to a point between the shoulder blades of the dog where the leads are brought to the surface and affixed to a standard dog harness. The newest procedure was described in our report of 1 January 1965, and it continues to be perfectly satisfactory in terms of durability (measured in months) of the electrode assembly and protection from infection, since the skin is closed entirely over the electrode site.

The electrode placements that we have employed subsequent to our earliest attempts have been satisfactory, and we have complete confidence in our ability to surgically produce a dog that will show strong reward effects in a lever pressing box and in the field. Figure O shows brain sections obtained from several of those dogs. The heavy, dark markers locate the electrode tips. The medial mammillary

Figure 0

Sample histological sections showing typical electrode placements producing reward effects in the dog.

Fig. 0



bodies of the posterior hypothalamus are evident in sections B and D. Placements in that region are known to be among the best in producing reward effects in rats. In sections A, B, and D, the electrode tips are in the Campi Foreli; in section C, the Medial Lemniscus, lateral to the Red Nucleus.

The substantial response rates in the lever-press box obtained with stimulation in the regions just defined was stated in our report of 1 January 1964. Subsequent to that report, we have performed experiments in which lever pressing could be maintained on schedules of intermittent reward in the dog. Fixed ratios in excess of 100 responses per reward were easily obtained.

2. The portable stimulator emerged as a major problem. We attempted construction of a small, remotely triggered stimulator in our own laboratory-- problems of minia-turization were soon encountered, and the engineering problem was undertaken by the [redacted] Their instrument was delivered in October, 1963, but it never functioned satisfactorily. A series of reports, written by [redacted] described the history of our relationship [redacted] and the performance of the stimulator. The reports were submitted to the [redacted] for information purposes. As described in our report of 1 January 1965, we turned to [redacted]

for the commercial development of the portable, remote controlled receiver-stimulator and transmitter units. Through a local representative of [redacted] the unit was designed, completed, and delivered to us early in 1964. Some modification to the basic instrument was necessary, and subsequent to those modifications, the unit has performed in a completely satisfactory manner. In terms of size, it is easily attached to an ordinary dog harness; in terms of weight, there is no interference with the dog's normal gait. The unit delivers a 100 cps sine-wave at an adjustable voltage, maximum: 50v peak-to-peak.

3. Prior to the delivery of the portable stimulator, we undertook field work employing a "direct-line" system, i.e., the dog was connected to a stimulator, located in the laboratory, by means of a cable suspended over a small, fenced enclosure. Our report of 1 January 1965 described the research. In summary, we developed two techniques for the control of a dog's behavior in the small enclosure. The first involved the <u>elicitation</u> of movements such as running, turning, stopping, etc. When produced in an appropriate sequence, a dog could be moved from one point in the enclosure to another. There are several disadvantages to the "elicited-behavior" method-- several electrodes, each producing one of the required movements, are necessary in each dog. Although implanting the several electrodes is no

special problem, one is never certain which elicited movements will be obtained from each of the electrodes until stimulation is attempted. Thus, there may not be a suitable combination of movements in a particular dog. Secondly, the stimulation intensities required to produce elicited movements are relatively high-- higher than we can obtain from our portable stimulator. The second method of control, also described in the 1 January 1965 report, involves rewarding electrical stimulation only. This system employs a single electrode, the tips of which are located in rewarding brain areas such as shown in Fig 0, and relatively lower intensities of stimulation. The intensities required are within the output capabilities of our stimulator. A comparison of the two methods was presented in our report of 1 January 1965.

We have not explored further the elicited control method; we have concentrated our field research efforts on the reward method. The results have been entirely satisfactory. Our 1 January 1965 report described field control with three dogs; the fourth dog was undergoing preliminary training. Since then, that fourth dog in addition to a fifth and a sixth have been trained to track in a free field under the control of remotely triggered, rewarding electrical stimulation of the brain. In addition, several parametric studies have been undertaken with those dogs in order to explore the control process. A striking result of our work has been the relative ease with which a dog may be trained to respond in the open field. The several steps in the procedure are as follows:

a) Following implantation under Nembutal anesthesia, the dog is provided with post-operative care in order to insure recovery.

b) After recovery, the electrode placement is tested for the result of stimulation. We have dispensed with testing in a dog box (using a lever press as the behavior) and we presently test by observing the free behavior of the dog in the small, fenced enclosure. The direct line arrangement employing a stimulator in the laboratory and the overhead connector is employed in these tests.

The effects of stimulation are assessed by observing the movements of the dog when stimulated. With the appropriate electrode placement, there is a clear tendency for the animal to repeat any movement which is immediately followed by stimulation-- the well known reinforcement or reward effect. Thus, if the dog is moving forward and that behavior is accompanied by stimulation, the dog will continue to move forward. A second important feature of stimulation is the strong tendency to initiate locomotion in the direction in which the dog's head is oriented. In fact, this latter feature is the key to the procedure. Thus, if the dog's head is turned to the left with respect to the rest of his body, the dog will begin moving to the left upon the commencement of stimulation. This tendency permits directional control over the dog's position in the field. The two tendencies mentioned, reward and locomotion, are maximized by varying the intensity of the 100 cps sine-wave stimulation. The intensity which, in the judgement of the experimenter, provides the best results is chosen for a given dog.

c) Following the above determinations, the dog, equipped with the portable stimulator, is shifted to the open field situation. This phase of the training technique is difficult to describe in words-- its aim is to obtain precise, directionally controlled movement (i.e., tracking) in the field. Because of the necessity of adjusting the details of the procedure to each individual dog, the overall technique may be poorly susceptible to complete automation. Given that a particular dog is appropriately implanted, and the intensity of stimulation has been found which maximizes forward locomotion and the reward effect, the precise relationship between the dog's fine behavior and the delivery of stimulation becomes critical.

With judicious application of stimulation by the experimenter, movement in a particular direction can be initiated when the dog's head is oriented in that direction. Once the movement is initiated, it can be maintained by intermittent stimulation which serves to reinforce moving in that direction. If the experimenter wishes to change the direction of movement at a particular point in the field, stimulation is withheld when the dog reaches that point. Very early in training, the dog learns that stimulation will be continued only if he orients in a new direction. Thus, when stimulation is terminated by the experimenter, the dog moves in small circles. When the dog's head is pointed in the appropriate direction, stimulation is again delivered and movement in the new direction is initiated.

A similar procedure is followed if the dog veers from the desired direction. The experimenter discontinues stimulation; the animal begins circling until stimulation is again delivered. He then moves forward in the direction in which he was oriented at the time stimulation recommenced, and intermittent stimulation is continued until the dog veers from the correct direction or until the experimenter wishes to change the direction of locomotion.

The individuality of each dog is expressed in the answers to such questions as:

i. Should each stimulation delivered to the dog be of fixed duration, or does variable duration provide better results?

ii. Are rapid bursts of stimulation better in that locomotion is thereby facilitated, or will rapid stimulation produce locomotion and then recoil?

iii. What are the particular behavioral signs which indicate that control is being lost, and how is control reestablished?

iv. What kinds of behaviors are more easily controlled with a particular dog? For example, will he traverse a water puddle, tall grass, etc., or should those geographies be circumvented?

We have found that the several dogs we have worked with are idiosyncratic with respect to each of the questions that must be answered. Once answers are obtained, however, field control becomes a relatively easy matter. It would be difficult to overemphasize the importance of a behaviorally sophisticated and competent person handling the dog during the early training and even during the final performance of controlled field behavior. General principles defining such sophistication cannot be given-- among research people, the phrase "feel for behavior" summarizes the requirement. [redacted] who has been with the principle investigator since the start of the work, has capably identified a number of the problems involved in the development of the procedure and has solved many of them himself.

While the above considerations strongly suggest that an automated procedure for training dogs to track in the open field is not promising, it must be emphasized that we have not explored the possibility at all-- our work has been concerned with the development of <u>some</u> procedure for obtaining remote control and an evaluation of its feasibility. It is conceivable, and even likely, that a common denominator across dogs can be established and a procedure developed which will provide for the automated training of the scout dogs.

d) When the experimenter is familiar with the idiosyncrasies of a particular dog, about one week's work, an hour to two hours per day, is sufficient to train the dog to track in the open field.

Two types of practice arrangements have been employed in our work:

i. General, open field patterns, with the precise pattern to be run predetermined by the experimenter.

ii. Patterns defined by a matrix of 15 stakes in the ground, 3 x 5 , each stake spaced 24 feet from another. This arrangement permitted running standard patterns for purposes of collecting quantitative data.

4. Figure 1 shows the stimulation equipment we employ in our field work. The units are those manufactured

Figure 1A shows the transmitter. The unit measures about 12 x 6 x 4 inches and is easily portable. The model shown, however, does need a power outlet; complete portability could be achieved by incorporating a battery

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Figure 1

The transmitter (Fig 1A) and receiver-stimulator units (Figs 1B and 1C). The latter are shown in place on the backs of experimental dogs.

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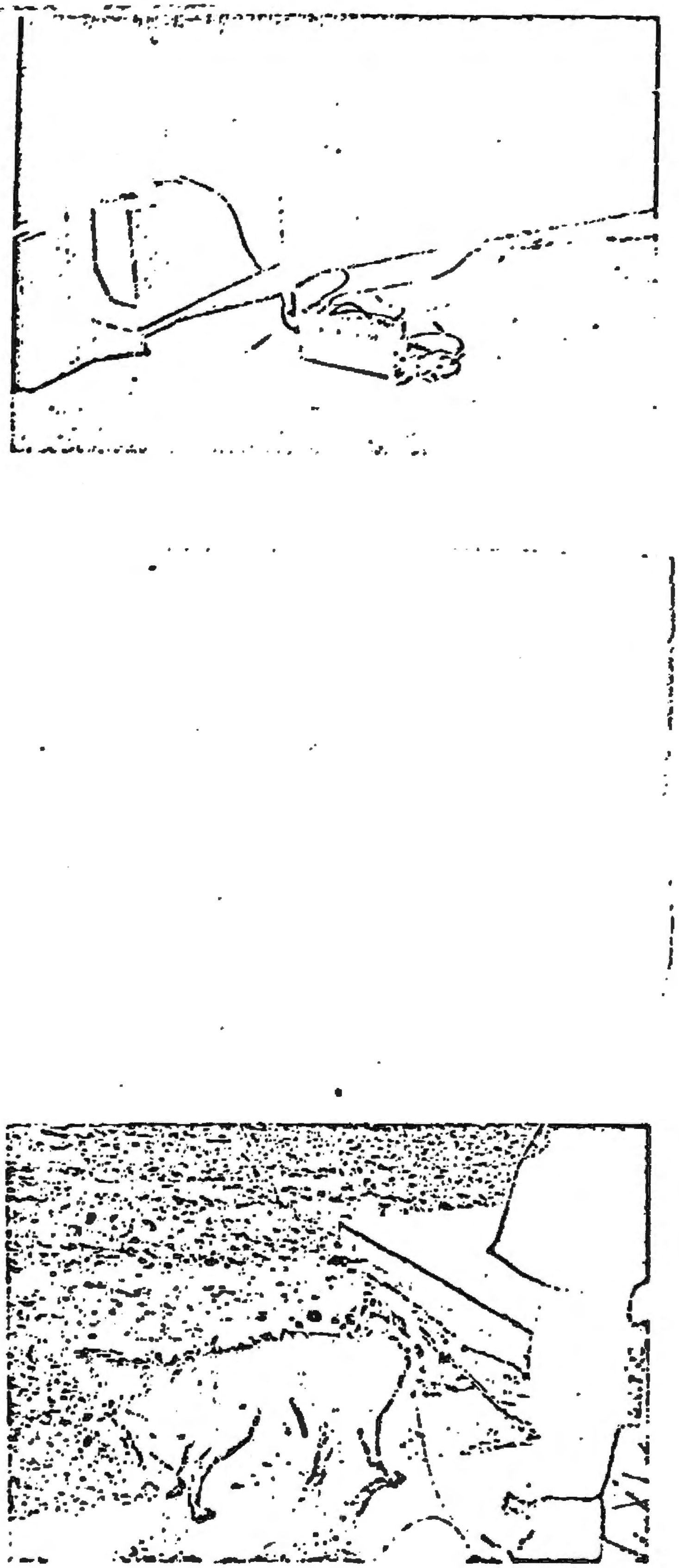
Fig 1



A

B

C

power supply. Figures 1B and 1C show the receiver-stimulator strapped to the backs of two dogs. The unit measures about 7 x 3 1/2 x 1 inches and weighs, including leads, connectors and small antennae, about one pound. Although some minor problems have arisen from time to time in the use of the transmitter and receiver-stimulator system, its performance has been, on the whole, quite satisfactory.

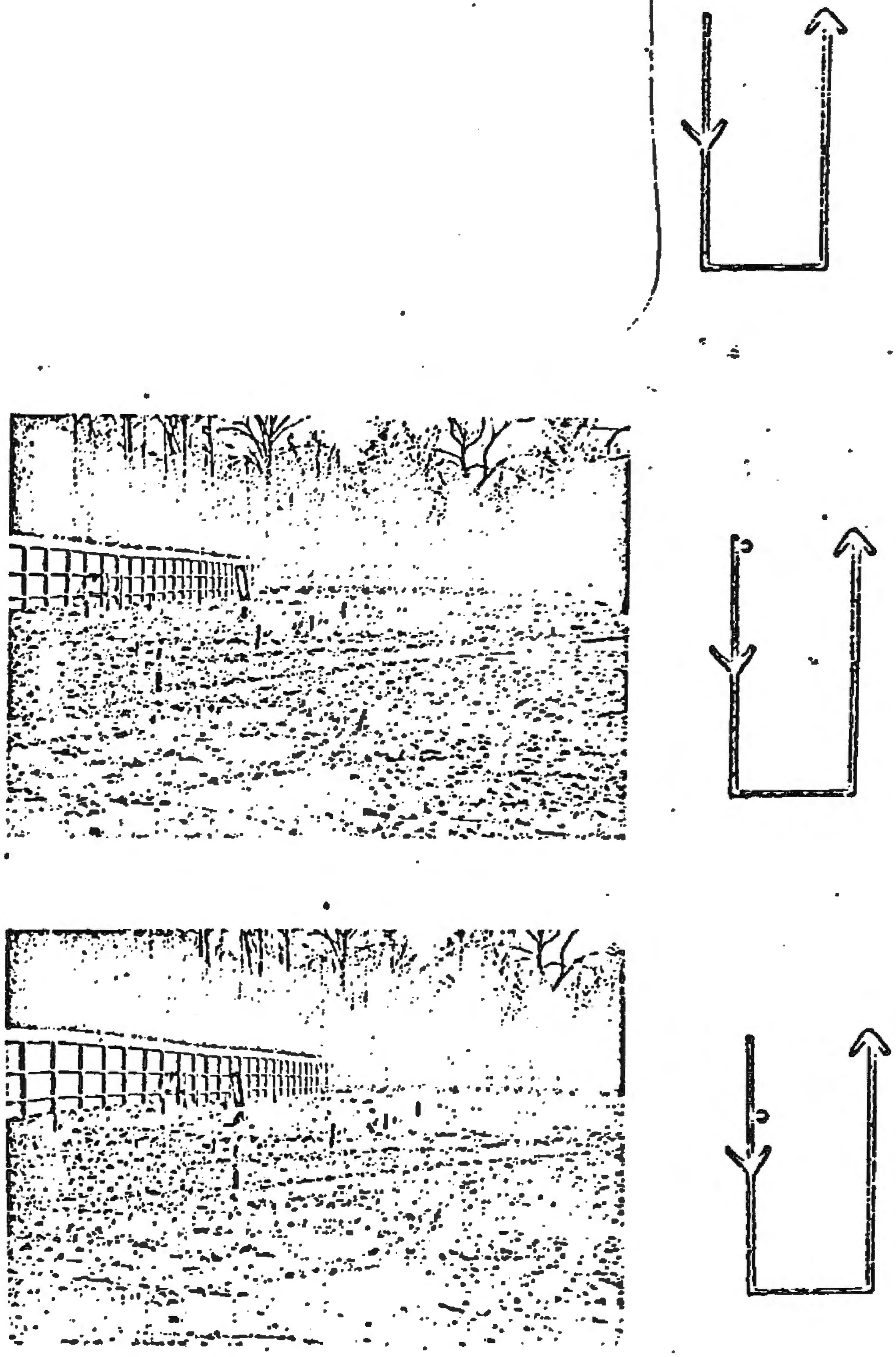
5. Figures 2 to 5 show the results of the field control procedure. Each of those figures consists of several plates with several 35 mm. photographs per plate. The first photograph in each of those figures shows the open field pattern through which the dog is to be guided. Alongside that photograph, and each of the others in the figure, the same pattern is reproduced. The arrows on the pattern indicate the direction of movement of the dog through the pattern. In addition, note that a round marker appears alongside the pattern adjacent to each photograph, except the first, in the figure. The dot indicates the general position of the dog at the time that photograph in the series was taken. For purposes of simplifying location of the dog, a black marker was affixed to each photograph. The dog is shown immediately below the marker. By following the progression of dots alongside the patterns adjacent to the photographs and relating that progression to the positions of the dog in the sequence of photographs, an appreciation of the action may be gained. The three figures, 2 through 5, show several patterns. Two dogs

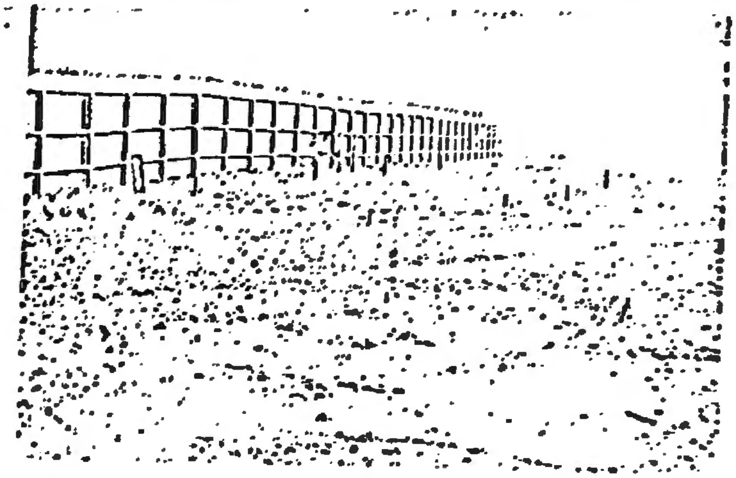
Figure 2

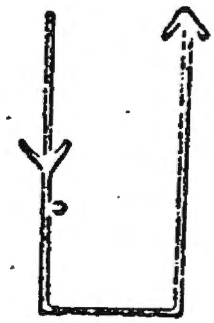
A sequence of photographs showing the control of open field behavior with a dog.

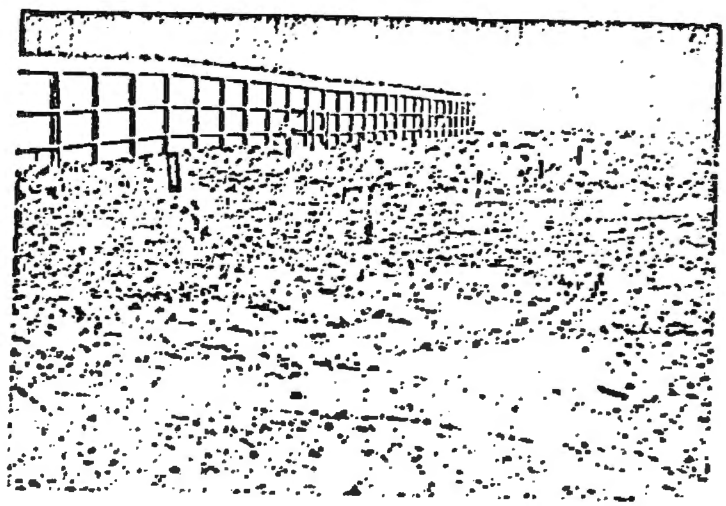
(See text for explanation of the several markers in each photograph.)

