entered or left the pond. This indicates that they probably climbed the fence on entering or leaving the enclosure. One of these animals died at the top of the fence when it became entangled. In 1965 a plastic fence has eliminated the climbing problem; all members of the breeding population are trapped at entrance and exit.

In 1965, 14 animals collected by hand as they migrated toward the pond were marked and released at the point of capture. They were from 10 to 44 m from the pond. All these animals were later trapped at the pond border nearest the original site of collection; therefore it is probable that the compass point at the pond border where the animals were trapped represents the direction from which the animals migrated.

An animal captured in the trap outside of the fence at "north" may have encountered the fence anywhere between NNW and NNE. Therefore, an animal leaving the pond might be trapped at any of these three stations should it choose the same track of exit as entrance. Thus, I judged a record "consistent" if a departing animal was trapped at any of these stations. This procedure was used for all compass points.

Fifty-six of the 155 animals were captured on entering and leaving the pond. These salamanders stayed from 4 to 20 days in the pond, and they distributed randomly while in the pond. Twenty-two chose consistent routes of departure; 12 were 22.5° from consistent; 9 were 45° from consistent; and 13 were 67.5° or more degrees from consistent (Fig. 3). The probability that the animals would choose a consistent heading by chance is 3/16 or 10.5 of the 56 animals. The probability that the animals would choose directions ranging from consistent to 45° from consistent is 7/16 or 24.5 of the 56 animals. The differences from the calculated probabilities are significant ($p <$ .01). The animals showed a marked preference in their direction of departure which was correlated with the direction from which they arrived. Results obtained in 1965 suggest that individuals use the same track in subsequent years.

That the migratory movements of ambystomatids involve some sort of orienting mechanism has long been obvious, yet studies of this phenomenon in any species of *Ambystoma* are few. Finneran (*2*) attributed the orientation of *A. maculatum* to breeding ponds to a rheotropic response in overflow brooks formed during heavy rains. Such a response fails to account for movements uphill and downhill, across meadows lacking temporary brooks, or during nights without rains—as I have observed in several species of migrating ambystomatids. Since the salamanders migrate during rain, fog, or cloudiness, they probably do not use visible celestial cues in orienting. Twitty (*1, 3*) indicates that *Taricha* may utilize olfaction in orienting to streams for breeding. The orienting mechanisms of *A. maculatum* are unkown.

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24 May 1965

Lateral Hypothalamic Stimulation in Satiated Rats: T-Maze Learning for Food

Abstract. *It is well known that electrical stimulation in portions of the lateral hypothalamic area is positively reinforcing and induces eating in satiated rats. We have found that continuous stimulation of this kind can also motivate satiated and previously untrained rats to learn the location of food in a T-maze. Efficient acquisition and reversal of discriminations for food indicate that lateral hypothalamic stimulation exerts motivational effects which are functionally equivalent to those of food deprivation.*

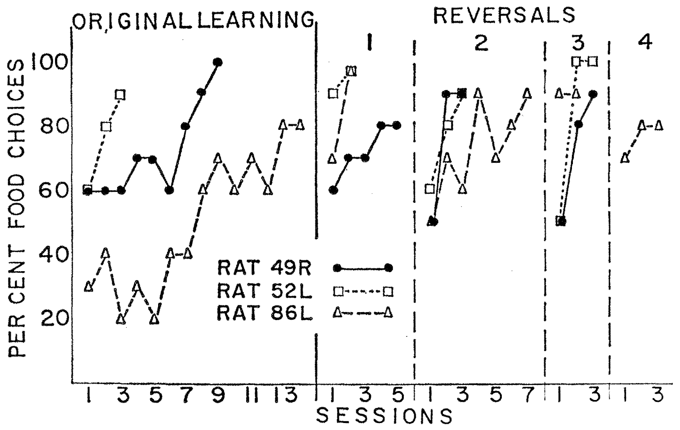
Hungry rats will learn a large variety of instrumental responses in order to obtain food. Since the discovery that electrical stimulation in the lateral hypothalamic area elicits eating in satiated rats (*1*), interest has been aroused concerning the extent to which the motivational state induced by such stimulation is similar to normal hunger produced by food deprivation. So far, it has been shown in satiated goats, cats, and rats that lateral hypothalamic stimulation induces performance of food-seeking responses previously learned under conditions of food deprivation (*2*).

