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EFFECT OF A CONSTANT MAGNETIC FIELD ON CONDITIONED REFLEXES IN SEA FISH

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Of the physical factors affecting the behavior of animals the magnetic field is the least investigated. Certain authors flatly deny that a magnetic field has any biological effect (Nasonov, 1948; Rozhanskiy, 1957). As we see it, however, science lacks the evidence to decide this question conclusively, particularly as such sensitive methods of receptor study as the conditioned reflex method have not been utilized in investigating it.

The object of the present study was to clarify the possible effect of a constant magnetic field on conditioned reflexes in fish. The experiments were performed on threespine sticklebacks, flounder, and fourhorn sculpins. These fish were selected because they were small enough to insert in the solenoid used to set up the relatively homogeneous magnetic field employed in the experiments. The theory, advanced in the literature, that in their long-range migrations fish orient themselves according to the earth's magnetic field also influenced our choice of subjects. The investigations were carried out in the summer of 1956 at the White Sea Biological Station of Moscow State University.

Studies of freshwater fish established that in a magnetic field inhibitory conditioned reflexes are developed more rapidly than positive reflexes (Kholodov, 1958). We therefore decided to develop in sea fish a conditioned inhibition with respect to a magnetic field and to trace its effect on previously developed visual and auditory conditioned reflexes.

A conditioned inhibition was produced in 4 sticklebacks: 2 males and 2 females. The conditioned response was the movement of the fish from one half of a tank to the other through an opening in a partition. The conditioned stimulus consisted in turning off a 50-watt bulb in the half of the tank where the fish happened to be at the time, and turning on an identical bulb in the other half. As the unconditioned stimulus employed mechanical stimulation with a rod, by means of which the fish were driven into the illuminated

TABLE 1

Rate of Formation of Temporary Connections in the Stickleback

No. of Fish	Conditioned Reflex "Light"		Conditioned Inhibition "Magnetic Field + Light"	
	Appearance of Reflex	Establishment of Reflex	Appearance of Reflex	Establishment of Reflex
1	3	22	1	-
2	16	25	1	5
3	4	11	1	14
4	2	72	1	1

half of the tank. The delay in applying the unconditioned stimulus was 5-7 sec; one experiment comprised 10 applications of the conditioned stimulus. If a conditioned response to light was observed, the unconditioned mechanical reinforcement was not applied. Before the conditioned inhibition was developed, the solenoid, slipped over the middle of the tank, was turned on 1 to 2 times per experiment, 5 seconds before the light was switched to the other side. The magnet and the light functioned for 15 seconds and were then turned off simultaneously. In the region of the partition the intensity of the constant magnetic field created by the solenoid was 100-200 oersteds.

The results of the experiments to establish a conditioned visual reflex and a conditioned inhibition are summarized in Table 1.

As the table shows, the conditioned reflex appeared after the conditioned stimulus had been applied 2 to 16 times and became established after the 11th to 72nd application. The conditioned reflex was considered established when observed after each of 5 successive applications of the conditioned stimulus. Once established, the conditioned response to light broke down less often in females than in males.

After establishing the conditioned positive reflex we began to develop a conditioned inhibition. The very first application of the magnet inhibited the conditioned response in all the fish (see Table 1). After 1 to 14 applications of the conditioned inhibitory stimulus this temporary connection was established. The effect of the magnetic field manifested itself not only in the total or partial inhibition of the response to the stimulus applied at the same time as the magnetic field but also in the inhibition of the conditioned response to subsequent stimuli, applied without the magnet. In this respect experiment No. 18 on stickleback No. 3, recorded in Table 2 below, is instructive.

We see that a single application of the magnet not only entirely inhibited the conditioned response to the stimulus applied concurrently with the magnet but also inhibited the response to the next 6 stimuli, although each of these stimuli was reinforced. At the beginning of the next experiment the conditioned response to light appeared without reinforcement.

Only once were we able to observe such a clear-cut series of inhibitions: the usual picture was inhibition or merely retardation (increase in delay period) of the conditioned response to the first one or two stimuli following application of the magnet. However, the effect of the magnet manifested itself not only in the

TABLE 2

Record of Experiment No. 18, Stickleback No. 3, 6 July 1956

No. of Application	Time	Conditioned Stimulus	Delay Period	Reinforcement
171	9 hrs. 50 min. 00 sec.	light	3	-
172	9 " 51 " 10 "	"	3	-
173	9 " 52 " 00 "	"	6	-
174	9 " 53 " 00 "	"	2	-
21	9 " 54 " 00 "	magnetic field + light	-	-
175	9 " 56 " 20 "	light	-	+
176	9 " 57 " 50 "	"	-	+
177	9 " 58 " 40 "	"	-	+
178	9 " 59 " 50 "	"	-	+
179	10 " 01 " 15 "	"	-	+
180	10 " 02 " 30 "	"	-	+

direct and subsequent inhibition of conditioned responses but also in the depression of the general background of conditioned reflex activity. Thus, in stickleback No. 1 three applications of the magnet were enough to dislocate the conditioned reflex activity completely. The original background could be restored only after 10 experiments. In other fish, too, the conditioned reflex activity was observed to suffer after the magnet began to be applied, although not as drastically as in fish No. 1.