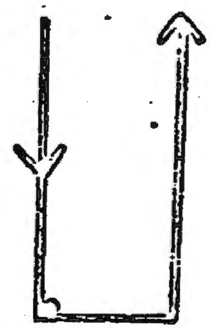
Fig 2-1

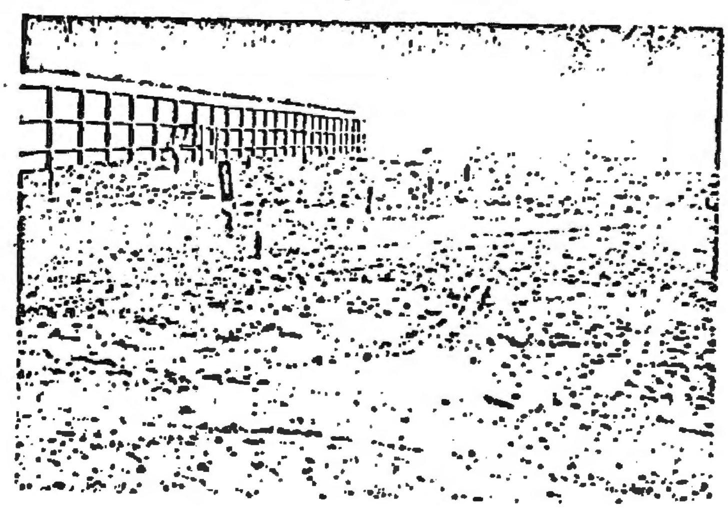












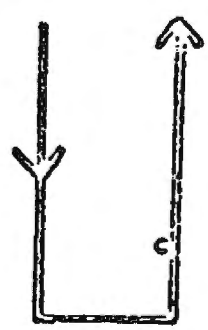


Fig 2-3

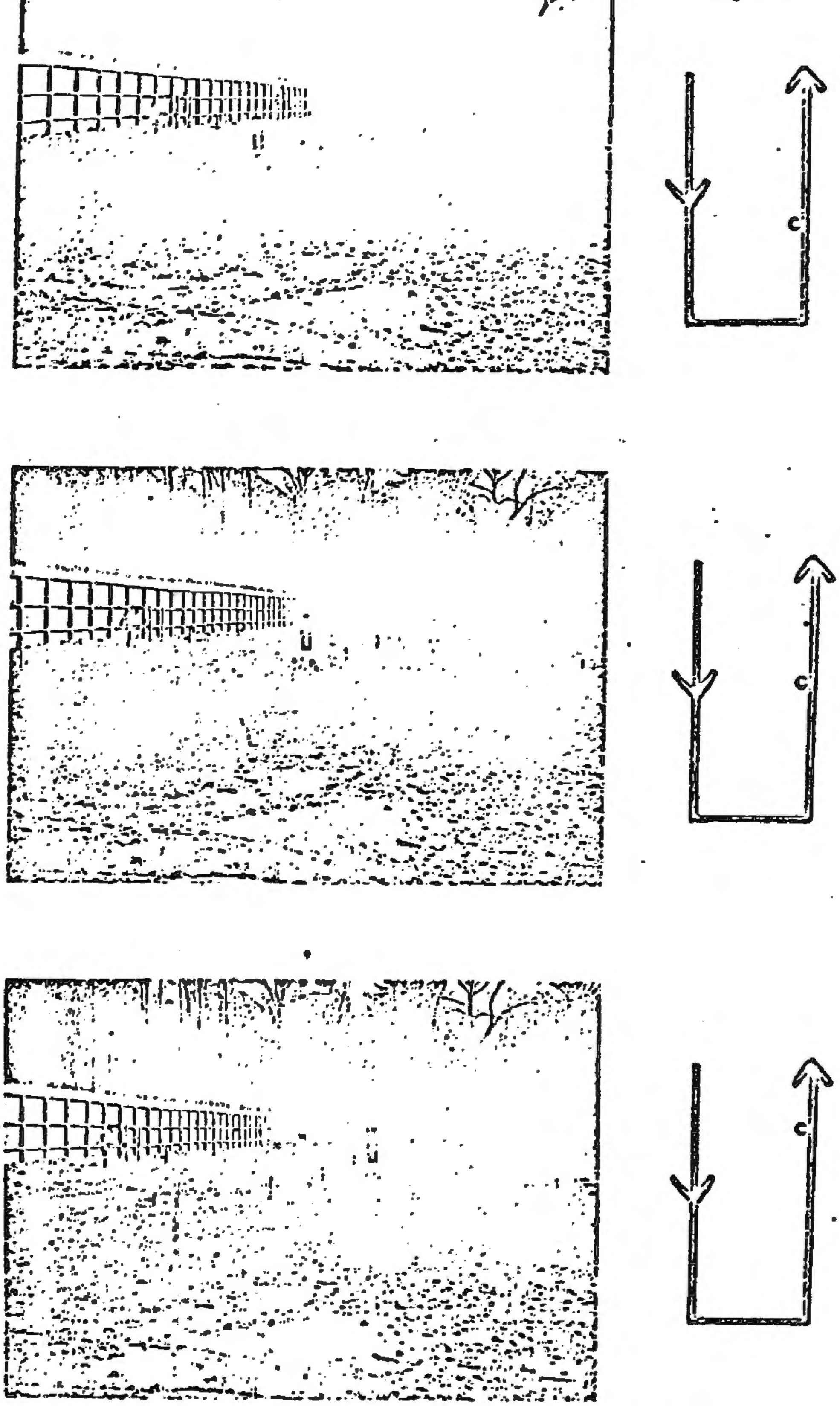
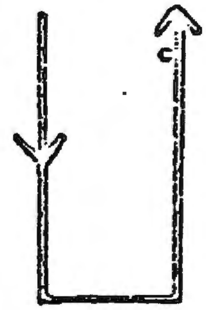
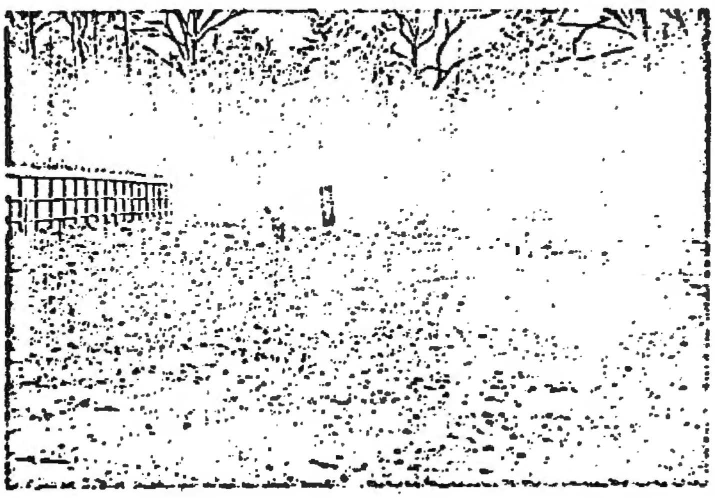


Fig 2-4





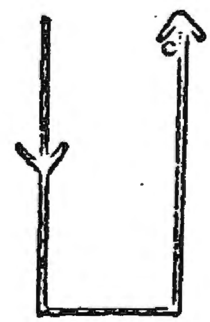


Figure 3

A sequence of photographs showing a second field pattern being run by an experimental dog.

(See text for explanation of the several markers in each photograph.)

Fig 3-1

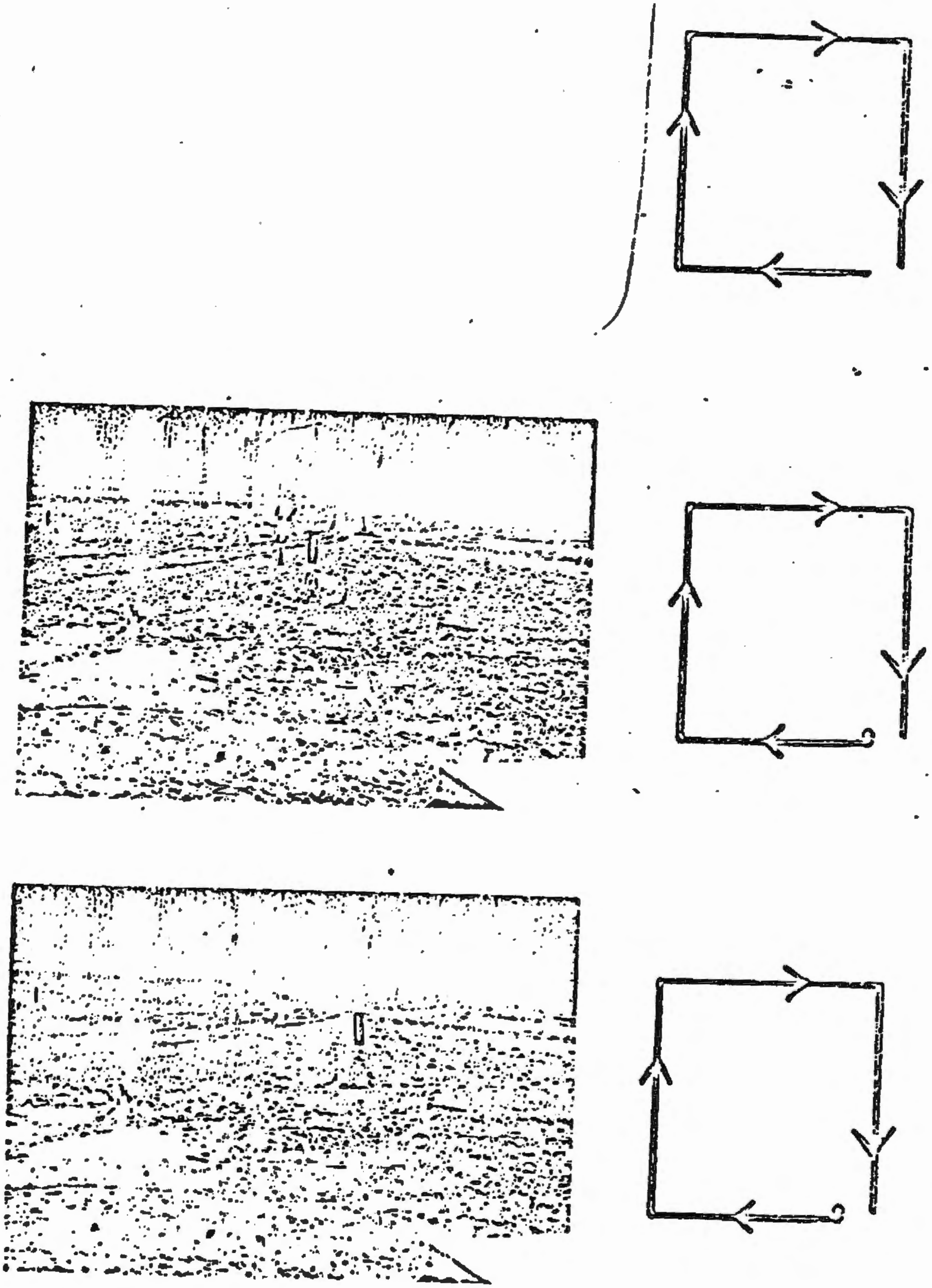


Fig 3-2

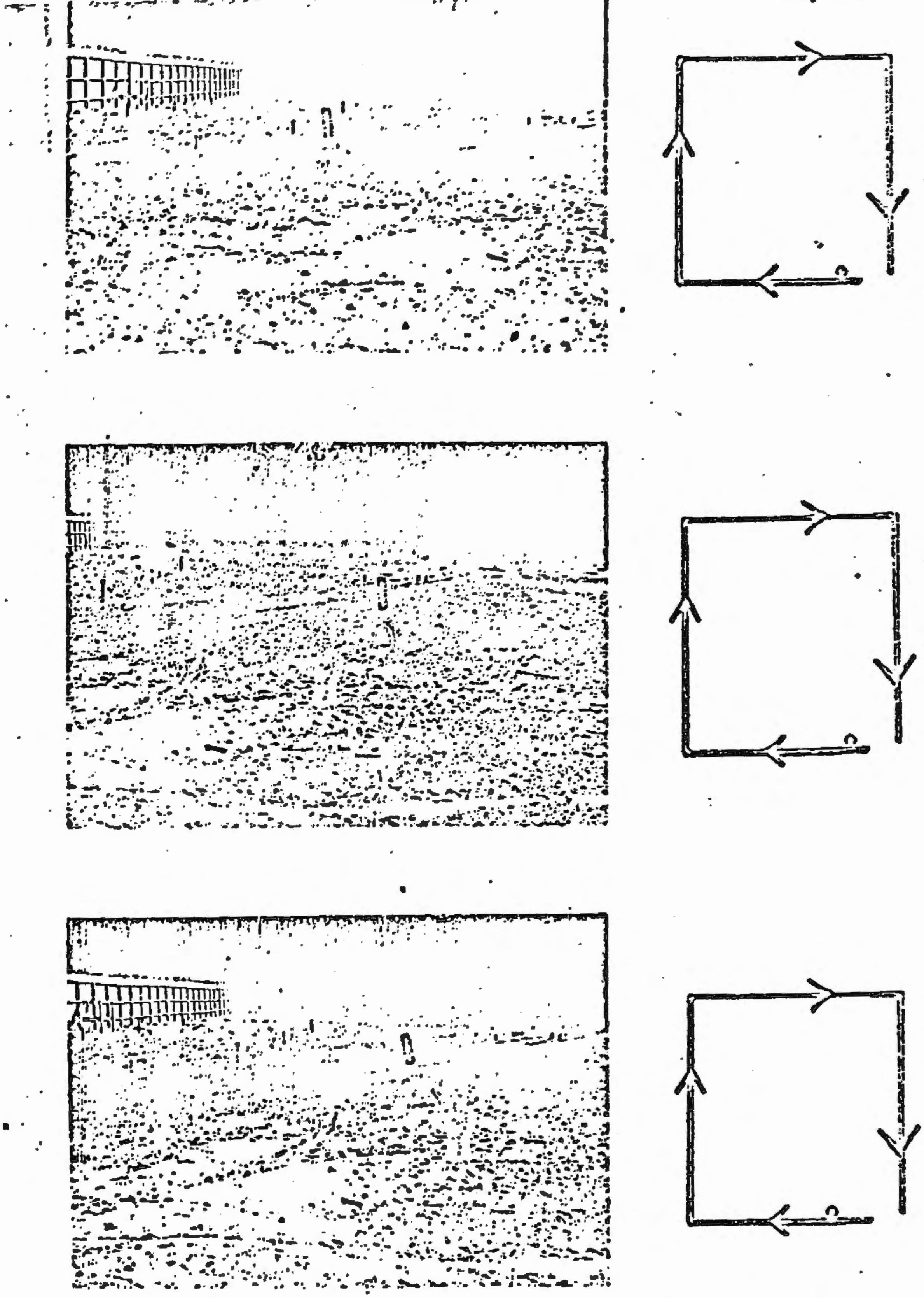


Fig 5-5

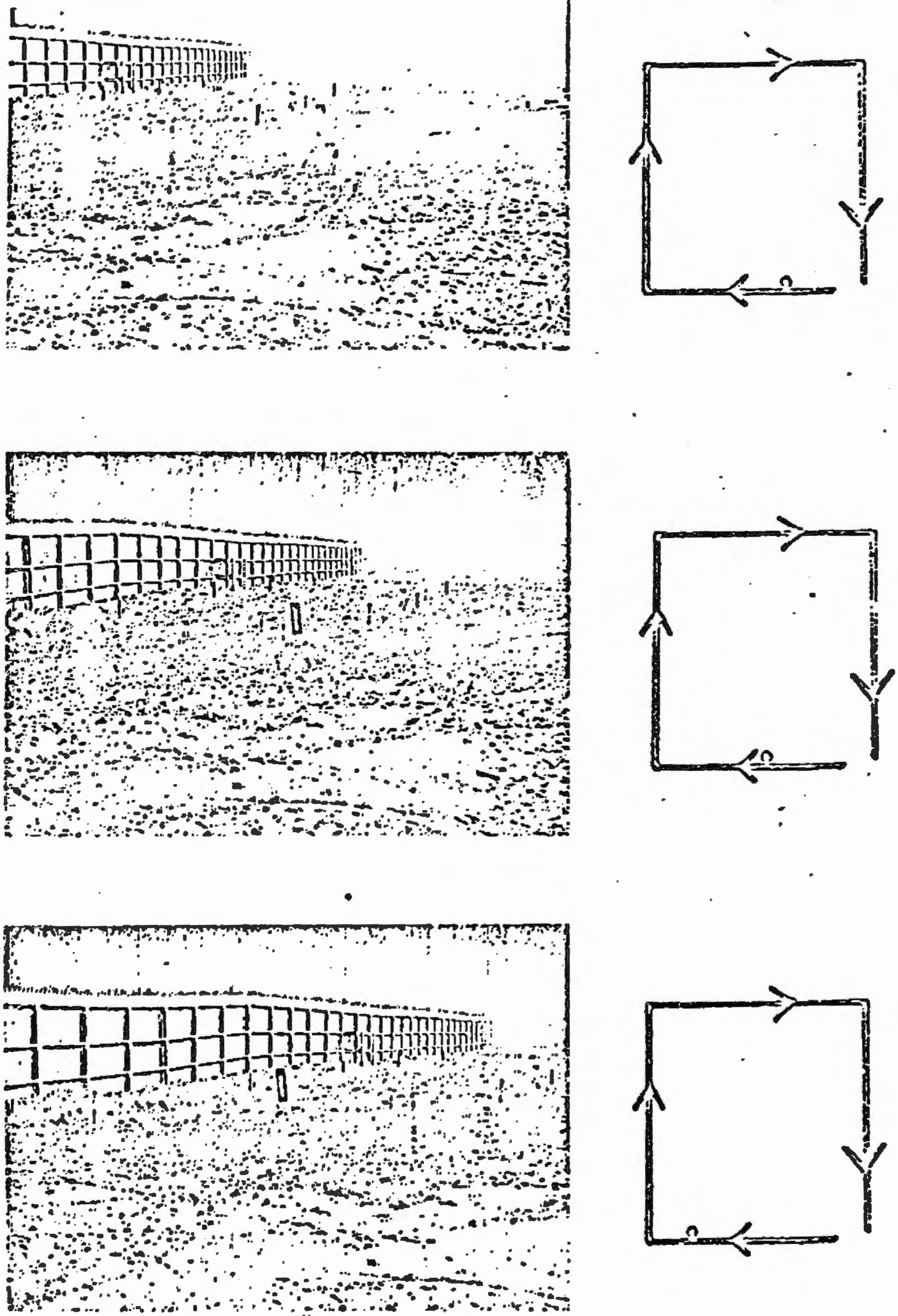
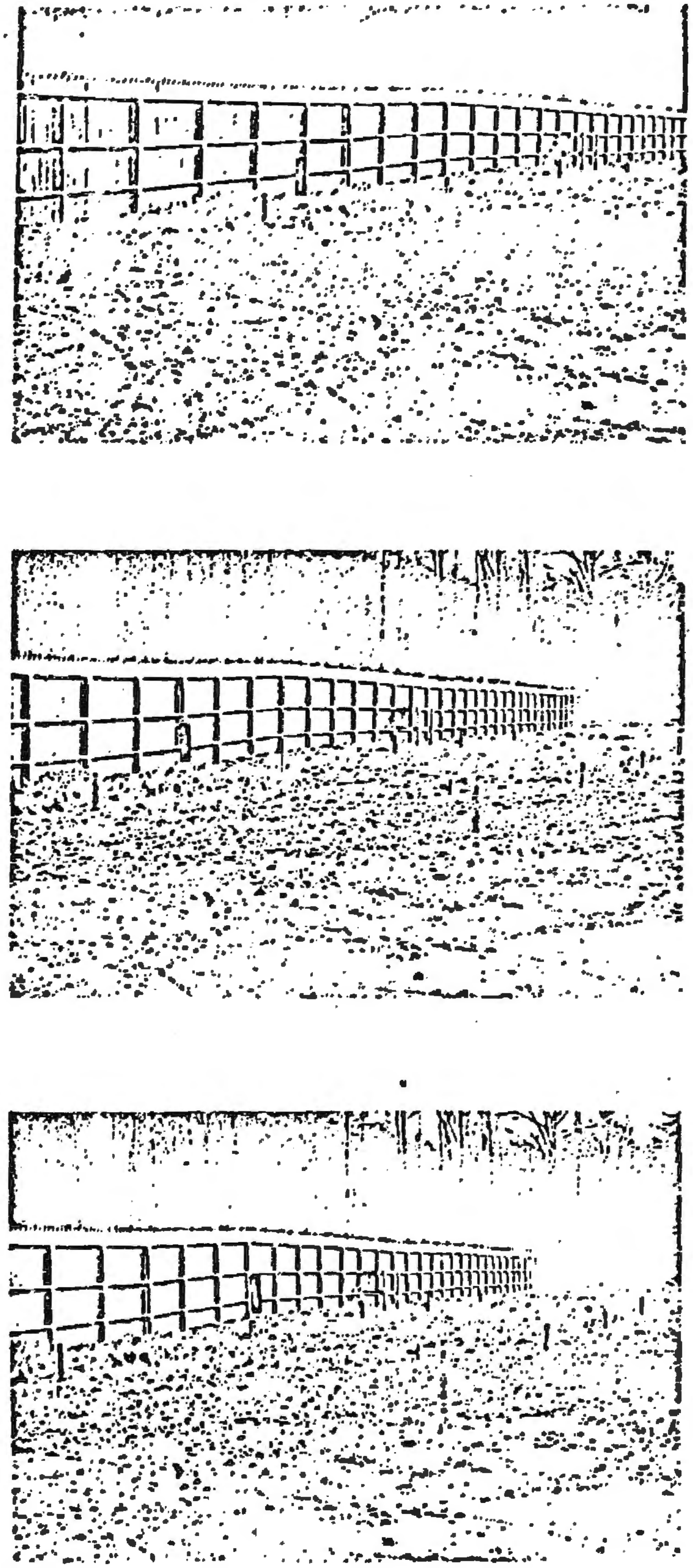