Since lateral hypothalamic stimulation can induce the performance of learned responses which, under normal conditions, are persistently made only by animals deprived of food, one might expect that such stimulation could also replace food deprivation as a motivational condition for the acquisition of food-seeking responses. However, there are two known factors which might be expected to interfere with such learning: (i) brain stimulation which induces eating is also positively reinforcing (*3*); (ii) positively reinforcing brain stimulation, delivered on a non-contingent basis during training, tends to interfere with learning (*4*).

In spite of these two factors, Coons (*2*) succeeded in training satiated rats receiving continuous lateral hypothalamic stimulation to perform a simple panel-pushing response to obtain food. The evidence for learning was a decrease in the latency of responding as trials progressed. Our purpose in the present experiment was to determine whether satiated rats receiving continuous stimulation in the lateral hypothalamus can learn a more complex, discriminative response for food. Specifically, under these conditions, will rats learn to choose consistently that arm of a T-maze which leads to food?

Six naive rats (five hooded and one albino) were selected from a group of 40 in which electrodes had been implanted in the vicinity of the lateral hypothalamus (Krieg coordinates: 0.8 mm posterior to bregma, 8.2 mm below the superior surface of the skull, and 1.5 mm lateral from the midline). The six rats selected were the only ones in which 60-cy/sec sine-wave stimulation reliably elicited eating in the satiated state (*5*). The animals were maintained individually in cages in which food pellets (Purina Lab Chow) and water were available continuously; at no time were they deprived of food or water.

Each animal was trained in a T-maze, of which the starting arm was gray, the left arm and goal box white, and the right arm and goal box black. On each trial the animal was placed at the beginning of the starting arm and stimulation was initiated. The intensity of stimulation used for each animal was the minimum which would induce eating in the satiated state (45 to 240 μa root mean square). The



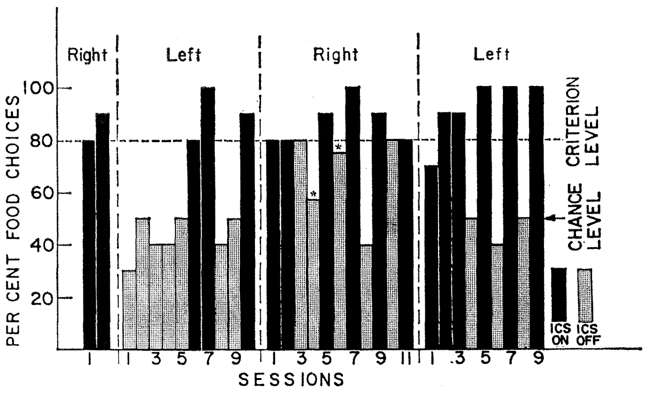


Fig. 1 (left). Percentage of responses made to the side of the T-maze containing food during successive blocks of ten trials by three satiated rats receiving continuous electrical stimulation in the lateral hypothalamus. The left-hand portion shows the scores obtained during the original learning; the right-hand portion, during a series of reversals. Fig. 2 (right). Percentage of responses made to the side of the T-maze containing food by a satiated rat (No. 49R) during successive reversals. (Solid bars, sessions in which stimulation was delivered; stippled bars, control sessions). On sessions marked with an asterisk the animal failed to run the maze within 3 minutes on three successive occasions; therefore the session was terminated before ten trials were completed.

stimulation was terminated 10 seconds after the animal entered either goal box. The rat was removed from the goal box just before the end of the 10-second period, and the current was terminated as it was placed in a cage where it waited for 1 minute between trials (*6*). Food pellets were always available in this cage, but unstimulated animals were never observed to eat them.

On two preliminary trials there was no food in the maze. On subsequent trials, food pellets (Purina Lab Chow) were available in one of the goal boxes. For those animals which, on the two preliminary trials, had shown a preference for one arm of the maze, the food was placed in the goal box of the nonpreferred arm. The food could not be seen from the choice point. Each animal then received one 10-trial session per day to a learning criterion of at least 16 correct responses in two consecutive sessions, with at least 8 out of 10 correct in the second session. After the animals reached the learning criterion they were subjected to two training sessions per day in which the location of the food (that is, the "correct" goal box) was reversed each time they reached criterion.