Fig 3-4



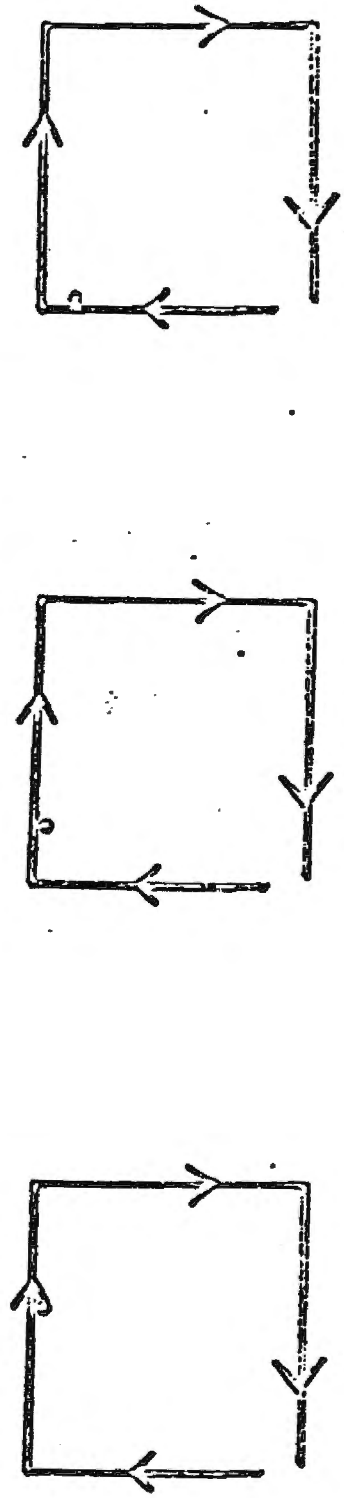
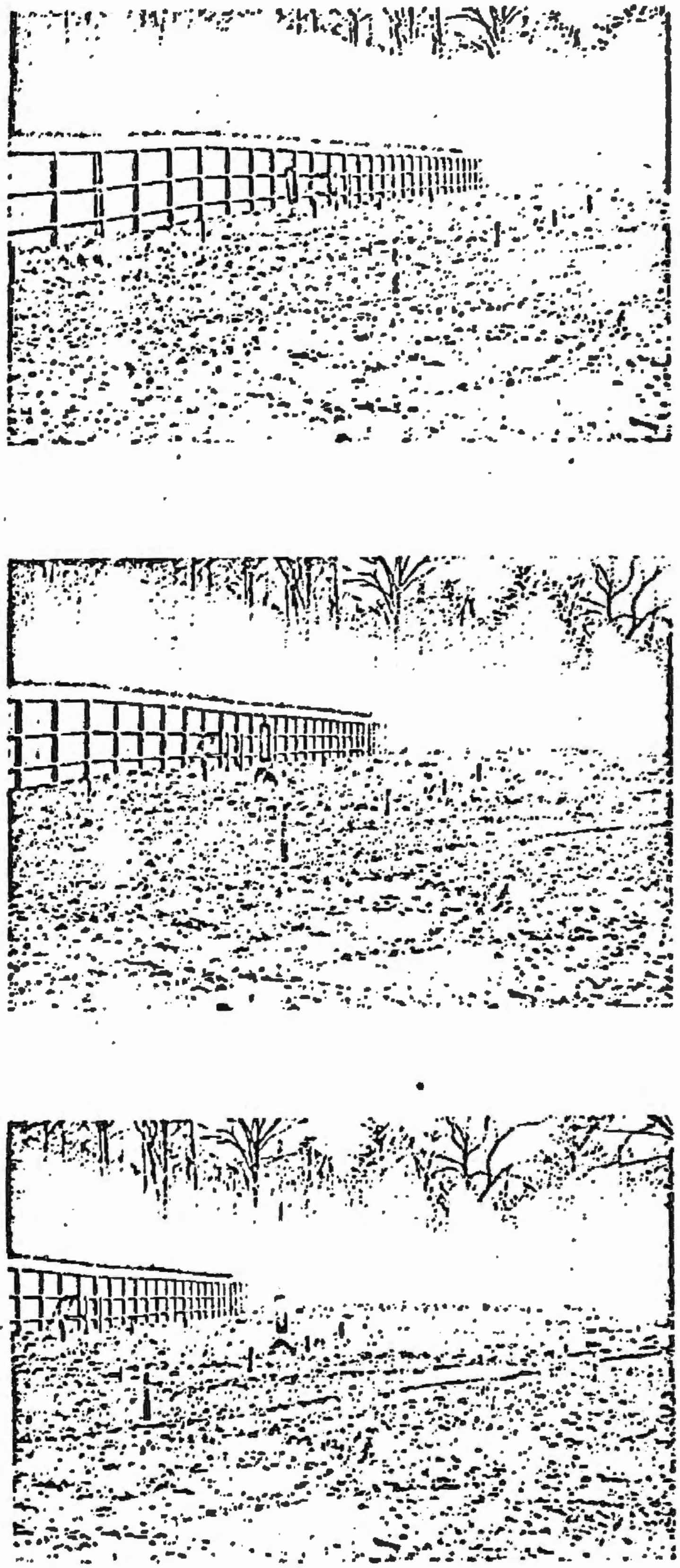
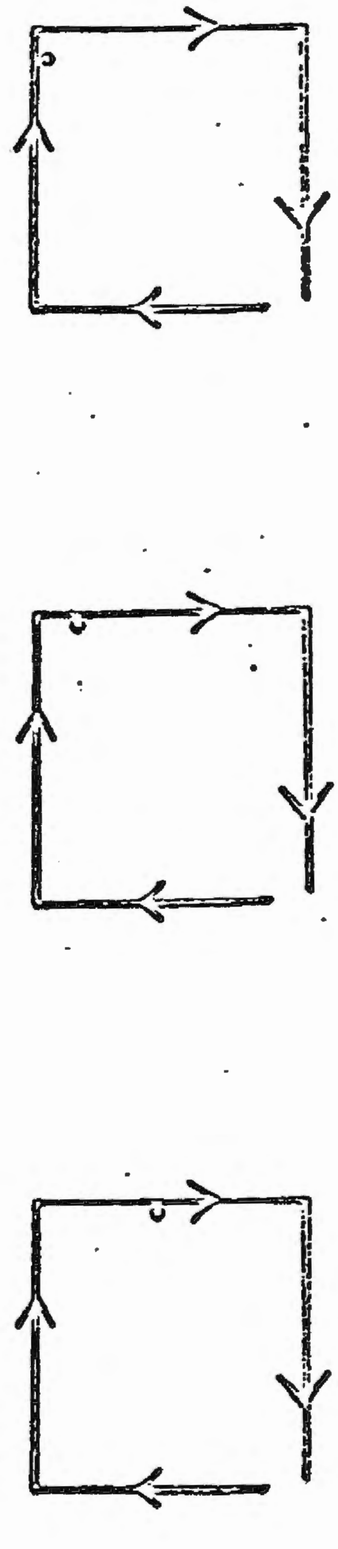
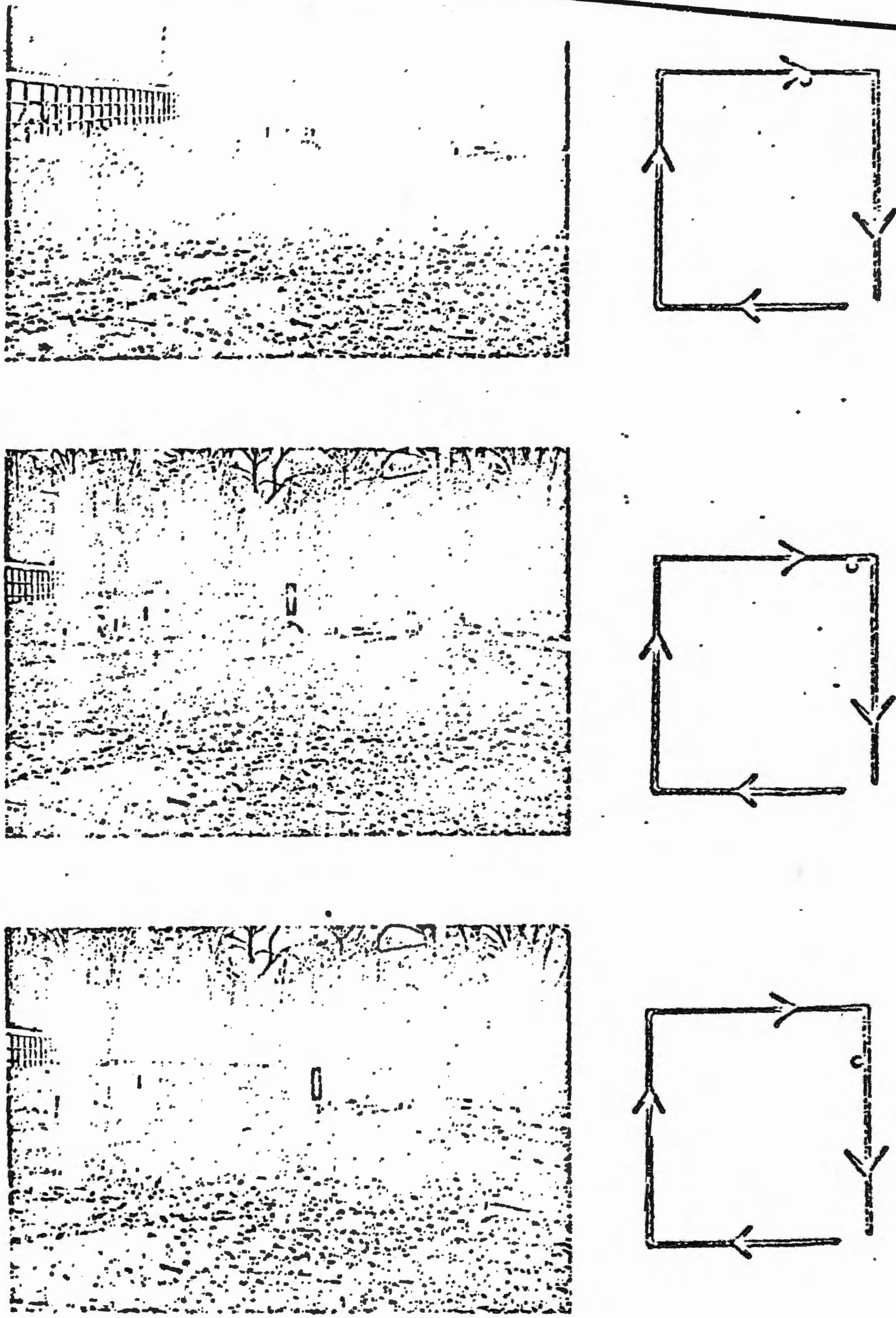
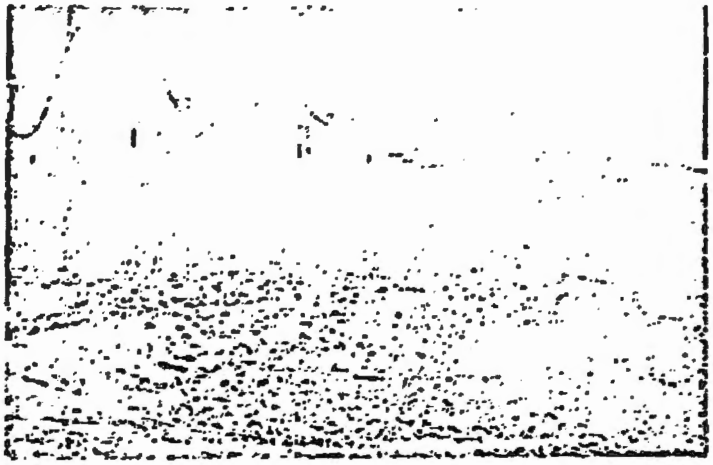


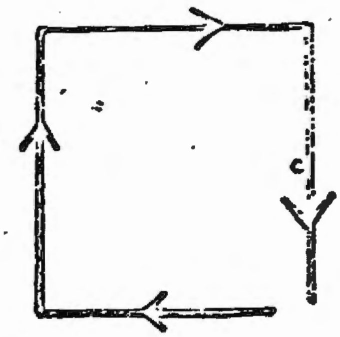
Fig 3-5

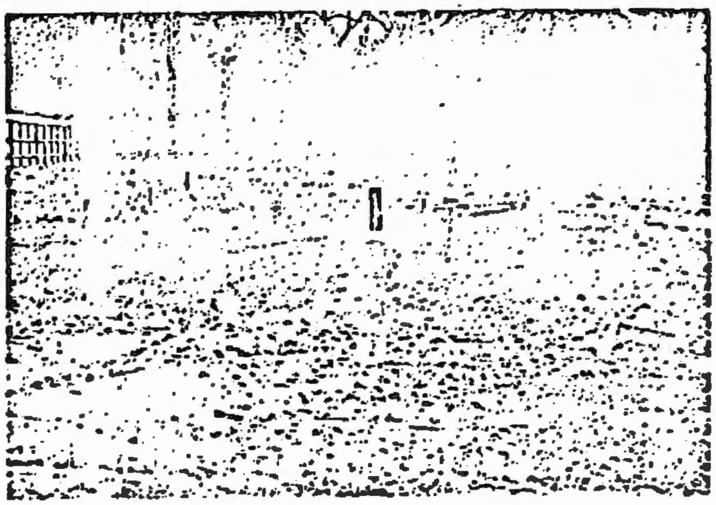


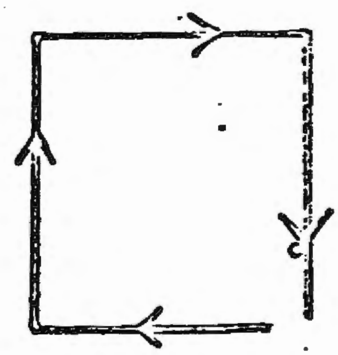


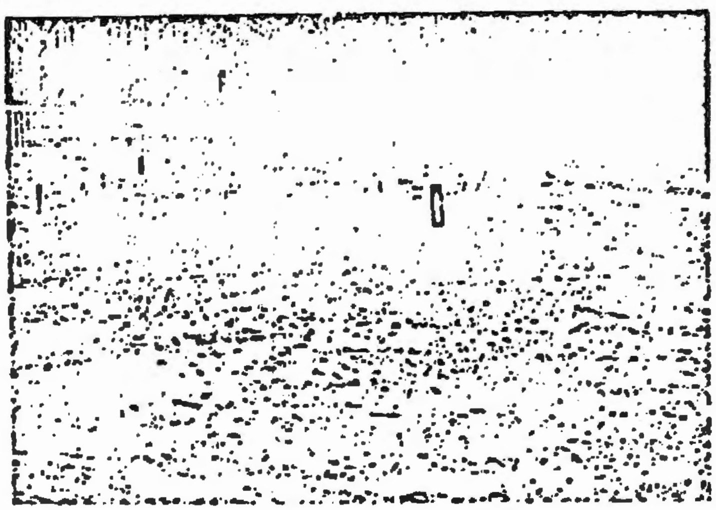












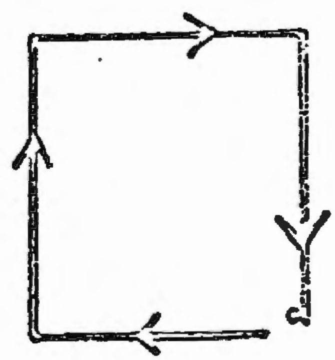
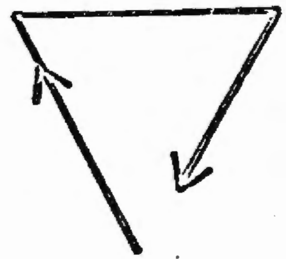


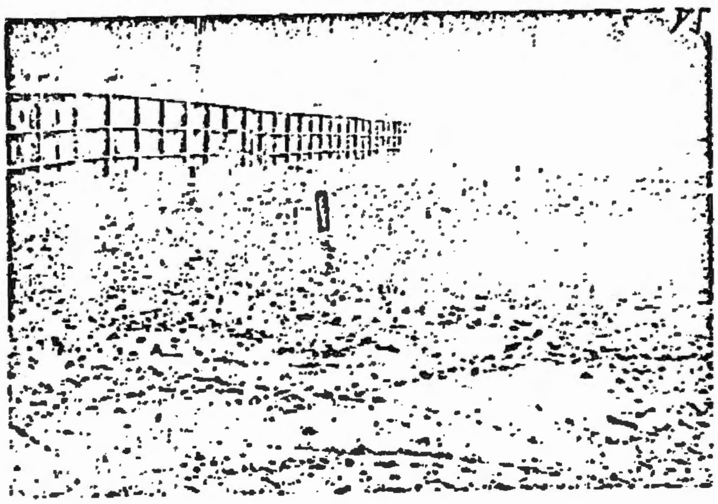
Figure 4

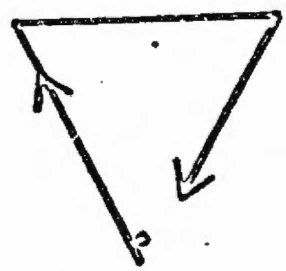
Still another pattern.

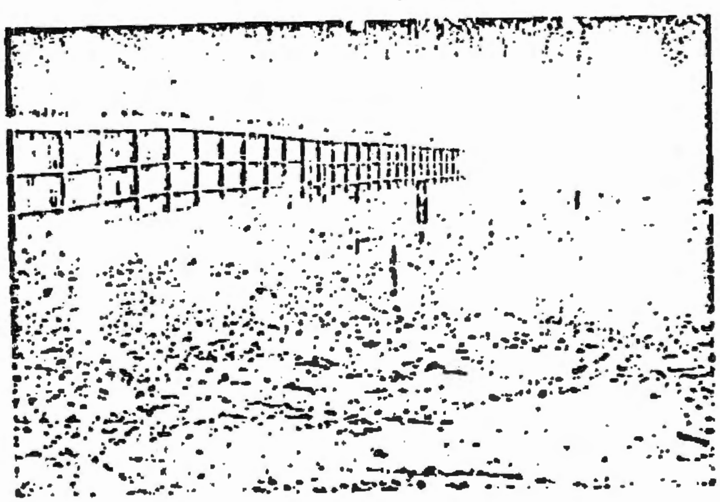
(See text for explanation of the several markers in each photograph.)

Fig 4-1









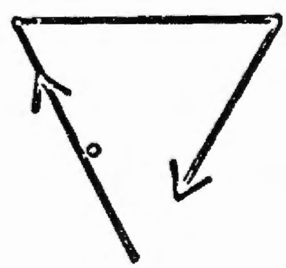
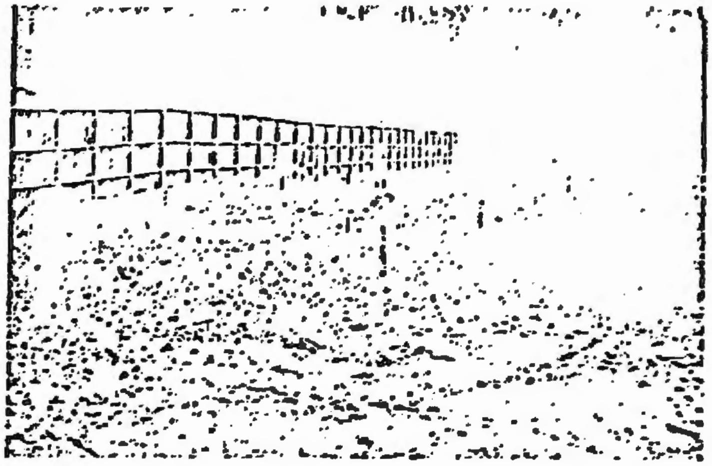
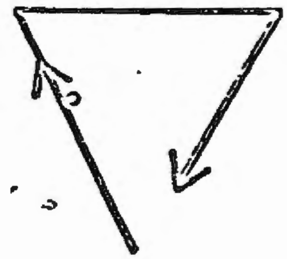
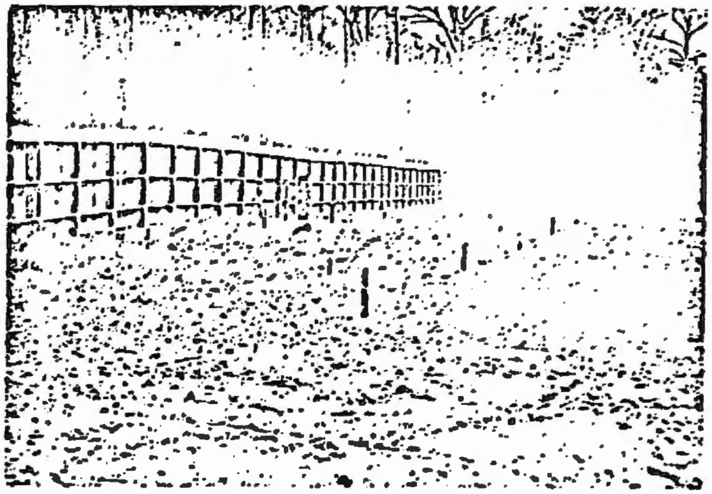
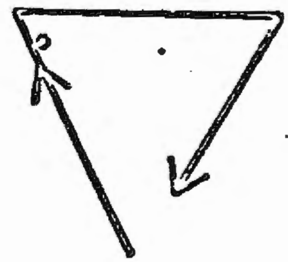


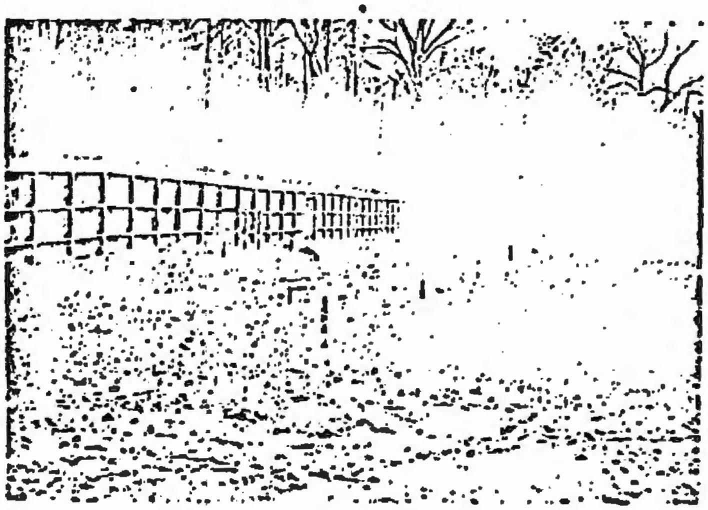
Fig 4-2











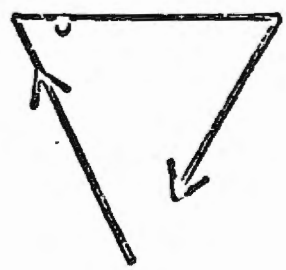
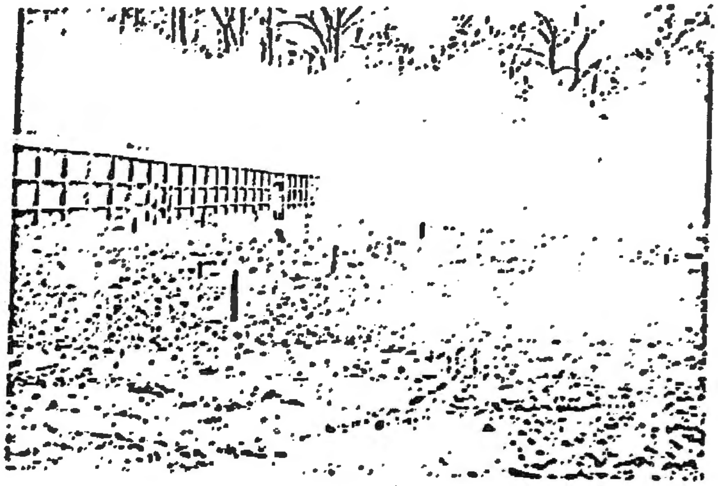
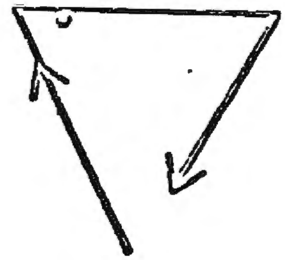
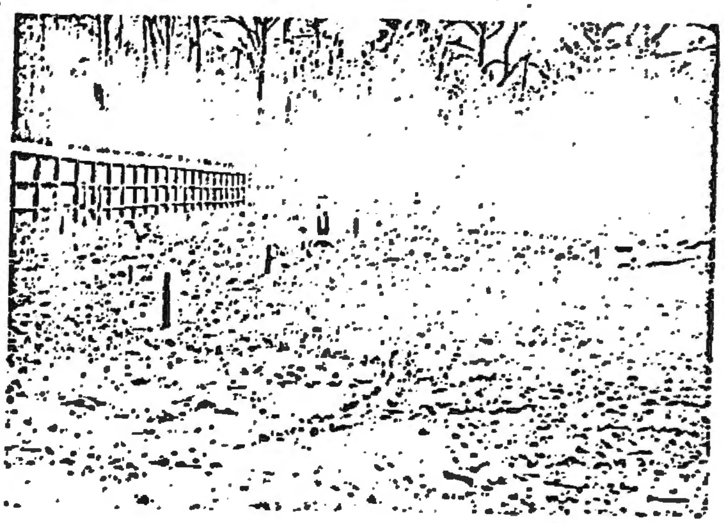
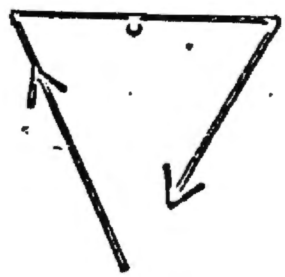


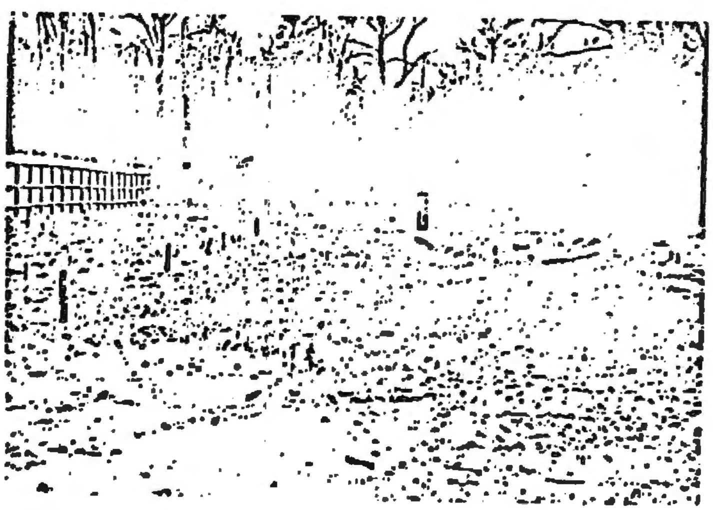
Fig 4-3











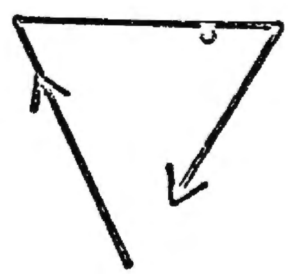
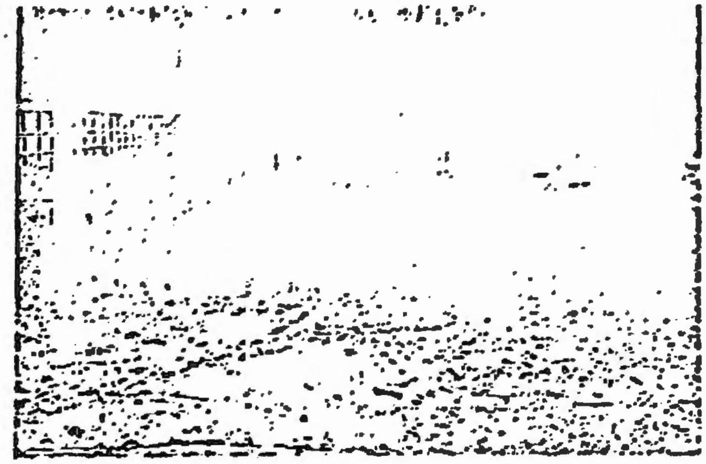
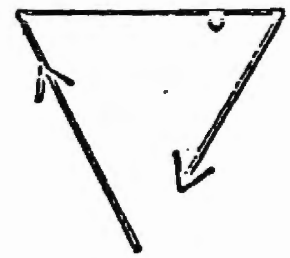


Fig 4-4





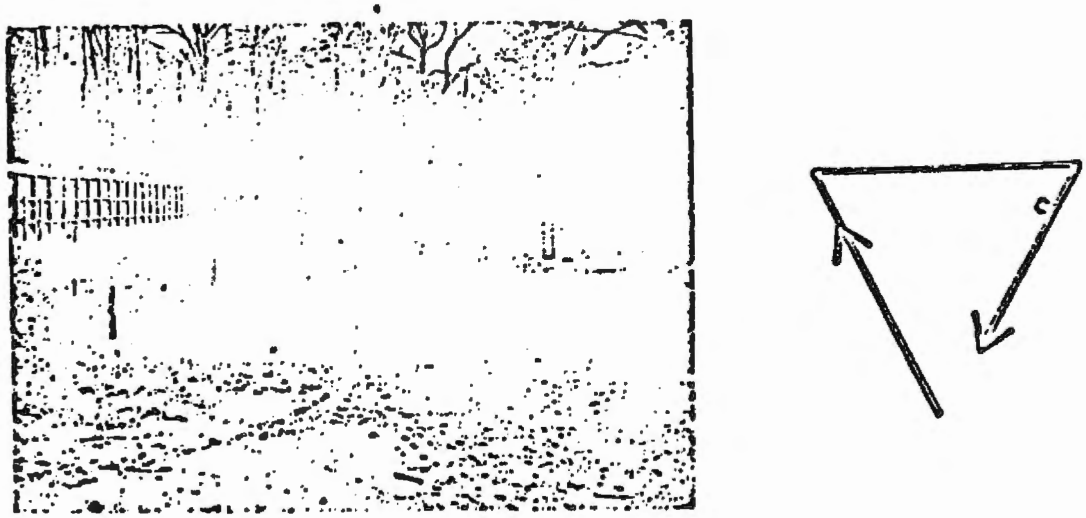


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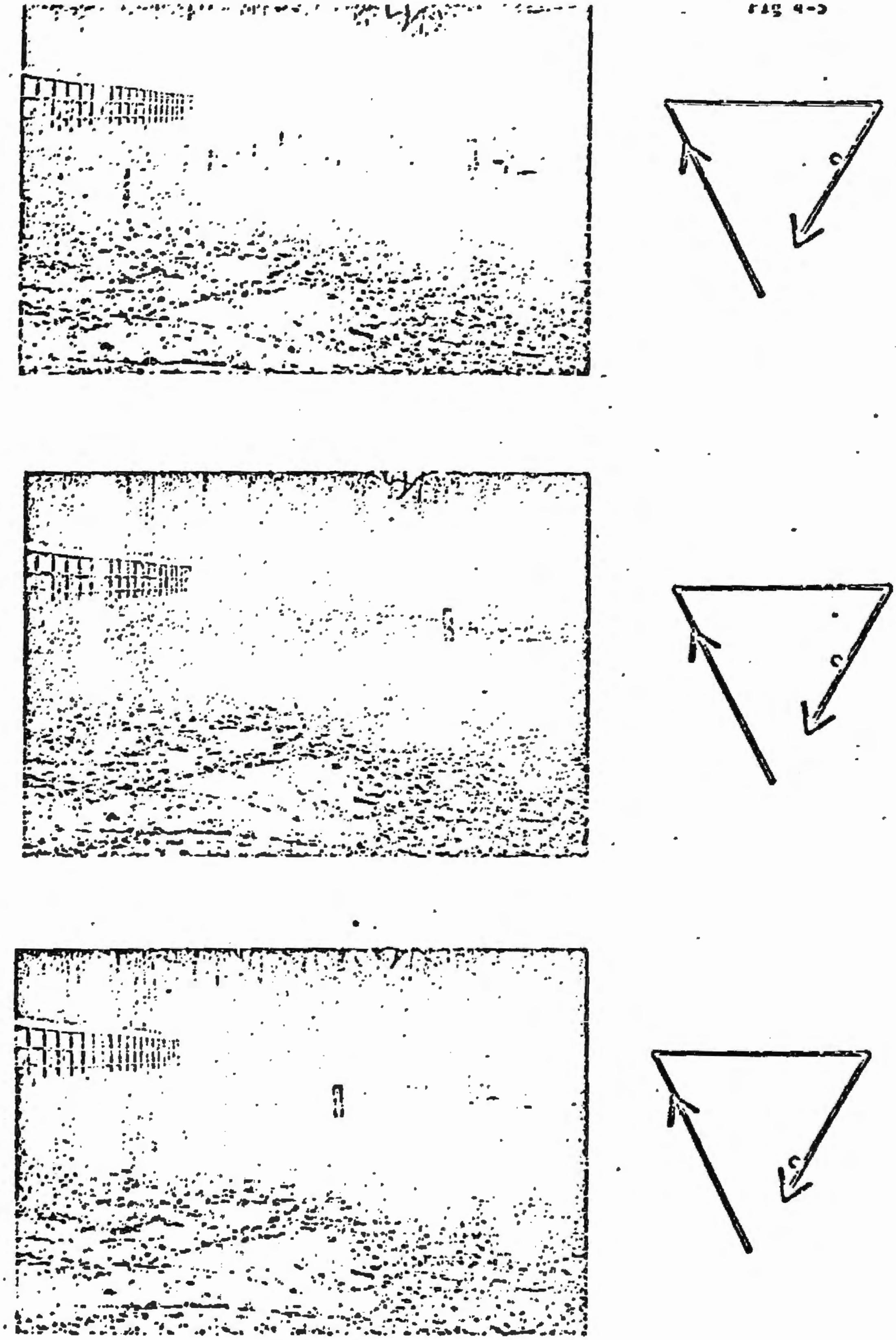
Fig 4-5



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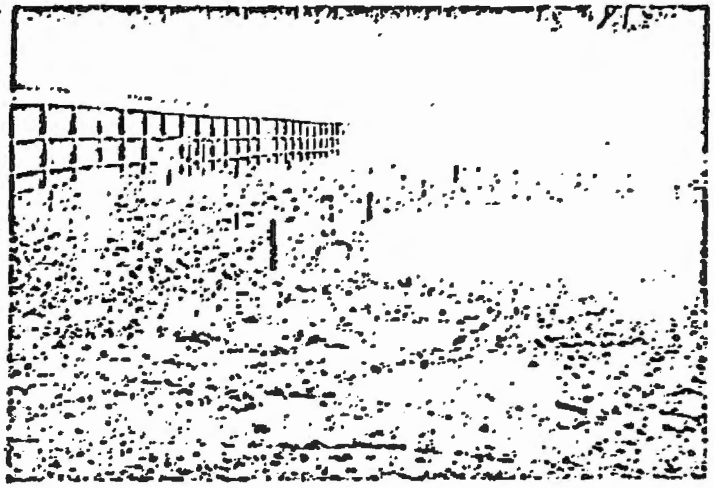

Fig 4-6

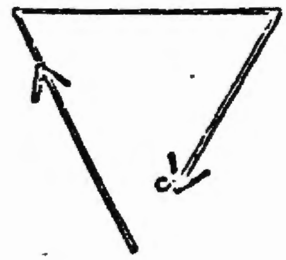

Figure 5

A fourth pattern.

(See text for explanation of the several markers in each photograph.)

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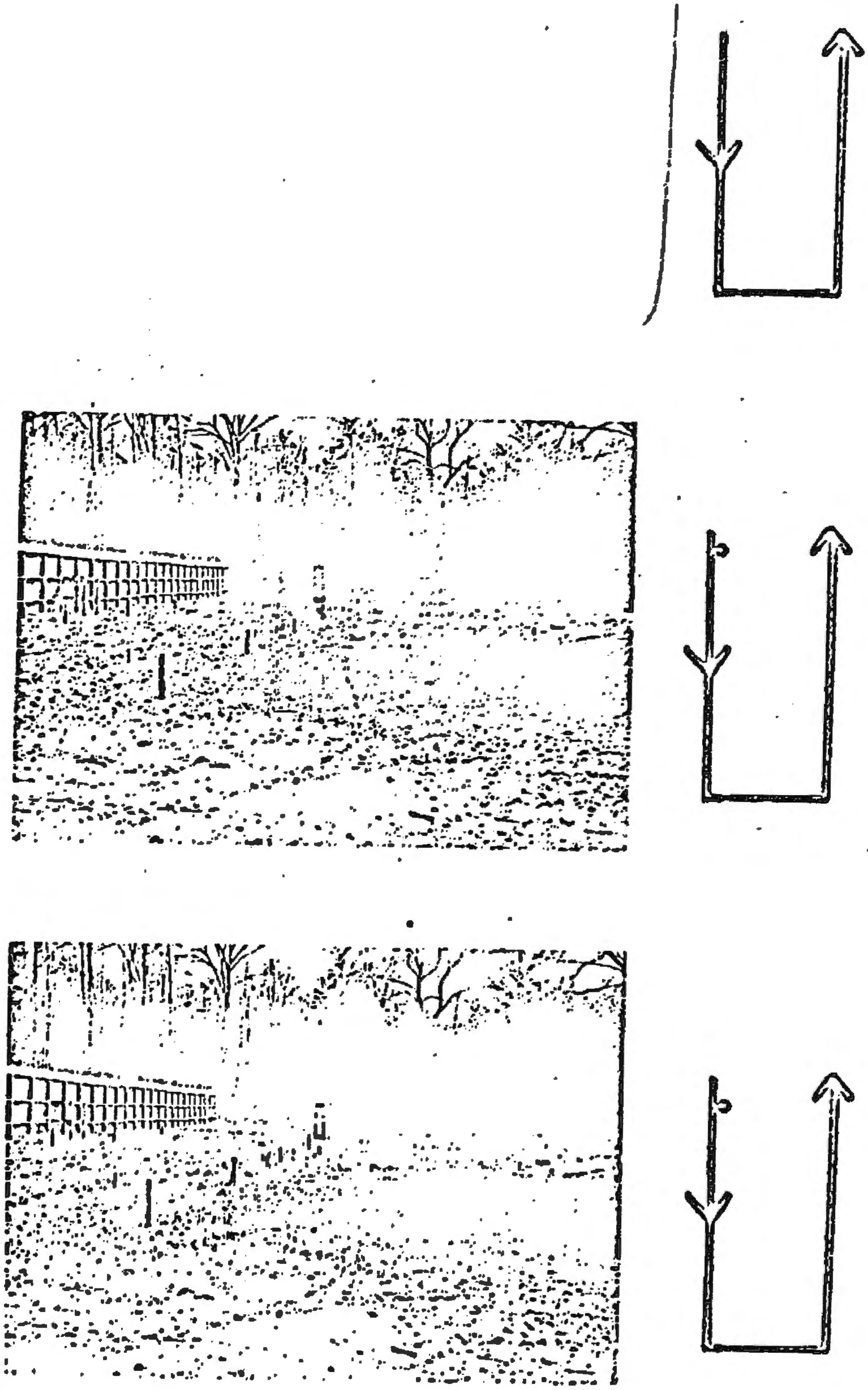
Fig S-1



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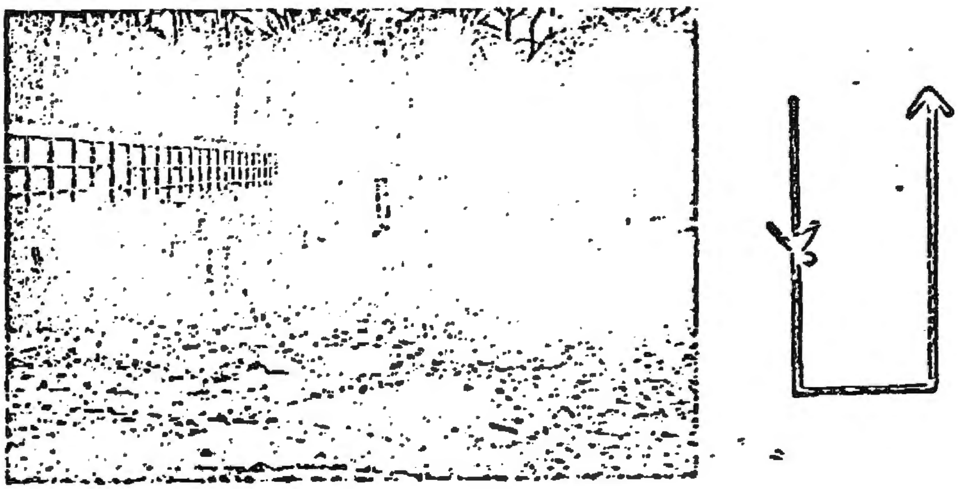
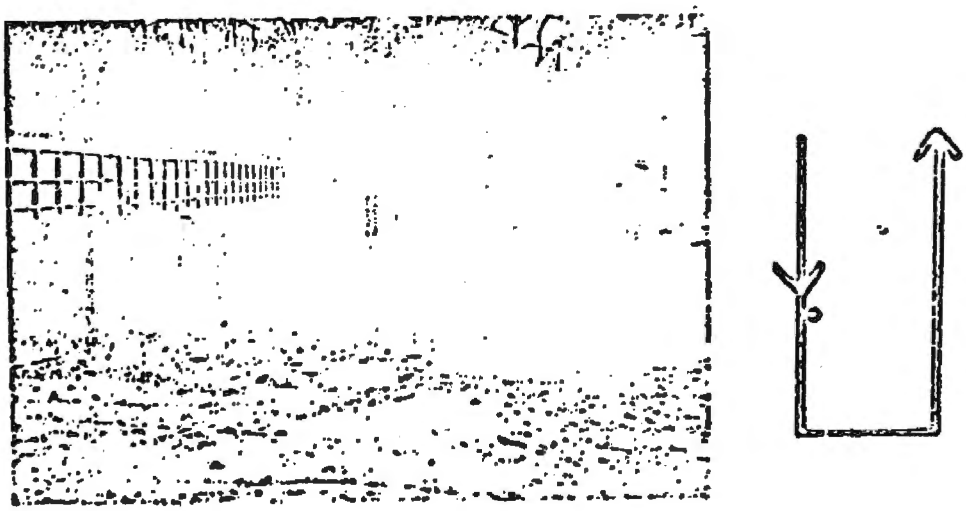