When the learning sessions and reversal training were completed, five of the rats were tested in the maze to determine the reinforcing effects of the lateral hypothalamic stimulation. During this phase of the experiment all food was removed from the maze; whenever a rat entered one of the goal boxes (left or right for different rats), stimulation was initiated and continued for 10 seconds. During the last second of stimulation, the rat was removed from the goal box. Following an entry into the other (or incorrect) goal box, no stimulation was delivered; after 9 seconds the animal was removed from the maze. Upon reaching criterion (as defined above), reversal training was initiated: the positions of the "correct" and "incorrect" goal boxes were interchanged and the animals were retrained to criterion.

In the first part of the experiment, animals receiving lateral hypothalamic stimulation required a median of 40 trials in order to learn to run consistently to the goal box containing food (*7*). They required a median of five trials to learn the first reversal. Three animals were subjected to three or more reversals. As shown in Fig. 1, two of them (Nos. 86L and 49R) developed reversal learning sets; that is, they tended to show a progressive reduction in the number of trials required to reach criterion on each successive reversal. In original learning and reversal training, the performance of the third animal was so rapid as to preclude the possibility of improvement during subsequent reversals. On control trials in which no stimulation was given, food-seeking behavior ceased; choices were either equally distributed between the two arms or a position preference developed which was unrelated to the location of the food (Fig. 2).

The results of the second part of the experiment indicated that the lateral hypothalamic stimulation was positively reinforcing for the five animals tested. With no food in the maze, they learned in a median of 10 trials to go consistently to the goal box in which stimulation was delivered. Reversal learning was accomplished immediately (median, zero trials).

Thus, the main finding of our experiment is that lateral hypothalamic stimulation which induces eating in satiated rats can also serve as a motivational condition for the learning of a new response to obtain food in a T-maze. In this respect, lateral hypothalamic stimulation has the same motivational effects as normal hunger induced by food deprivation. However, the effects of stimulation differ from those of food deprivation in that the minimum current intensity required to induce eating is also positively reinforcing. Taken together, the two parts of the experiment demonstrate that rats receiving non-contingent, positively reinforcing lateral hypothalamic stimulation can rapidly learn a discrimination task and can efficiently perform successive reversals of that task.

Although these data appear to conflict with a number of reports that positively reinforcing brain stimulation interferes with learning, there are several procedural differences which may in part account for this discrepancy. (i) In previous experiments (*4*) the brain stimulation was intermittent, while in our experiment it was continuous. Stein (*8*) showed that, with electrodes in the hypothalamus, continuous stimulation is less reinforcing than intermittent stimulation. This suggests that the continuous stimulation used in our experiment did not significantly impair learning because it was less conducive to the development of competing ("superstitious") responses which might tend to interfere with the acquisition and performance of the "correct" response (*9*). (ii) In our study the stimulation was relevant to the testing situation in that it induced the animals to consume the food in the goal box. In the other studies the stimulation was not shown to have any such relevance. (iii) There is some evidence that highly motivated rats can overcome the disruptive effects of positively reinforcing brain stimulation (*10*), and that rats receiving lateral hypothalamic stimulation are more highly motivated to obtain food than are rats which have been deprived of food for up to 7 days (*11*). Although in the present experiment satiated animals received the minimum current intensity which would reliably induce eating, it is possible that, even at this threshold level, lateral hypothalamic stimulation produces a degree of hunger which is sufficiently high to overcome any deleterious effects of positively reinforcing brain stimulation on the learning of instrumental responses to obtain food.

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4. Positively reinforcing brain stimulation delivered to septal or hypothalamic loci at the onset of an auditory stimulus severely impairs the learning of a discriminative response to the stimulus [L. Stein and E. Hearst, *Amer. Psychol.* **13**, 408 (1958)]. Positively reinforcing lateral hypothalamic stimulation has been reported to disrupt performance on a food-rewarded, discrimination-reversal maze problem [M. E. Olds and J. Olds, *J. Comp. Physiol. Psychol.* **54**, 838 (1961)]. The disruptive effect is apparently not restricted to situations in which positive reinforcers are used to motivate learning; similar effects are reported in a study of shock-avoidance learning by R. M. Cooper and J. H. Bauer, *Can. J. Psychol.* **17**, 338 (1963).
5. Histological examination revealed that the electrode tips were located in the lateral hypothalamic "feeding area" as defined by Coons (*2*).
6. On rare occasions three of the animals left the goal area before 10 seconds elapsed. When this occurred, the animal was allowed to return to the choice point, where it was picked up and held for the remainder of the 10-second period.
7. The final 20 criterion trials were excluded in computing the learning scores reported here.
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9. It is interesting that investigators concerned with the effects of frontal lobe stimulation on the delayed alternation performance of monkeys have reported that severe deficits are produced only by intermittent, but not by continuous, stimulation [see L. Weiskrantz, L. J. Mihailovic, C. G. Gross, *Brain* **85**, 487 (1962) and J. S. Stamm, *J. Neurophysiol.* **24**, 414 (1961)]. In these studies the stimulation was presumably not reinforcing [E. Briese and J. Olds, *Exptl. Neurol.* **10**, 493 (1964)].
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18 June 1965

Temperature Independence of an Arbitrary Temporal Discrimination in the Goldfish

Abstract. *Goldfish were taught to press a lever for food reinforcement and were placed on a 1-minute fixed-interval schedule. They developed the characteristic temporal discrimination (scalloping) seen in rats and pigeons. There was no change in their relative response rate through the 1-minute interval when ambient temperature was decreased by 10°C. This 10°C temperature drop, which approximately halves the metabolic rate, approximately halved the absolute response rate. These results indicate that a temporal discrimination can be established in the goldfish, and suggest that discriminations of short intervals in fish are not dependent on a mechanism tied directly to metabolic rate.*

A great deal is known about natural behavioral and physiological rhythms in the animal kingdom. These rhythms usually have a period of about 24 hours (circadian rhythms) and seem to reflect the operation of an endogenous clock, influenced by environmental factors. Much less is known about learned temporal discriminations involving short and arbitrary time intervals, although a few mammals and birds have been taught to perform particular responses at certain short intervals (*1, 2*). One purpose of the experiment described herein was to determine whether similar temporal discriminations can be established in a poikilotherm, the goldfish. Wolf and Baer (*3*) recently reported that such discriminations could be established in a single gourami fish maintained on fixed-interval schedules, but Gonzalez, Eskin, and Bitterman (*4*) failed to establish temporal discriminations in the African mouth breeder, *Tilapia macrocephala*.

Should a temporal discrimination be demonstrated in the goldfish, it could then be tested for temperature dependence to determine whether the "timing mechanism" is tied to metabolic rate. A number of circadian rhythms are not dependent on temperature (*5*). However, it has been suggested that variations in the diurnal environment may play some role in this independence (*6*). A discrimination involving arbitrary short intervals is almost certainly not correlated with significant environmental (diurnal) changes, and thus provides a possible means of analyzing a timing mechanism.

Three goldfish, *Carassius auratus*, were employed in the first part of this study. They were kept in small aquariums at a constant temperature of 30° ± 0.1°C and were trained to press a lever (*7*). Each time the lever was pressed, one white worm (*Enchytraeus albidus*) was released into the tank by an automatic dispenser (*8*). The fish were trained for 30 to 40 minutes each day in their home tanks. After a few days, they were required to press the lever three times in order to receive each worm, and then training on a temporal discrimination was begun. The same conditions prevailed for the rest of the experiment. The fish were trained on a 1-minute fixed-interval (FI-1) schedule. After the fish had received a worm for pressing the lever, a

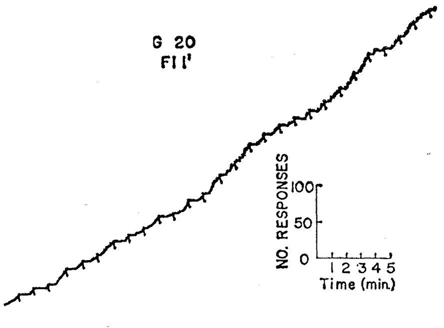

Fig. 1. Cumulative record of one session from a well-trained fish (G 20) on a 1-minute fixed-interval schedule (FI-1). Downward "blips" indicate delivery of reinforcement. Scale, lower right.