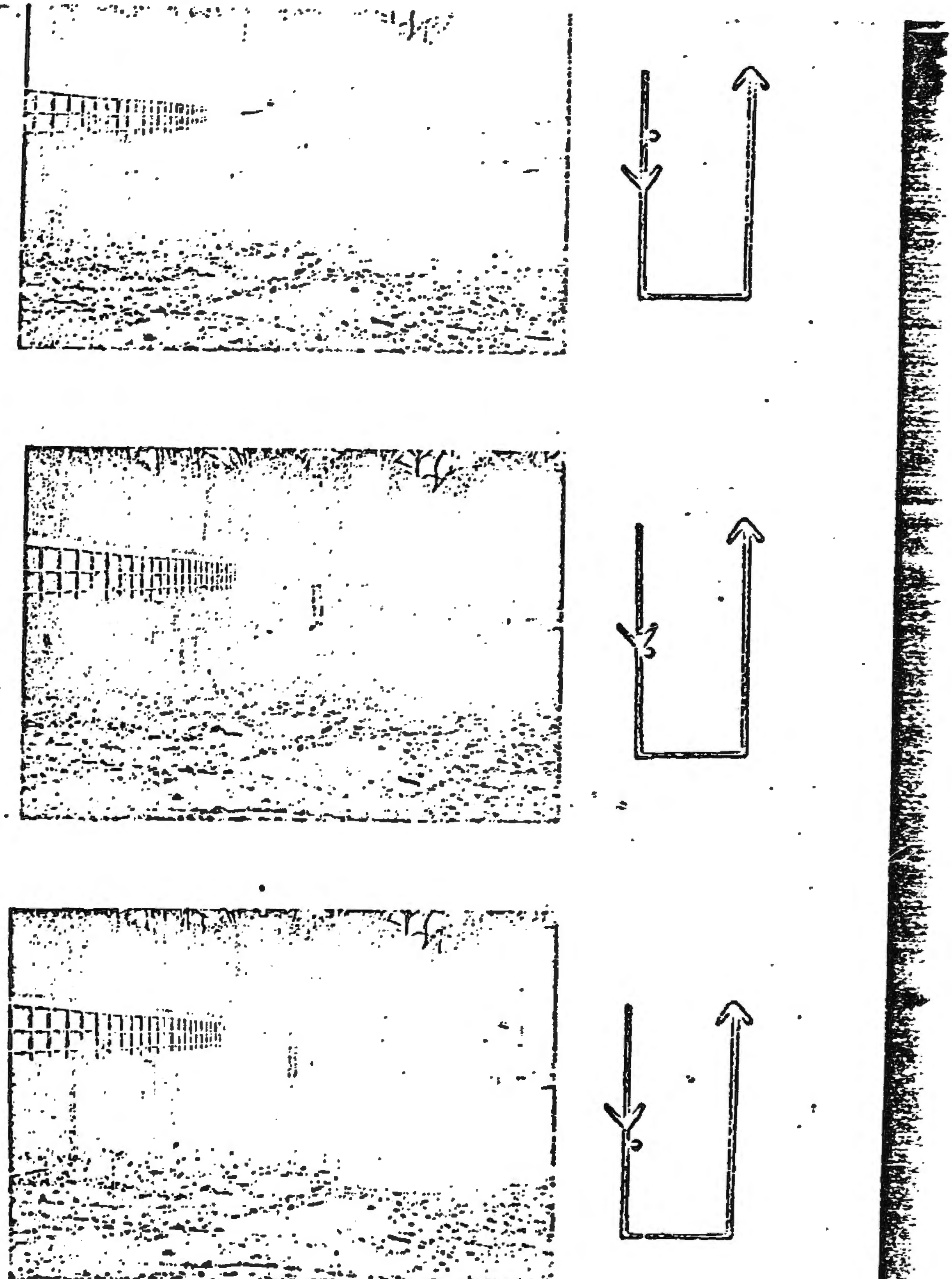


Fig 5-3

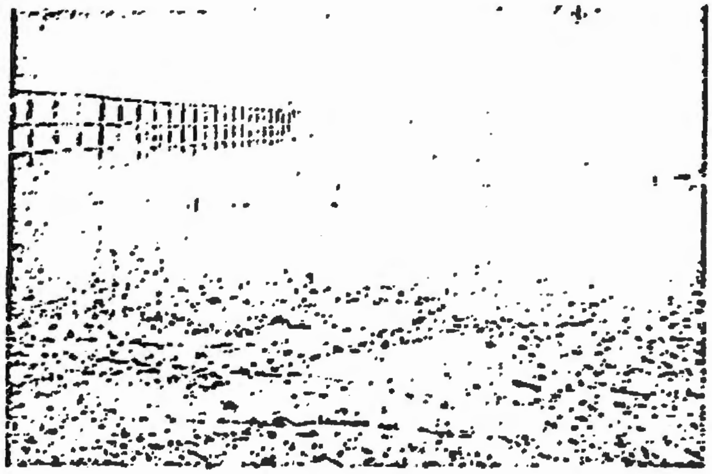
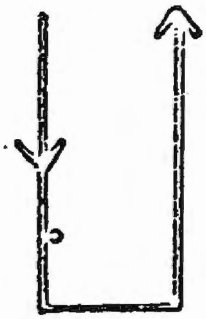
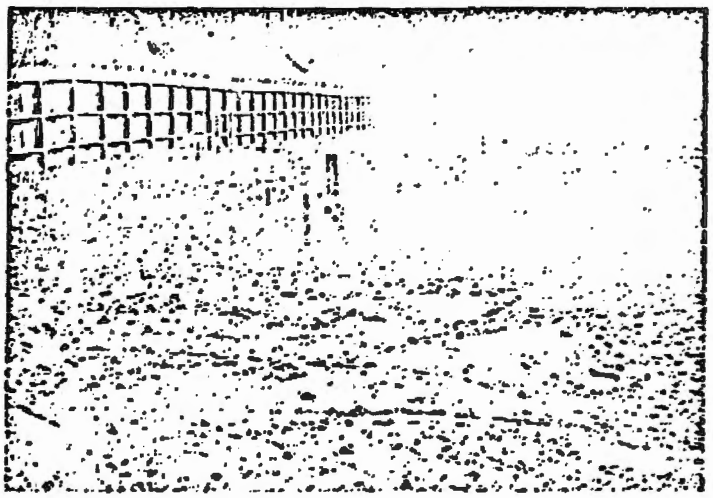
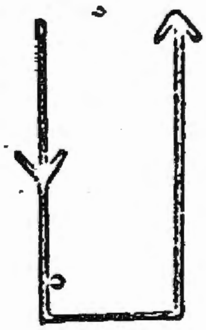
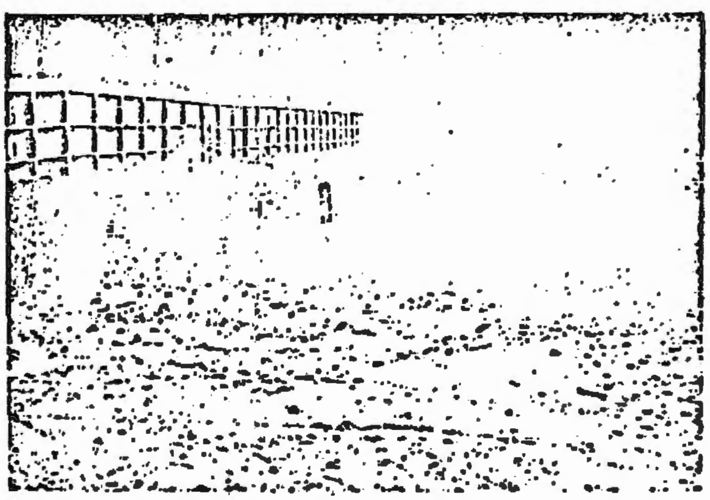
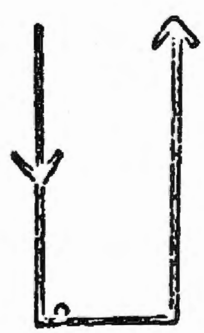







Fig 5-4

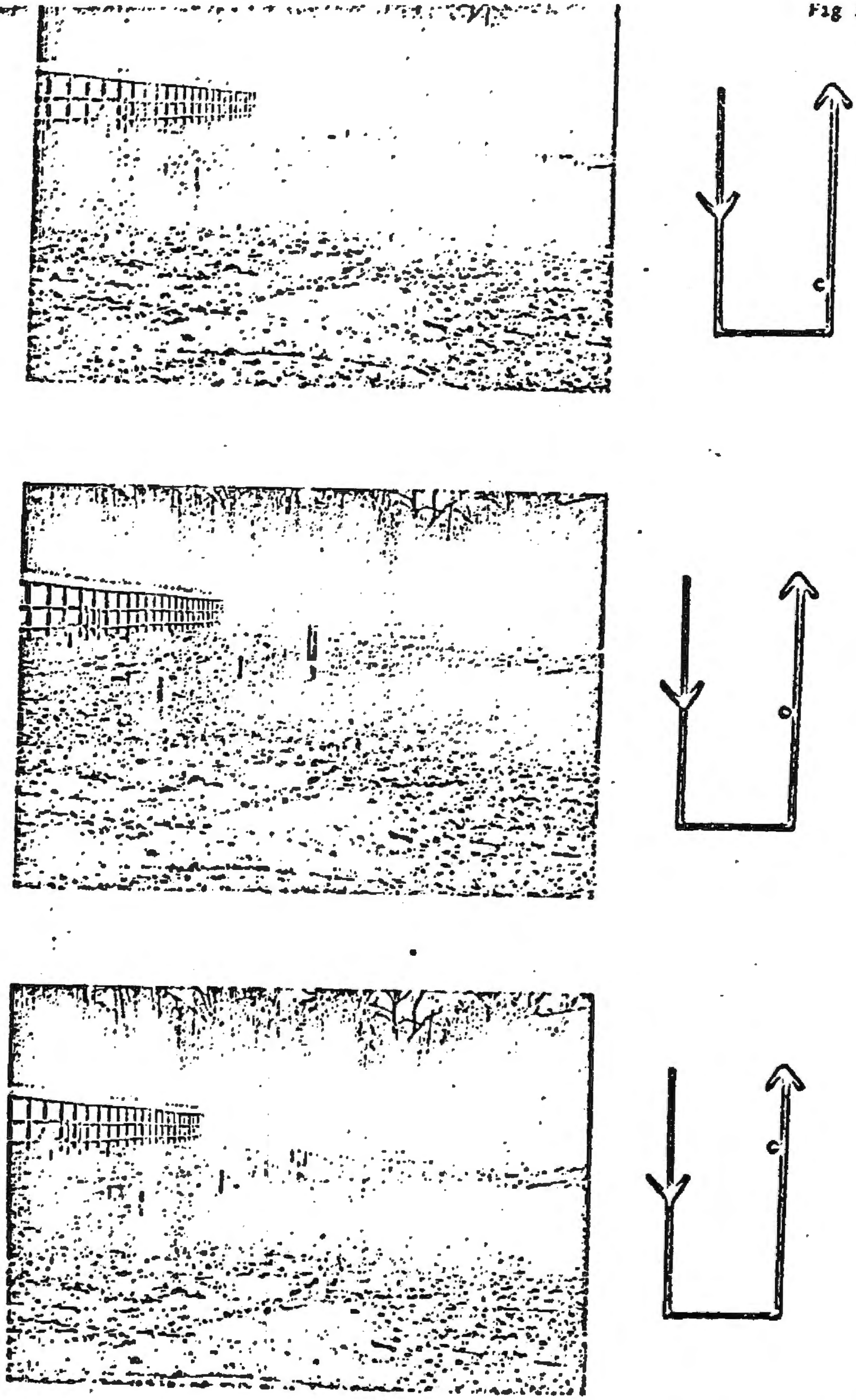
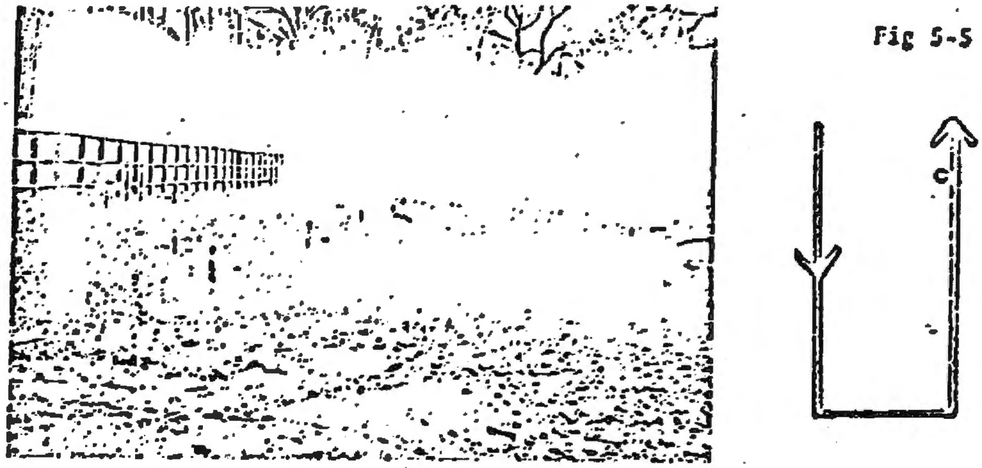
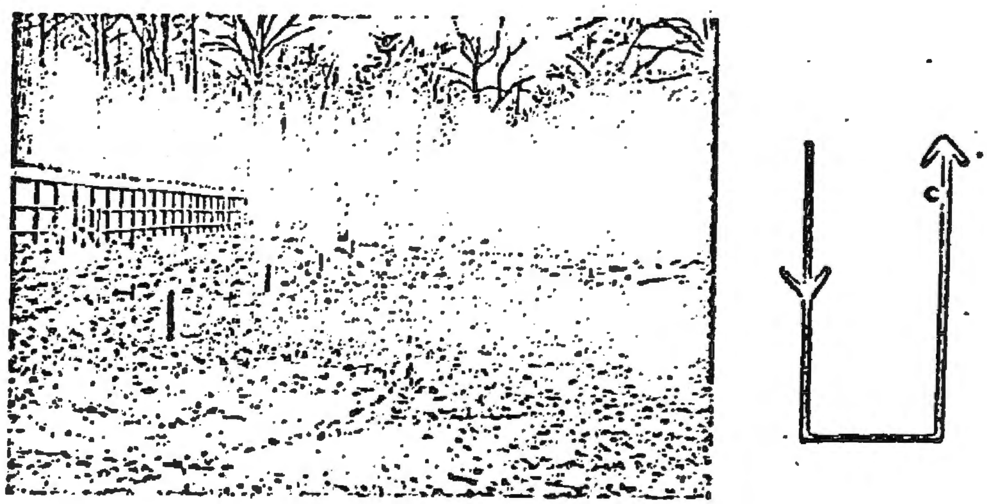


Fig 5-5





were employed in running the several sequences. The patterns were arbitrarily chosen, but deliberately kept simple in order to facilitate presentation in the present format. Unphotographed sequences were more complicated; the degree of behavioral control was much as shown in the simpler sequences. It is clear from the data presented that the experimenter has excellent control over the behavior of the unrestricted dogs.

6. Examination of Figs 2 through 5 shows an effect that was found to occur in all of our dogs while being guided through a field pattern under the control of rewarding brain stimulation. That effect is seen most clearly in several of the photographs where the dog was close to the camera— see, for example, the middle photograph in Fig 2-2, the bottom two photographs in Fig 3-1, the middle photograph in Fig 4-1, and the bottom photograph in Fig 4-5. In each case, and for both dogs, the animal sniffs along the ground while following the path selected by the experimenter— it seems as though the animal is following the path of an olfactory cue. It is entirely possible, however speculative, that that is precisely what is happening, with the stimulation producing a central process like that produced by an olfactory stimulus which serves as a reward and evokes "following" or tracking behavior. While we cannot confirm or infirm that interpretation of the behavior, we can ask the question whether or not a dog can be trained to track a pattern with

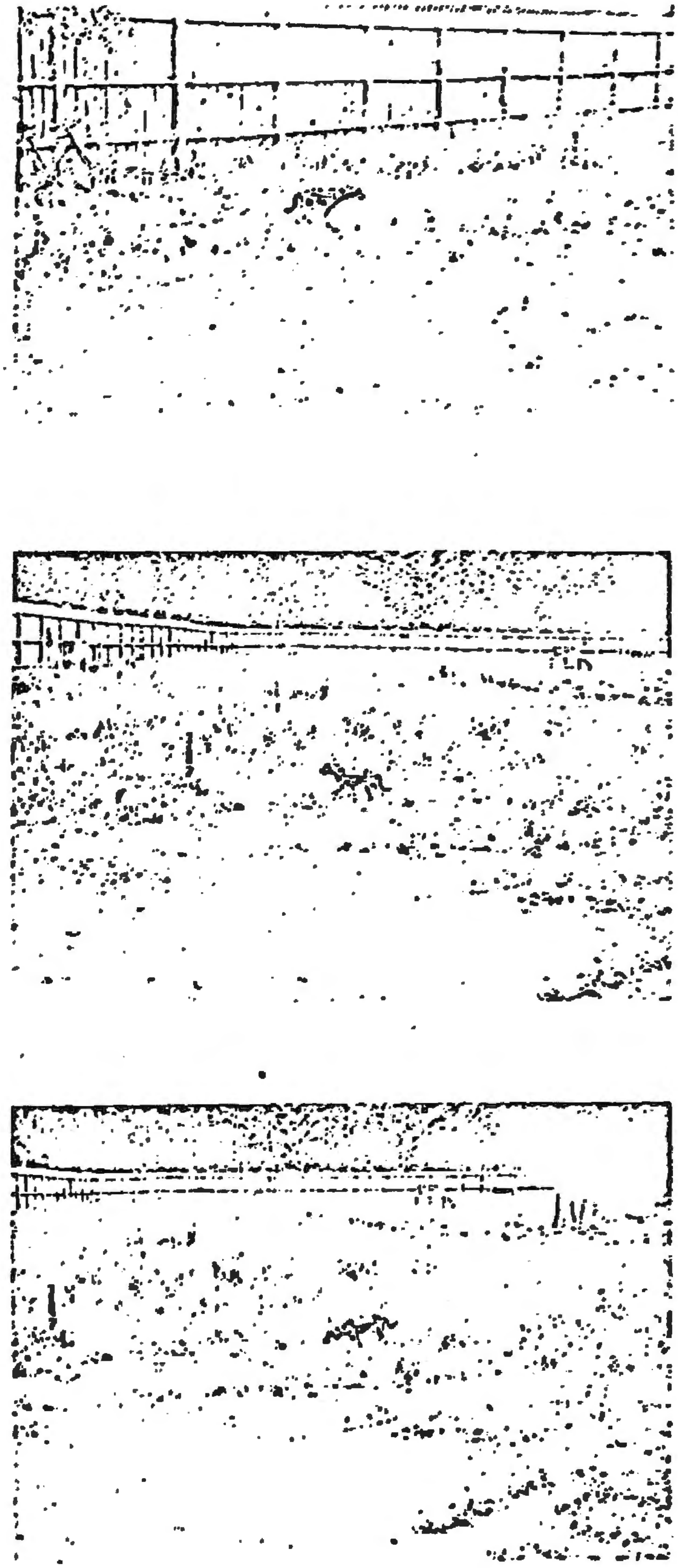
his head held high.

In order to examine the possibility, another dog was implanted and trained to track according to the procedures described above. In this instance, however, rewarding brain stimulation was delivered so as not only to initiate and maintain locomotion but also differentially in order to reinforce (the reward effect of brain stimulation) head position. The dog was given about two weeks of such training and his tracking performance in the open field was found to be much like that shown for the other dogs in Figs 2 through 5. This dog, however, progressed through a pattern with a distinctly different head position. Figure 6 consists of three photographs taken during a tracking session. Note the position of the dog's head in the upper two photographs-- in both, the head points straight forward rather than down at the ground. The center photograph gives only a suggestion of the exaggerated high head position that was seen on occasion with this dog. The bottom photograph shows a reversion to a partial head-down position. While the lowered head occurred, it did so relatively infrequently, and the high head postiion could be quickly reestablished by momentarily withholding rewarding stimulation. It may be concluded, therefore, that the head down, sniffing behavior is not a necessary concomitant of open field behavior control with rewarding electrical stimulation of the brain. We cannot state, however, that it is irrelevant-- the present experiment may have involved the

Figure 6

Photographs showing the results of an experiment in which a dog was trained to traverse a controlled pattern with head held high.

Fig. 6



A

B

C

suppression of an important though not necessary concomitant.

7. The above work, which examined behavioral control through arbitrary patterns in the open field, was not easily susceptible to quantification. In order to obtain quantitative data with respect to some of the elementary parameters of stimulation, such as the duration and intensity of each train of stimulation delivered to the dog during the course of a pattern, a matrix of stakes was placed in the field. The matrix consisted of five rows of three stakes in each row. Twenty-four feet separated adjacent stakes in the rows and columns. A standard pattern and its mirror image could be run from day to day and quantitative data in terms of elapsed time from stake to stake could be taken. Elapsed time was studied as a function of train duration and intensity of stimulation. Within a range of intensities and durations producing no behavioral control at the low end and clearly disrupted performance at the high end, relatively small differences in time measures were obtained as a function of intensity and duration. A general conclusion stemming from these experiments is: intensities and durations markedly lower than the optimum produced increases in the times taken to traverse a pattern. These time scores, however, were frequently meaningless in the sense that control over the dog's behavior had been lost and the performance completely disrupted. Intensities and durations within the optimum range produced stable performance measures from day to day. The shorter

durations (about 200 msec) and moderate to high intensities within the range are preferred: the data showed slightly faster running times at those intensities and durations. Increases in intensity and duration beyond optimum values produced longer running times due to a variety of effects, including recoil.

Although the behavior sequences shown in Figs 2 through 5 did not employ the stake patterns just described, the stakes may be seen in the photographs.

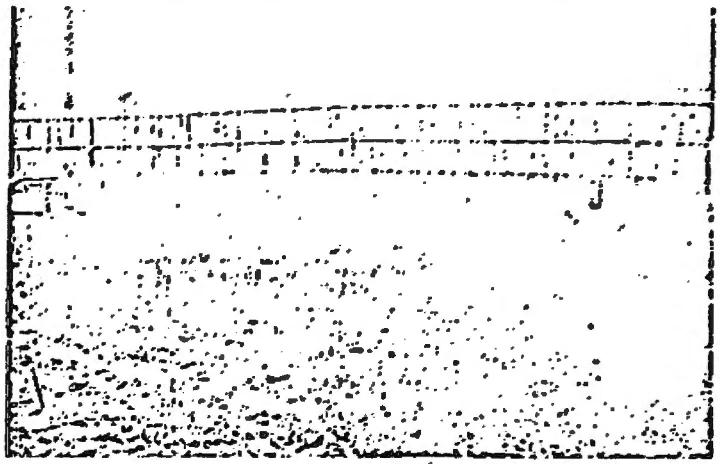
8. One of the interesting questions regarding the control of field behavior in dogs by means of brain stimulation reward concerns the effects of competing reinforcers. The question we entertained in a recent experiment was: if a dog is under the control of brain stimulation reward and is running a controlled pattern in the field, how likely is it that he will leave the pattern when given the opportunity to obtain a different reinforcer?

Two implanted dogs were deprived of food and slowly reduced to 80% of their free feeding weights. They were then magazine trained, i.e., a large metal box with feeder attached was located in the field (see Fig 7). Through control circuitry located in the laboratory and a switch in the hand of the experimenter, the dogs were trained to run into the box at the sound of a tone (the speakers can be seen in the center photograph of Fig 7-2) in order to obtain food. No brain stimulation was delivered during these training sessions, and

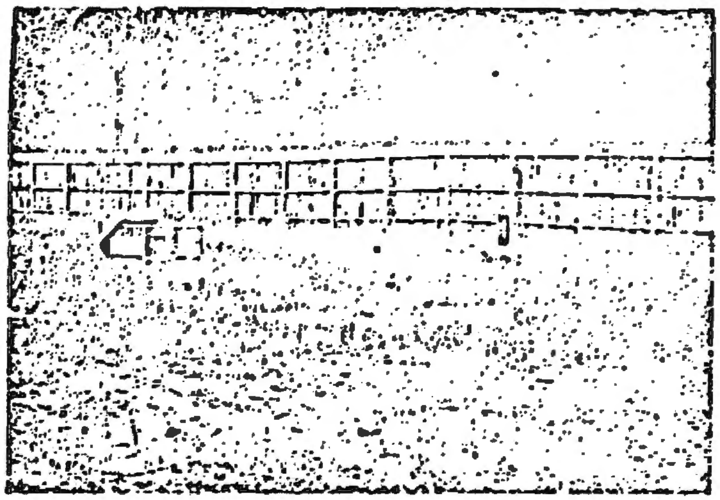
Figure 7

Response to the tone in an experiment designed to investigate competition between food reward and brain stimulation, with the latter serving to control free-field behavior.

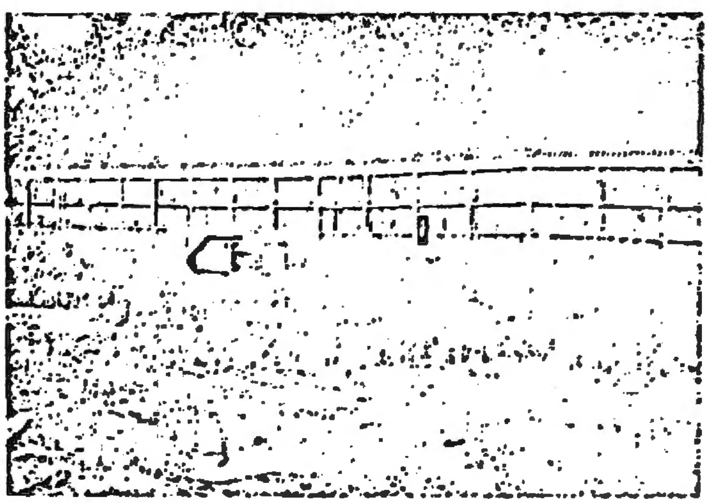
Fig 7-1



A



B



C

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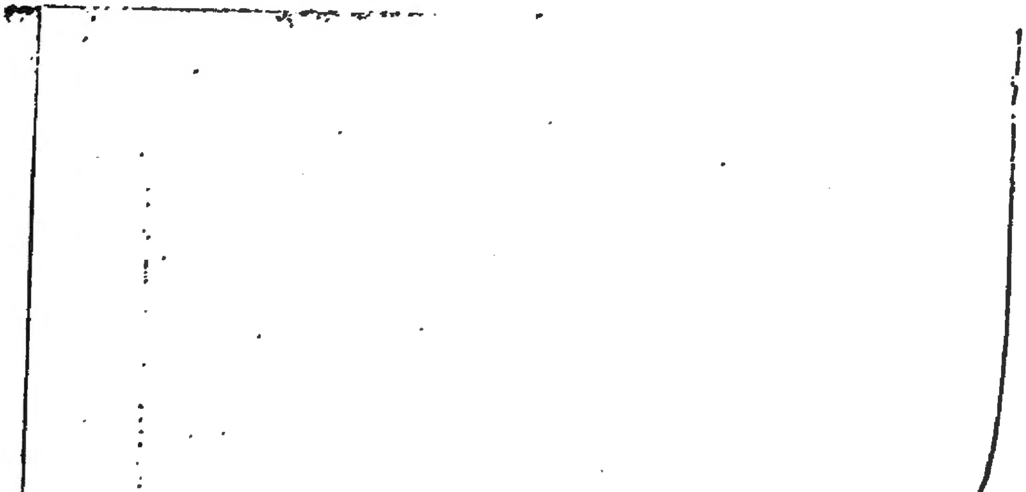
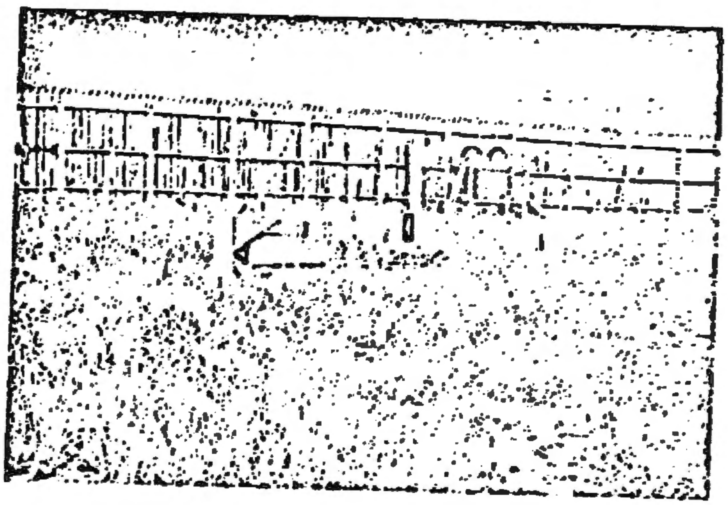
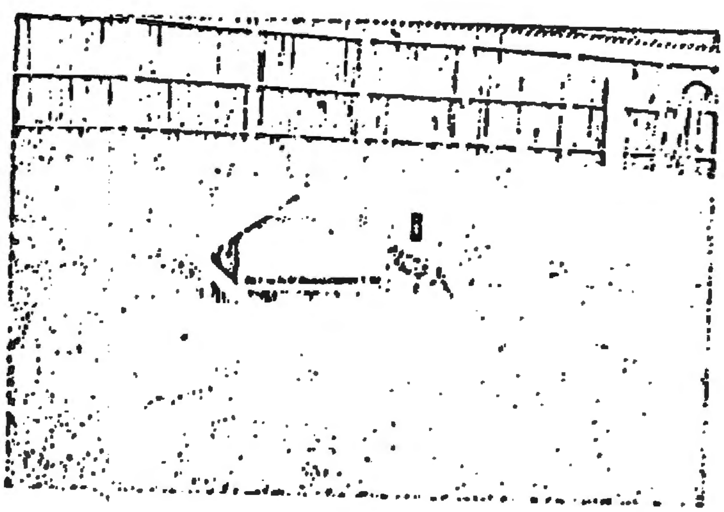
Fig 7-2



D



E



F

care was taken never to present the tone (and, hence, reward the immediately preceeding behavior) so that the dog learned to "squat" near the box. Rather, the dogs learned to roam the field freely and to run to the box only and when ever the tone sounded.

When the food maintained behavior was under good stimulus control, i.e., rapid approach to the box at the sound of the tone, sessions were run in which no tone presentations were used. The dogs were trained to run a rectangular pattern for brain stimulation during these sessions. The food box was located immediately outside the rectangle, at the center of a long side. The dimensions of the rectangle were 48 x 24 feet. Note that these dimensions consist of six 24-foot legs as defined by the ground stakes described earlier, with one leg at each end of the rectangle and two legs comprising each side. When the performance for stimulation was stable, competition sessions were run as follows:

Two experimenters worked together; one guided the dog through the rectangular pattern employing brain stimulation, while the other operated the tone-feeder control. The points in the pattern at which the probes occurred were determined by the second experimenter and were unknown to the first-- a blind procedure.

a) Using this technique, probes were applied, i.e., the tone turned on, during one leg of the pattern and during a different leg for each circuit of the rectangle. On another day, the probe tones were kept on for two consecutive legs of the pattern.

b) The above procedure was repeated, but the intensity of stimulation used to control the behavior of the dogs was varied from optimum (2500 microamperes for one dog and 900 microamperes for the other) to several values below optimum.

The results obtained on the competition tests were strikingly orderly and allowed general conclusions which applied to the two dogs. First, however, note the experimental arrangement in Fig 7. The photographs were taken at the termination of training to enter the box for food, i.e., before the brain stimulation sessions were run. The food box can be seen in each of the photographs A through F. Photographs A through E show a single sequence. In photograph A, the dog (note the dark marker indicating the position of the dog) is facing away from the food box, and that photograph was taken before the tone was turned on. The tone had just been turned on when photograph B was taken; the dog is on his way to the box. In photograph D he is entering the box, and is leaving it, having consumed the food, in photograph E. Photograph F shows the second dog entering the box during a tone trial.

The general conclusions resulting from this experiment were:

a) At <u>optimum levels of stimulation intensity</u>, where excellent control of the field behavior was obtained, <u>neither dog entered the food box even once when the tone</u>

was presented for either one or two legs of the pattern. The control exercised by brain stimulation was sufficient to compete successfully with a food reinforcer 100% of the time.

b) At the lowest intensities employed, 2000 microamperes and 400 microamperes for the two dogs, control by stimulation was virtually nonexistent. Both dogs entered the food box on 100% of the tone presentations. At the lowest intensities, therefore, food provided maximum competition.

c) At intermediate intensities of stimulation, clearly intermediate effects were obtained. Whether or not the food competed successfully depended on several other factors.

i. If the dog was facing the food box when the tone came on, he was more likely to enter than if he was facing away from the food box.

ii. If the dog had immediately before been run under higher intensities of stimulation, he was less likely to enter the food box than if the same intermediate intensity was tested following a lower intensity test.

iii. The degree to which each of the reinforcers controlled the behavior with intermediate intensities of stimulation depended on the level of the intermediate intensity. Food control was weaker at higher intermediate intensities and stronger at lower intermediate intensities.

In summary, then, brain stimulation emerged as a powerful means of behavioral control. Under optimum conditions, a strong reinforcer like food could not compete. Under less than optimum conditions, food was able to compete to a degree inversely related to the intensity of stimulation used to control the dog's behavior.

B. Summary and Conclusions

The results of our work on dogs involving the control of open field behavior employing remotely triggered electrical stimulation of the brain have demonstrated the feasibility of such control techniques. Control of the behavior is positive and can be maintained over relatively long periods of time. Training a dog to perform in the open field under the control of rewarding electrical stimulation of the brain can be accomplished in a short period of time-- about 15 hours of work per dog is a fairly typical value. Advantages of the system we developed are:

1. Behavioral control is obtained at intensities of stimulation which permit portable stimulators of moderate size and weight. Highly specialized miniaturization is not necessary, although such techniques might reduce even further the size and weight of the unit.
2. The use of a single electrode provides for a relatively simple surgical preparation.
3. The system is "quiet," i.e., environmental stimuli such as tones and clickers are unnecessary. Stimulus control over the behavior is exercised by the brain stimulation which serves

also to reward precise movements and initiate locomotion.

4. It has not been necessary to employ aversive electrode placements, i.e., placements at which stimulation is punishing.

Disadvantages of the system as developed are:

1. While the electrode preparation has been satisfactory for research purposes, it is unlikely that it would serve over very long periods of time. Better anchoring and surgical procedures would be necessary.

2. The system is restricted to line of sight. It is necessary for the experimenter to observe closely the orientation of the animal and, particularly, his fine movements. While optical systems could extend the range of such observations, visual obstacles such as trees, hills, foliage, etc., cannot be surmounted. Electronic devices providing out of sight monitoring might extend the range of the system.

3. Individuality among dogs is such as to suggest that automated training procedures might not be a simple matter to develop, but it is worth an attempt.

C. Supporting research

Research which supported our primary aims was performed during all phases of the program. Initially, and particularly during the time before completion of the new research laboratory, we concentrated our activities on research at the level of the rat. With increasing sophistication, and the solutions to problems such as electrode placement in the dog and the development of the portable receiver-stimulator unit, increasingly more attention was focused on dog research. The significant results of the latter efforts were summarized above; this section of the report summarizes the research subsidiary to the dog work. Since much of the supporting research has been summarized in previous reports from this laboratory, our description of the experiments will be relatively concise.

The experiments to be reported below involved the use of several schedules of reinforcement. A schedule of reinforcement may be defined as a rule which relates in an explicit manner the occurrence of a reinforcer and the behavior of an organism. In laboratory practice, these rules are interpreted into relay logic, and electrical circuits consisting of relays, stepping switches, timers, etc. are constructed. While knowledge of the electrical circuit employed in each experiment is unnecessary, a statement of the behavior-reinforcement rule, or schedule, is necessary. Each schedule that we employed is identified in the appropriate place. In some instances, "reminder" definitions have been included. For purposes of completeness, however, a list of the reinforcement schedules we employed will now be presented, and reference to this list may, depending on the reader's background, aid in reading what is to follow.

Response or behavior: An overt, observable movement of the organism. An instrumental response is a skeletal muscle movement that serves to change the organism's environment in some identi-

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fiable way. In the laboratory, a switch operation by means of a lever press (rat) or a key peck (pigeon) have been most often used.

Reinforcement: An instrumental reinforcer is a stimulus change which increases the probability or frequency of a behavior which closely precedes it. The occurrence of such a stimulus change is a reinforcement. A positive reinforcer is synonymous with the colloquial "reward." There is no colloquial equivalent for a negative reinforcer, but the latter are stimulus changes which punish, generate escape, and motivate avoidance.

Schedule of Reinforcement: A rule relating the occurrence of reinforcing stimulus changes to behavior.

Ratio Schedule: A schedule of reinforcement in which the occurrence of a reinforcer is made dependent on the occurrence of a number or count of responses.

1. Fixed ratio: the reinforcer is dependent on the occurrence of N responses, and the size of N does not change from reinforcement to reinforcement.
2. Continuous reinforcement: A fixed ratio schedule in which N equals one response. Thus, each occurrence of the criterion response is reinforced. All other schedules are intermittent reinforcement schedules.
3. Progressive ratio: A ratio schedule in which the size of N increases (in a systematic fashion) throughout an experimental session. The size of the initial N, the progression constant

(i.e., the increment to N) and the number of reinforcements permitted at each value of N, define the schedule. In the experiment reported below which employed a progressive ratio:

Initial N-- one response.

Progression constant-- three responses.

Number of reinforcements-- five at each value of N.

Interval Schedule: A schedule of reinforcement in which the assignment or the availability of a reinforcement depends on the time elapsed since the preceding reinforcement. Note, however, that a response is required to deliver the reinforcement once assigned by the schedule.

1. Fixed interval: The elapsed time for the assignment of reinforcements is constant from reinforcement to reinforcement.
2. Variable interval: The elapsed time varies from reinforcement to reinforcement in an unsystematic fashion. The schedule is identified by the mean (arithmetic) of all the intervals programmed. The distribution of intervals should also be specified; arithmetic distributions were employed below, and the largest interval in the program was always twice the mean of all the intervals. The shortest interval was always several seconds.

Differential Reinforcement of Low Rate (DRL): A schedule designed to generate a "low" rate of responding. A minimum interval of time must elapse (the DRL interval) between successive responses for a response to be reinforced. "Early" responses start the interval anew, and in each instance of an early response, the accumulated elapsed time is lost.

Extinction: After a behavior has been reinforced according to a schedule, withdrawal of the opportunity for reinforcement of the criterion behavior defines extinction.

Chain Schedule: A compound schedule in which more than one requirement must be met in succession for a reinforcement to occur. A subsequent requirement is not initiated until the prior requirement has been satisfied. The situation is arranged so that a distinct environmental condition (stimulus) is associated with each requirement in the sequence. The occurrence of reinforcement reinstates the initial requirement.

Multiple Schedule: A compound schedule in which more than one simple schedule is programmed, each leading to reinforcement, and each component is correlated with a distinct environmental condition (stimulus). Several instances of each simpler schedule may occur in succession; the simpler schedules may change systematically or unsystematically with regard to sequence.

Concurrent Schedule: A compound schedule in which two or more simpler schedules are in effect simultaneously. Where a different response is required for each schedule, as on different levers, the animal may change freely among the several schedules. Reinforcements are assigned by each schedule according to the rules defining each schedule.

1. An early experiment studied the performances of three rats on fixed ratio schedules of reinforcement. On some days, the behavior was rewarded with brain stimulation delivered to the posterior hypothalamus and on other days in the conventional fashion with food pellets. Only one type of reward was used on a given day. Our results demonstrated (in all three rats) that performance with brain stimulation as the reinforcer was clearly inferior to performances maintained by food pellets. In general, pauses in responding after reinforcement, a typical feature of fixed ratio performance, were considerably lengthened with brain-stimulation reward. Increases in the intensity and the duration of the train of stimulation served to temporarily "improve" performance. In a chronic extinciton test in which one hour of extinction was preceded by 20 reinforcements on fixed ratio 10, more responses were emitted when the 20 reinforcements of the daily test session were food pellets as compared with a session in which the 20 reinforcements were brain stimulation.

2. Our attention turned to devising a method for maintaining more behavior with brain stimulation reward than we were able to maintain in the first experiment described above. Two experiments were performed. In both, a schedule of intermittent reinforcement was programmed on one lever of a two-lever rat box. The consequence of responding on that lever was the insertion into the box of another, retractable lever. Brain stimulation (posterior hypothalamus), one train per lever press, was programmed on the second lever and a fixed number of stimulations (continuous

reinforcement) was permitted. Upon completion of that number of stimulations, the lever retracted from the box and the rat could reproduce it only by working on the other, schedule lever.

In the first experiment, a progressive ratio was programmed on the fixed, schedule lever; in the second experiment, a variable interval schedule of 30 seconds. Both experiments gave evidence of better schedule performance, a higher maximum ratio in the progressive ratio experiment and a higher response rate on the variable interval schedule of the second experiment, with increases in the number of stimulations permitted on the retractable lever.

3. Based on the data just reported, we undertook a general and fairly extensive experiment in order to determine the general characteristics of schedules of intermittent reinforcement employing the two-lever, multiple-stimulation procedure described above. Septal and posterior hypothalamic placements were used. Specifically, we were interested in determining whether or not we could maintain schedule performances in the same range of parameter values as ordinarily used with food as a reinforcer. The reinforcer in these experiments, however, was 20 to 100 stimulation-reinforced presses on the retractable lever. The schedules studied were programmed on the fixed, nonretractable lever and were: fixed ratio, fixed interval, variable interval, differential reinforcement of low rates. In all cases, the performances on the fixed lever approximated those typically obtained with intermittent schedules of food reinforcement. Transitions from one schedule to another were also typical. An

implication of this work was: it should be possible to maintain complex performances with our dogs in the field. The critical variable in generating performances using brain-stimulation reinforcement was not the nature of brain stimulation as a reinforcer, but rather the precise way in which it is used. Specifically, the present experiment demonstrated that if a brain-stimulation reinforcement is defined as several response-produced trains of stimulation rather than a single train as is typically the case, substantial behavioral output and characteristic schedule performances could be obtained. Septal placements, however, were inferior to hypothalamic.

4. The procedures just described may be classified as chain schedules of reinforcement, i.e., one performance has as its consequence the opportunity to engage in another performance which leads to reinforcement. Employing a variable interval schedule on the fixed lever (initial member of the chain) and manipulating the parameters of brain-stimulation reward on the retractable lever (terminal member of the chain) a series of experiments was undertaken to systematically study the effects of stimulation parameters. Posterior hypothalamic placements were used throughout, except in the second experiment (Duration) in which septal placements were also used.

a) Intensity: Five stimulations were permitted in the terminal chain member. The intensity, measured in microamperes, was the same for each of the five stimulations. That intensity was changed systematically, however, in order to study the relationship between two response rates: the rate at which the rat pressed the lever on the variable interval schedule in order to gain access to the stimulation lever and the rate at which the sitmulation lever was pressed to produce stimulation once it was obtained. Our results indicated that the variable interval rate of response was low at low intensities of stimulation, increased with increases in the intensity of stimulation and increased still further at the highest intensities of stimulation. The rate at which the rats accepted stimulation was lower at the extremes of the intensity variable, i.e., maximum rates of self-stimulation occurred at moderate intensities. These results were interpreted to mean that the rate of self-stimulation in the terminal member of the chain was a poor predictor of the behavior-maintaining property of brain stimulation.

b) Duration: A similar procedure was employed with a single train of stimulation permitted on the retractable lever (terminal chain member). Again, a variable interval schedule of 30 seconds on the permanent lever (initial chain member) assigned opportunities to respond on the stimulation lever. Train durations from 125 msec to 15 sec were studied, and the primary datum was the rate of responding on the variable interval lever. The results were not clear: they suggested that the "best" performances, i.e., highest variable interval response rates, were obtained at train durations of about five seconds. Somewhat lower variable interval response rates occurred at the longest durations studied. We could not, however, unambiguously attribute the lower rates to the longer train durations-- it was possible that the lower response rates at the longer train durations represented drifts in the baseline rather than effects of the experimental variable. Our experience with this experiment motivated us to seek new methods of studying brain-stimulation variables; the use of concurrent scheduling procedures, to be mentioned later, was the result.

c) Frequency: The frequency of a sine wave is known to affect the performance of rats in a brain stimulation experiment in which the behavior is continuously reinforced, i.e., where each lever press produces stimulation. We examined the effects of sine-wave frequency (peak-to-peak current intensity and train duration held constant) within the context of the chaining procedure outlined above. In this case, the variable interval 30 sec schedule led to a fixed number (20) of stimulation-reinforced lever presses on the retractable lever; the variable interval response rate was evaluated at each of several different frequencies of the stimulation sine wave from 20 cps to 2500 cps. The results were clear: high response rates on the variable interval schedule were obtained with sine wave frequencies between 100 cps and 500 cps. The peak of the function relating rate and frequency was approximately 100 cps to 200 cps. On the basis of these data, the portable stimulator we employed in our dog work was built to provide a 100 cps sine wave.

Subsequent to that initial study, a more complex study was performed in which train duration, current intensity and sine-wave frequency were manipulated in a statistical, factorial-type design. In this experiment, a single stimulation-reinforced press was permitted in the terminal chain member, i.e., on the retractable lever. The above findings were confirmed with the additional result that efforts to manipulate train duration and current intensity so as to keep peak-to-peak microcoulombs constant did not produce equal rates of responding on the variable interval lever. The coulomb, or microcoulomb, may not be a useful indicator of reinforcement value, as has been suspected.

5. Employing the more traditional self-stimulation technique, i.e., a single lever on which self-stimulation may be programmed for each press or according to a schedule of intermittent reinforcement, in our laboratory performed an experiment in which train duration and current intensity were jointly varied. The performance measure was response rate on a schedule of continuous reinforcement, i.e., stimulation delivered for each press, and on a fixed ratio of five to one. Both septal and median forebrain bundle placements were studied in the same animals. Repsonse rates for septal stimulation were consistently lower than for median forebrain bundle stimulation. A train duration of 0.1 sec was consistently "best" for septal stimu-

lation, but the train duration producing maximum response rate for median forebrain bundle stimulation depended on current intensity. Higher current intensities, 400μA and 600μA produced increases in response rate with increasing train durations up to about 0.2 to 0.3 sec. Response rate decreased beyond that point. Optimum train durations were longer for the fixed ratio schedule. The results were interpreted as indicating that microcoulombs is an important determinant of self-stimulation rate. That conclusion differs from the conclusion of the experiment mentioned above in which sine-wave frequency, train duration, and current intensity were jointly varied in the two-lever procedure. The question regarding the possibility of relating reward value of brain stimulation to a single electrical dimension is not answered, and it remains as an interesting possibility.

6. Another experiment by Dr. investigated resistance to extinction as a function of the method of reward presentation. Brain stimulation reward (median forebrain bundle) was presented for one group of animals immediately as the lever was depressed in the traditional fashion. For another group of animals, lever depression activated a dry water dipper in another part of the box, and licking the dipper produced brain stimulation (a chain schedule). Suitable controls were employed, including a standard water reinforcement group. Extinction scores, where lever pressing no longer led to brain stimulation in the first two groups or water in the water control group, showed maximum resistance to extinction in the water control group. Significantly, resistance to extinction

was greater in the brain stimulation group which obtained stimulation by licking the water cup as compared with the group that received stimulation in the traditional fashion, i.e., "on the lever." These results to some extent illuminate our findings reported above (paragraph 3 of this section) in which substantial intermittent schedule performances were maintained through the use of a chaining procedure in which the terminal member of the chain consisted of access to a lever on which a predetermined number of stimulations was programmed on continuous reinforcement. Evidently, the multiple stimulation feature of that work was only one of the variables responsible for the result-- the chaining technique was also important. A general conclusion seems to be that as the methods employed to study rewarding electrical stimulation of the brain approach more and more closely the methods employing conventional reinforcers, differences between brain-stimulation reward and the conventional rewards tend to vanish.

7. Because we entertained the possibility of having to employ an aversive electrode placement in the dog in order to obtain control over the free-field behavior, we studied the effects of aversive stimulation contingent upon a lever press, i.e., punishment. Rats, with electrodes implanted in the medial lemniscus and lateral geniculate areas, were reduced to 80% of free feeding weight and then trained on a variable interval one minute schedule to press a lever for food pellets. When the variable interval performance was stable, stimulation was introduced for each lever press. Response rate was studied as

as a function of the intensity of stimulation. Typical punishment effects were found: the rate on the variable interval schedule varied inversely with the intensity of stimulation. Stated otherwise, the more intense the punishing stimulus, the lower the frequency of the behavior which produced it. That responding was maintained at all was due, of course, to the food pellets which served as a source of positive motivation for the behavior. Further, when stimulation was discontinued, recovery occurred, i.e., the response rate returned to the previously unpunished level. At the very highest intensities of aversive stimulation, recovery was delayed in that the low response rate persisted for some time (minutes) after the removal of the aversive contingency. After low intensities of stimulation, recovery was almost immediate. Significantly, compensation, or a tendency to "overshoot" the <u>prepunishment</u> baseline rate, was seen after moderate intensities of punishment. All of the results of this experiment conformed to findings reported in the literature employing conventional aversive stimuli, such as foot shock in rats.

8. An experiment which provided crucial data in designing the free-field control system for the dogs was performed inside the laboratory and employed rats as the experimental subjects. The procedures and results were described in detail in our report of 1 January 1965. In summary, a small, wooden "field" was prepared. It measured approximately 8 x 4 feet and was located in a corner of the laboratory. A rat, with electrodes located in the region of the mammillary bodies of the posterior hypothalamus, could

roam freely over the field and was connected to a stimulator by means of a flexible cord hung from a pulley device over the center of the field. The experimenter viewed the rat by means of a mirror inclined 45° from the horizontal. Several procedures were attempted in order to control the field behavior of the rat. It was discovered, almost by accident, that if short trains of stimulation are delivered to the rat at a fairly rapid frequency, forward locomotion in the direction of head orientation was initiated. The intensity of stimulation was critical and had to be determined empirically for each rat. Too low an intensity and locomotion was not initiated; too high, and recoil was obtained. The procedure, then, for moving the rat from a point in the field to another point was to turn on stimulation when the rat's head was pointing in the desired direction-- stimulation was kept on (200 msec bursts, three per second) as long as the rat locomoted in the desired direction. The rat quickly learned to wave its head from side to side when stimulation was terminated, because that behavior was rewarded with the renewal of stimulation. If a change in direction was desired, or if the rat veered off course, stimulation was terminated. The rat remained stationary in the absence of stimulation and "sought" the new direction by means of the aforementioned head movement. In a short period of time, good control over the rats' free-field behavior was established.

We next examined the control procedure just described under more stringent conditions from the point of view of maintaining behavioral control. Obstacles were placed in the field which the rat had to surmount in order to continue locomotion in a direction which maintained stimulation. The obstacles were easily surmounted, and little if any degradation in performance was observed. Finally, the field was flooded, and the rat was required to leave a corner platform and swim in order to receive stimulation. Again, control over the direction of locomotion was positive. The significance of the finding with regard to swimming rests in the nature of the behavior-- it is not "rat like." Apparently the control technique is powerful enough to generate and maintain control over a behavior which is not common to the species. While swimming has been studied in rats over the years, we were nevertheless impressed with the finding.

Because the effects just described were obtained in three out of three rats, it seemed promising as a technique for the dog. It will be recognized that the procedure has much in common with the dog control procedure described earlier in this report.

D. Additional research

This classification of research activities is included to cover research which was aimed at exploring the properties of brain stimulation as a reinforcer, the development of techniques to accomplish that goal, and an exploration of some implications of our findings from other experiments.

1. In the typical brain stimulation experiment, stimulation occurs immediately upon closure of the lever switch-- the only

delays involved are those that result from the use of electrical programming devices, and such delays are calculated in milliseconds. Food reinforcement involves delays between a lever press and the receipt of food reinforcement in the order of a second or so. Employing a multiple schedule technique in which the rat had to alternate between two levers to obtain successive reinforcements (perseverative responses going unreinforced) we correlated one stimulus in the multiple schedule with a zero delay between the lever press and stimulation and the other stimulus with a half-second delay. Posterior hypothalamic electrode placements were used. The two delay conditions of the multiple schedule alternated every five minutes. The purpose of the experiment was to study resistance to extinction as a function of the zero and half-second delays; the main data turned out to be the performance of the rats during the half-second delay condition. With no delay, the alternation between levers was smooth; with a half-second delay, rather bizzare response topographies developed between a lever press and the occurrence of stimulation-- the rat would stand erect on its hind paws, forepaws extended and head cocked in an unusual position. That both the smooth and the bizzare topographies occurred in the <u>same</u> rat suggested that the latter was a conditioned response rather than an elicited motor effect of the stimulation. We speculated with regard to the genesis of the delay behavior and suggested that it could have resulted from the instrumental shaping of an originally classically conditioned motor response. To investigate the possibility of classical conditioning, two new rats were employed in a classical conditioning experiment. A brief tone was followed a half-second later by brain stimulation. No instrumental response was required to produce the stimulation, of course, and the intensity of the stimulation was set at a level that produced an easily observable head cock. We succeeded in conditioning and then extinguishing the head cock. Our data were interpreted as being relevant to the discriminative stimulus hypothesis, and we suggested that the logical conclusion that brain stimulation does not require a consummatory response cannot be used as evidence against the discriminative stimulus hypothesis, which relates the discriminative and reinforcing properties of a stimulus. A half-second delay between a stimulus and reinforcing brain stimulation offers ample opportunity for responses other than consummatory to come under the control of an environmental stimulus.

2. A theory of brain stimulation in the current literature identifies a dual role for each response-produced stimulation--it rewards the response in the conventional fashion and also provides motivation for additional responding. Thus, the rat presses the lever because previous stimulation has rewarded the lever press and also motivated further lever pressing. This theory makes an unusual prediction with regard to extinction

after continuous reinforcement. It states that extinction is essentially independent of the number of unreinforced responses and primarily dependent on the time since extinction began. The prediction follows from the theoretical postulation of a time-dependent decay process in the level of the motivation, i.e., when the stimulator is turned off (extinction) the level of motivation decays to zero (presumably). At that point, extinction is complete. The decay process is independent of unreinforced responding during the decay interval.

We examined some implications of this theoretical prediction and obtained mixed evidence. Posterior hypothalamic electrode placements were used. After continuous reinforcement for lever pressing, the lever was automatically removed from the rat box for a period of 22 sec. When returned, the stimulator had been turned off, i.e., extinction was introduced. The number of responses emitted was approximately the same as in a condition where the lever was not removed from the box and extinction responses were counted starting 22 sec after the stimulator was turned off. The theory was confirmed-- the number of extinction responses after 22 sec since the last stimulation was independent of whether or not the lever was present (and responses occurred) during the 22 sec interval. As a further test of the theory, we repeated the condition described above in which the lever was removed from the box for the first 22 sec of extinction. Now, however, "free" stimulations were delivered to the rat at a rate of one stimulation per second. This operation should retard or prevent the decay of stimulation-induced motivation, and the number of extinction responses occurring when the lever is returned to the box should be greater than when "free" stimulation is not given during the 22 sec interval. That result was obtained. As a final test of the theoretical implications of the drive-decay interpretation of brain-stimulation reward, we manipulated the conditions of training, i.e., before extinction testing began. While the rats were being trained to press the lever for continuous reinforcement, the lever was removed from the box every so often for 22 sec and then returned to the box for continued stimulation-reinforced responding. After this type of training, extinction tests with and without lever removal (as described above) were run. The neat relationships failed to appear. The theory, however, predicts that the same relationships should have obtained, since extinction is postulated to be a function of drive decay and not method of training. We concluded that the theory is of limited generality.

3. Because the chaining procedure used extensively in the research reported above was susceptible to baseline drift (see Section C, para. 4b above), we became interested in devising a better method for studying the kinds of problems in which we were interested. The technique we have explored and found to be markedly superior to the simple chaining procedure involves the use of concurrent schedules. With

this procedure, two schedules of reinforcement are programmed for the rat, one schedule on each lever of a two-lever box. Any schedules may be programmed, but, for theoretical and practical reasons, variable interval schedules were used in our work. The programmed schedules run independently. Under these conditions, rats typically respond on both levers and generally obtain the reinforcements assigned to each of the two levers within a short period of time after assignment. The critical feature of the procedure which makes it useful in the analysis of behavior is the fact that the proportion of the total responses emitted on each lever is functionally related to such variables as the relative frequency of reinforcement on the two levers, the amount of reward per reinforcement on each lever, etc. Hence, the proportion of responses emitted on each lever in the concurrent schedule may be studied as a function of different intensities of stimulation, different train durations, different sine-wave frequencies, etc., programmed concurrently. Since the rat samples both experimental conditions in a short period of time, problems of baseline drift are attenuated. We no longer attempt a comparison between performances separated by several weeks. We do not mean to imply that concurrent scheduling procedures are the solution to all ills-- there are new problems in the use of concurrent schedules, but we have found such schedules to be superior to our earlier procedures. Some experiments employing the procedure are now described. Again, posterior hypothalamic placements were employed.

a) Variable interval schedules of one min were programmed concurrently. The reinforcement on one of the schedules was a fixed, standard number of stimulation reinforced lever presses delivered on continuous reinforcement. The number of stimulation-reinforced lever presses per reinforcement on the other lever was varied over values of 1, 2, 3, 5, 10, 50 and 100. The standard against which each of those values was pitted on the first lever was one stimulation in one experiment and 100 stimulations in another experiment.

In both experiments, the proportion of responses, i.e., relative rate of responding on the two levers, was greater on the lever for which variable interval responding was reinforced by a larger number of stimulations. As the number of stimulations approached equality at either the one-one or the 100-100 conditions, the percentage of responses on each of the two levers approached 50%. The shapes of the functional relations obtained paralleled previously published data on concurrent schedules. On those grounds, we were encouraged to attempt further applications.

b) It is possible to deliver a fixed stimulation time to a rat by varying the train duration per stimulation jointly with the number of such stimulations permitted the rat. Thus, for example, five seconds of stimulation may be delivered in a single 5-sec train, in two 2.5 sec trains, etc. We examined the rats preference for train durations of 1.2, 2.4, 4.8, 9.6 sec, each paired with a number of 120 msec trains so chosen that total stimulation time was the same. The schedules programmed on the two levers were variable interval one min schedules; the reinforcer for one of the schedules was the single train of stimulation, and the reinforcer for the other schedule was the multiple stimulation condition. The data examined were the proportion of responses emitted on the two levers. The data were unequivocal in pointing to a lack of preference for one method of stimulation as compared with the other.

In order to determine whether the concurrent performances were sensitive to the experimental variable, so that the conclusion of equal performances implied no preference rather than no experimental control or an insensitive baseline, various degrees of inequality were introduced. A single train was favored by reducing the number of 120 msec stimulations paired with the single train, and the multiple stimulations were favored by reducing the duration of the single train. Both types of manipulations resulted in shifts in the proportions of responses emitted on the two levers in the expected directions away from equality. We concluded, therefore, that the equalities previously obtained represented "no preference." The electrode placements were in the posterior hypothalamus.

c) An important feature of concurrent variable interval schedules is the change over delay (COD). If one of the schedules assigns a reinforcement while the rat is responding on the other schedule, the first response after a change to the concurrent lever will ordinarily produce the assigned reinforcement. With a COD, however, the first response does not produce the assigned reinforcement but rather starts the delay timer. The first response to occur after the delay timer times out produces the assigned reinforcement. The delay serves to "punish" and thereby reduce the frequency of change over responses, i.e., switches from one lever to the other. Employing the concurrent procedure with a short COD (a half to several seconds) an interesting relationship has been reported in the literature. Pigeons distribute their responses on the two levers (or keys) in the same proportion as variable interval schedules assign reinforcements. In other words, the relative rate of responding equals the relative rate of reinforcement. Thus, if, for example, the pigeon obtains one third of its reinforcements on one of the keys, one third of the responses will be emitted on that key. As stated above, the reinforcement schedules employed in these experiments are variable interval schedules; these schedules permit a wide range of response rates with little or no difference in reinforcement frequency. An implication of that property of variable interval shcedules is the fact that the matching relation stated above is not trivial; relative reinforcement rate could take on a single value with widely divergent relative response rates. The fact that relative reinforcement rate matches relative response rate, in spite of the above considerations, suggests that the relation may be theoretically important.

While it is known that the COD is important in producing the matching relation, its exact role has not been experimentally determined. Two possibilities exist: matching occurs provided a COD of some size is programmed; alternatively, matching is an artifact of the tendency for a COD to "amplify" a bias for one of the schedules, and the degree of amplification is a function of the size of the COD. The second interpretation states that matching will occur only with a critically chosen size of COD.

In order to examine the two possible interpretations of the role of the COD in the matching relation, four rats were implanted with electrodes in the posterior hypothalamus. Two were placed on concurrent variable interval schedules of one and a half minutes; the other two were placed on a variable interval one minute schedule concurrent with a variable interval three min schedule. For all the rats, COD was varied from zero to 20 seconds. In conformity with the second interpretation of the role of the COD, a smooth and approximately linear, rising function relating COD to proportion of responses on the one minute variable interval schedule was obtained with the rats on the concurrent one minute--three minute schedules. "Matching" occurred when the function passed through 75% at a COD of about 10 sec. At a zero sec COD, the function was at approximately 50%; at a 20 sec COD, it was at approximately 90%. A function at 50% across all CODs was obtained with the rats on the concurrent one and a half minute schedules. That result was expected, since the equal variable interval schedules provided no bias on which the COD could operate.

4. Dr.

investigated some physiological effects of stimulation in the dog. It is known, on the basis of Dr. work with rats, that septal stimulation produces a deceleration in heart rate while hypothalamic stimulation usually produces acceleration. Precise location of the electrode within the area in question is critical in determining the magnitude and sometimes the direction of these changes. Three dogs were implanted: electrode placements were in the dorsomedial nucleus of the hypothalamus, ventromedial nucleus of the hypothalamus, and the field of Forel. The data recorded were heart rate, blood pressure, and respiration rate during 5-min periods of self-stimulation alternated with 5-min periods in which lever pressing produced no stimulation. An exteroceptive stimulus was correlated with the stimulation-available condition.

All three dogs showed transient hypertensive states during self-stimulation. Heart rate increased in all three dogs, and to a statistically significant degree in two dogs. Exercise as a factor in the cardiovascular changes was evaluated by paralyzing two dogs with curare, providing for artificial ventilation, and stimulating manually. Under those conditions, the blood pressure changes persisted and heart rate changes were reduced in magnitude.

A parasympathetic blocking agent, atropine, did not affect self-stimulation behavior; nor did it affect heart rate or blood pressure. An adrenergic blocking agent, dibenzylene, completely blocked the blood pressure changes but accentuated heart rate changes. Another such agent, dichloroisoproternol (DCI), also accentuated heart rate changes during self-stimulation. Neither adrenergic blocking agent affected self-stimulation rate. The dosages used were: atropine, 0.1 mg/kg; dibenzylene, 5 mg/kg; DCI, 3 mg/kg.

5. Several experiments employing pigeons as experimental subjects were performed. The experiments are relevant to several problems in the analysis of behavior.

a) The principle investigator had previously demonstrated distinctive changes in response rate during a relatively brief stimulus preceding a change from one variable interval schedule to another where the two variable interval schedules are characterized by different frequencies of reinforcement. An increase in response rate was obtained during the stimulus which signalled the unavoidable transition from a high frequency of reinforcement schedule to a lower frequency of reinforcement schedule; a decrease in response rate was obtained during the stimulus signalling the opposite transition. The two rate changes, therefore, were obtained on different baseline schedules. The rate-change finding was replicated in a control experiment designed to obtain both rate changes (in opposite directions) with reference to the same baseline schedule. A variable interval schedule of two minutes (white response key) always preceded a transition to a variable interval schedule of 30 sec (green key) or 15 min (red key). Whether the 30 sec or 15 min schedule would follow a particular exposure to the two min variable interval schedule was not predictable until the onset of a distinctive stimulus, two min in duration, which preceded each type of transition. Food was used as the reinforcer in this experiment. The results indicated clearly a tendency for the pigeons to increase response rate on the 2 min variable interval schedule during the stimulus signalling the transition to the 15 min variable interval schedule; a rate decrease was in evidence during the stimulus signalling the transition to the 30 sec variable interval schedule. These results

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clarified the previous finding by demonstrating that the two rate changes (in opposite directions) did not depend for their occurrence on different baseline frequencies of reinforcement and response rates. Both changes were obtained on a variable interval schedule of two minutes in the present experiment.

b) Experiments which study stimulus control, i.e., the process whereby stimuli gain control over behavior, typically employ environmental stimuli such as sounds and lights-- stimuli external to the organism. The concept of proprioceptive stimulation emphasizes stimuli internal to the organism, i.e., stimuli

which result from the organism's own behavior. Behavioral control exercised by behavior-produced stimulation was explicitly studied in our laboratory through the use of a novel experimental design. The pigeon was required to peck on a red key either a large or a small number of times. Completion of either response requirement extinguished the red key, and it was replaced by two white keys. If the larger number of pecks was required on the red key, a single peck on the right white key produced food (reinforcement); a peck on the left white key produced nothing. The converse relation obtained after the smaller requirement on the red key. The white key choice behavior of the pigeons was studied as the larger and smaller requirements on the red key were varied. Paired requirements of 95-5, 75-25, 65-35, 60-40, 58-42, and 50-50 were studied. The results demonstrated clearly that the pigeons could use feedback stimuli from their own red-key behavior to control the choice response on the white keys. Further, as the difference between the two requirements was reduced, error frequencies increased, particularly when the 60-40 and 58-42 pairs were introduced. Error frequencies were about 50% with the 50-50 pair, as expected, since the pigeon could not discriminate one requirement from the other when the two were equal. Finally, it was found that a delay introduced between the completion of the red-key requirement and the opportunity to make a choice response increased error frequencies. The "memory" function was variable among the several birds, and the variability was attributed to the differential development of "mediating behaviors," i.e., stereotyped behaviors which filled the delay intervals. The results of the experiment were interpreted as demonstrating a basic similarity between proprioceptive stimulus control and exteroceptive stimulus control.

c) As noted above, experiments on concurrent scheduling most often employ a COD. The COD, or change over delay, is symmetrical in that the same delay is programmed for change over responses between the two levers in both directions of change. An experiment was performed in which asymmetrical change over delays were programmed. All combinations of CODs of 1, 3, 9, and 27 sec were studied. In addition, the symmetrical pairs 0-0, and 1/3-1/3 sec were studied. The concurrent schedules in the context of which the CODs were programmed were variable interval schedules of three min. The experiment is in the last stages of completion, and a separate report will be submitted when the data are analyzed and the experiment is written in a form suitable for publication.

Another part of the present experiment is concerned with a second method of controlling the frequency of the change over response. The first method, programming a change over delay, was described above. The alternative method is to establish stimulus control over the change over response. While the pigeon is working on one of the two concurrent variable interval schedules, the assignment of a reinforcement on the <u>other</u> schedule is accompanied by a distinctive environmental stimulus. Since a change over response is never reinforced in the absence of the environmental stimulus and always reinforced in the presence of such a stimulus, the occurrence of the change over response comes under the control of the environmental stimulus. The outstanding characteristic of the data is a marked reduction in the frequency of change over responses as compared with the experimental condition involving no stimulus correlated with the availability of reinforcement on the other member of the concurrent schedule. These data are presently undergoing analysis in detail, and they will be reported when in a form suitable for presentation.

IV. Applications

There are two general classes of application suggested by the research performed in our laboratory. One set of applications involves problems of a practical nature, military problems perhaps representing the most interesting and useful subclass. The second set of applications stems from basic research problems.

Practical applications can be recognized by a unifying principle: it is desired to place a living organism in a certain geography which may be too dangerous for a human. The fundamental requirement of any solution to that problem is that the behavior must be under constant surveillance and control from a position remote from the terrain in question. The work reported in section IIIA of this report described a procedure which is effective in establishing and maintaining remote control over the behavior of a dog. Surveillance of the dog's behavior is no problem, provided line of sight is an acceptable restriction. The development of a surveillance system free of that restriction is primarily an electronics problem. Possible uses of the controlled dog are not difficult to formulate.

A. A dog may be used as an ammunition and message carrier over terrain too dangerous or, for some other reason, inaccessible to man.

B. A dog may be used as a "guided missile" in destroying small, strategic structures. In this case, the dog would carry explosive charges which can be detonated from a distance by means of a radio signal.

C. A dog may be used to carry sensing devices which detect radiation or chemical agents in concentrations potentially harmful to troops. By this means, a terrain may be evaluated prior to actual occupancy. An elegant development of this application would involve the use of the dog's physiology as the sensing instrument. Heart rate, blood pressure, etc., would be monitored and telemetered to the home base.

D. A dog under good behavioral control could serve as a scout dog, or, in old cavalry terms, "ride point." A dog trained to detect and signal the presence of enemy troops would serve to prevent ambush.

Some of the above applications involve destruction of the animal; all of the applications risk loss of the animal. One advantage of the control system we developed is the relatively small investment in training time necessary to prepare a dog for some of the possible applications. As stated earlier in this report, about 15 hours of working time are often sufficient to obtain a usable dog.

Basic research applications involve the removal of a restriction often faced in behavioral experiments. Extended daily experimental sessions are impractical in the behavior laboratory because of satiation effects when food is used as the reinforcer for the behavior under study. Special techniques employing "second order schedules" have recently extended the permissible session length. Application of second order schedules for prolonged observation of food-maintained baselines is promising and will come into use as more is learned about the dynamics of such schedules. The advantage of rewarding brain stimulation may be realized in the use of the more common, first order schedules. Electrode placements which do not yield adaptation or "satiation" effects may be used in studying the long-term effects of drugs, radiation, etc., on simple behaviors. Additional basic research applications are easily devised in many areas of bio-medical research.

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A PREPARATION OF DOGS FOR SELF-STIMULATION OF THE BRAIN

Complete Address:

Running Head: Preparation of the Dog for Self-Stimulation

ABSTRACT

A detailed description of the surgical procedures involved in the preparation of a dog for self-stimulation is presented. The authors emphasize the preparation of the tip of the stimulation electrode and the preparation of the leads so that no wound is left on the dog's head. A description of the electrical and general behavior characteristics of self-stimulation are included.

Indexing Items:

1. Physiological Psychology.
2. Experimental surgical procedure.
3. Self-stimulation in the dog.
4. Brain-stimulation in the dog.
5. Electrode implantation.

Investigations of intracranial stimulation in the dog in our laboratory have encountered two major problems in the surgical preparation: 1) electrodes placed in areas which when stimulated support operant behavior in other species would not produce bar-pressing for self-stimulation in the dog. Also, 2) the electrode pedestal cemented to the skull would loosen during the animal's general activity in the home cage. This paper describes the techniques developed to overcome these difficulties.

Preparation of the electrode:

The electrodes used were obtained from Plastic Products Corp. and are made of bipolar twisted .010 inch insulated platinum wire. The wire is bent to the position shown in Fig 1 and cut to 40 mm. of vertical length. Using a needle, the poles of the electrode are untwisted so that a gap of 1.5 to 2 mm. is formed. The electrode is grasped with a hemostat which is mounted in the electrode carriage. Placing the point between the electrode poles on the mid-line and equidistant from the two ear bars gives a reference zero from which coordinates are measured.

(Figure 1 about here)

Surgical Procedure:

The dogs are routinely give 1/4 grain Morphine Hydrochloride 45 minutes prior to surgery. Deep surgical anesthesia is accomplished with Pentobarbitol. After routine surgical preparation of the operative fields over the head and shoulders, a longitudinal skin incision is

Surgical Procedure: (cont'd)

made over the implantation site. The skin and subcutaneous tissue are reflected and the periosteum is elevated. The exposed bone is now marked with a scalpel at the desired coordinate (anterior-posterior and lateral) positions. A hole is drilled with a dental burr sufficiently large to allow passage of the electrode into the brain tissue without deflection (about 8 mm. in diameter). The dura is nicked with a Graef Cataract Knife and after final check of the coordinate distances the electrode is lowered to the verticle depth desired. Stainless steel screws 0-80 x 1/4" are placed around the electrode and crainoplastic cement is applied. Sufficient cement is added to include the screws and the electrode pedestal in a firmly bonded island of cement. The electrode leads are then attached, the adapter threaded on and a final overlay of cement is applied. This layer is sufficiently thick to thoroughly waterproof the adapter-pedestal connection, to fix the polyethylene lead and to form a smooth surface (see Fig. 1).

A stab wound over the shoulders is made and a Rumel #2 thoracic forceps is forced anteriorly through the subcutis until it exits in the implantation wound. The distal end of the lead is grasped with the jaws of the forceps and withdrawal of the forceps positions the lead subcuteneously exiting at the shoulder. Wounds are closed in a routine manner. The distal end of the leads are attached to a

Surgical Procedure: (cont'd)

commercially available dog harness.

The placements which have been most successful with respect to reward characteristics have been those aimed at the inferior portion of the fornix at the level of the hypothalamus. The following coordinates were used as read from

} Anterior 20 mm., Lateral 2.5 mm., Vertical 7.0 mm. above instrument zero. Histological examination of various dogs has shown that the electrode tips were in 1) the fornix, 2) the campi Foreli and 3) ventral-medial hypothalamus.

Stimulation Characteristics:

Electrical: A 100 cycle sine wave with 800 μA - 2000 μA peak to peak amplitude produces strong reward characteristics. Resistance of the tissue varies among dogs and is from 6 to 12000 ohms. However, it is very constant during stimulating sessions and across days. On a square wave with a 200 μsec pulse width a 200 μsec interpulse time (i.e. 100 cps, see inset, Fig. 2) a peak amperage of about 1000 μA is necessary. Train duration used is a function of schedule and individual animal, the range of effective durations is .2 to .5 of a second.

(Figure 2 about here)

Behavioral: Figure 2 presents cumulative records from the lever-responses of a beagle prepared in the above manner. At first, the animal is trained to lever-press for immediate stimulation. Then the ratio of responses to stimulations is fixed at higher values. At fixed ratios of 120 presses for each stimulation the dogs will work steadily in long sessions (5-8 hours), but will eventually show breaks from responding of 10 to 20 min in longer sessions.

Discussion: In contrast to techniques such as described by which anchors a protruding pedestal to the skull, this preparation allows the scalp to completely heal and leaves no protrusions. A procedure for implanting electrodes in rats has been described by and also leaves a pedestal protruding. As they describe, the healing of the scalp is fairly complete in the rat and, therefore, the procedure is very satisfactory. However, in the dog this procedure leaves an open wound, and a preparation vulnerable to damage from the vigorous activity of the animal.

If the investigation requires no more than three electrodes the procedure is convenient. However, Discussion: (cont'd)

if more electrodes are needed the necessity of attaching more adaptors and of passing them posteriorly to an opening at the shoulder becomes cumbersome.

Also, the preparation of the bipolar electrode with the unusually large gap has limited use in certain research. When the purpose is to stimulate a relatively large area in an effort to present a stimulation which has reward properties, the described procedure is recommended. However, when stimulation of a precise point is intended the field between the electrode tips would be prohibitively large.

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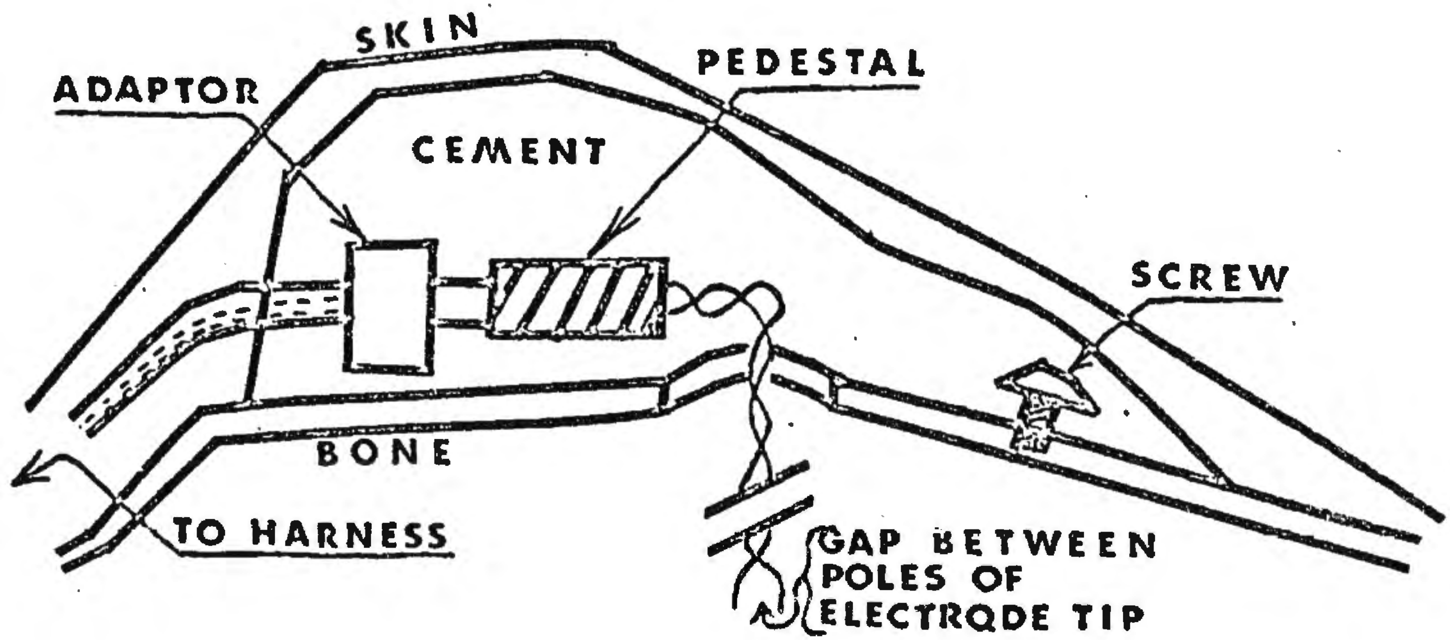
SKIN
PEDESTAL
ADAPTOR
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TO HARNESS
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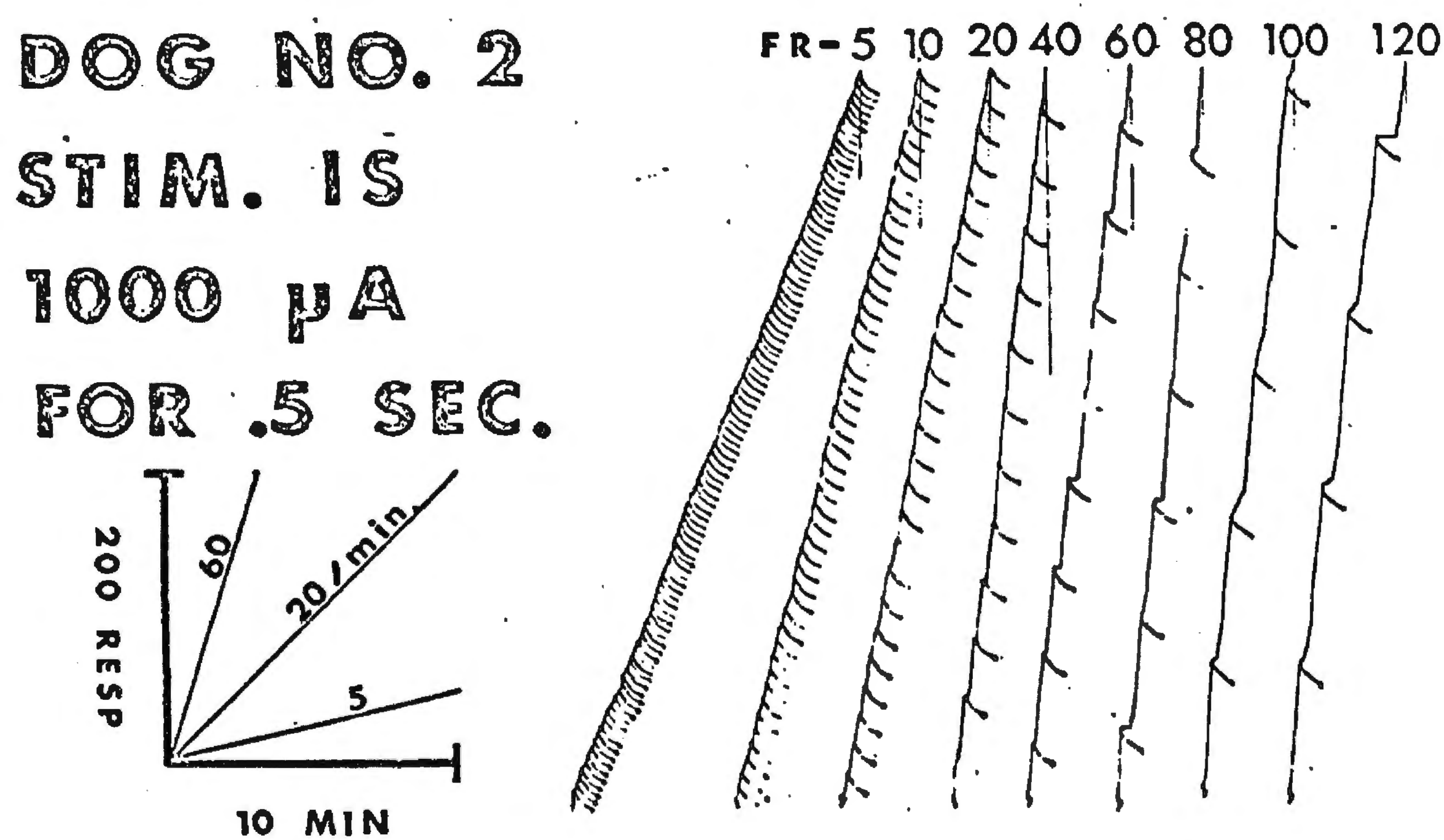
DOG NO. 2
STIM. IS
1000 μA
FOR .5 SEC.
200 RESP
10 MIN
60
20/min.
5
FR-5
10
20
40
60
80
100
120

FIGURE CAPTIONS

Figure 1 Corpleted preparation of the electrode placement.

Figure 2 Cumulative records of lever presses under different fixed ratios (FR) of lever presses to stimulations.