The general results relating to the inhibiting effect of the magnetic field are presented in Table 3.

TABLE 3

Inhibiting Effect of Magnetic Field in the Development of Conditioned Inhibition in the Stickleback

No. of Fish	Number of Applications of Magnetic Field	Number of Cases of Inhibition Direct	Number of Cases of Inhibition Subsequent
1	4	3	4
2	14	12	10
3	22	14	8
4	6	6	4

We see that in stickleback No. 3 the inhibiting effect of the magnetic field was relatively less pronounced than in the other fish. This indicates individual differences in the response of the fish to the magnetic field. In sticklebacks Nos. 1, 2, and 4, nearly every application of the magnet produced direct and subsequent

TABLE 4

Rate of Formation of Visual and Auditory Conditioned Reflexes in Fish

Fish	Conditioned Stimulus			
	Light		Bell	
	Appearance of Reflex (Number of Combinations)	Establishment of Reflex (Number of Combinations)	Appearance of Reflex (Number of Combinations)	Establishment of Reflex (Number of Combinations)
Sculpin No. 1	14	45	14	45
Sculpin No. 5	10	15	12	15
Flounder No. 2	18	32	13	47
Flounder No. 3	3	9	6	14

inhibition. The inhibition observed the first few times the magnet was applied can be attributed to the unconditioned inhibiting effect of the magnetic field in accordance with the principle of external inhibition. The absence of conditioned response upon further applications of magnet plus light is attributable to the development of a conditioned inhibition with respect to the magnetic field.

To determine the nature of the unconditioned action of the magnetic field, we investigated the effect of a constant magnetic field on visual and auditory conditioned reflexes developed in fish. The experiments were performed on sculpins and flounder. During the experiments the fish were kept in a glass tank 15 cm in diameter. The tank was placed inside a solenoid which, when turned on, produced a constant magnetic field with an intensity of 100-200 oersted. The light of a 50-watt bulb and the sound of an electric bell suspended from the tank wall served as conditioned stimuli. The general movement of the fish following mechanical stimulation of the animal by means of a rod was the conditioned response.

The fish investigated usually lay motionless on the bottom of the tank. Light and sound did not induce any movement so long as they were not combined with mechanical stimulation. The delay in applying the unconditioned stimulus was 5-7 seconds. The conditioned stimuli were applied for 1-2 minutes. In these experiments light and sound were alternated. In the average experiment a conditioned stimulus was applied 10 times. If there was a response to the conditioned stimulus, the unconditioned stimulus was not applied.

The experiments were performed on two flounders and two sculpins. The rate of formation of conditioned reflexes in these fish is illustrated in Table 4.

It follows from the table that visual and auditory reflexes appear at the same time: after 3 to 18 combinations of the conditioned stimulus with unconditioned reinforcement. The establishment of the reflex was observed after 9 to 47 combinations. After establishment, the fish did not always respond when the conditioned stimulus was applied. Usually 1 to 3 out of 10 stimuli did not produce a conditioned response. Against this background of conditioned reflex activity, we carried out experiments on the effect of a magnetic field. To approximate the conditions of the experiment to those observed in producing conditioned inhibition in the stickleback, the solenoid was turned on 20 seconds before turning on the conditioned stimulus, and turned off together with

TABLE 5

Effect of Constant Magnetic Field on Visual and Auditory
Conditioned Reflexes in Fish

Fish	Number of Cases of						
	Application of Magnet	Inhibition of Conditioned Responses		Intensification of Conditioned Responses		No Effect	
		Light	Bell	Light	Bell	Light	Bell
Sculpin No. 1	4	4	3	0	1	0	0
Sculpin No. 5	2	1	2	0	0	1	0
Flounder No. 2	2	1	1	1	1	0	0
Flounder No. 3	5	5	3	0	1	0	1
Total: abs.	13	11	9	1	3	1	1
%	100	85	70	7	22	7	7

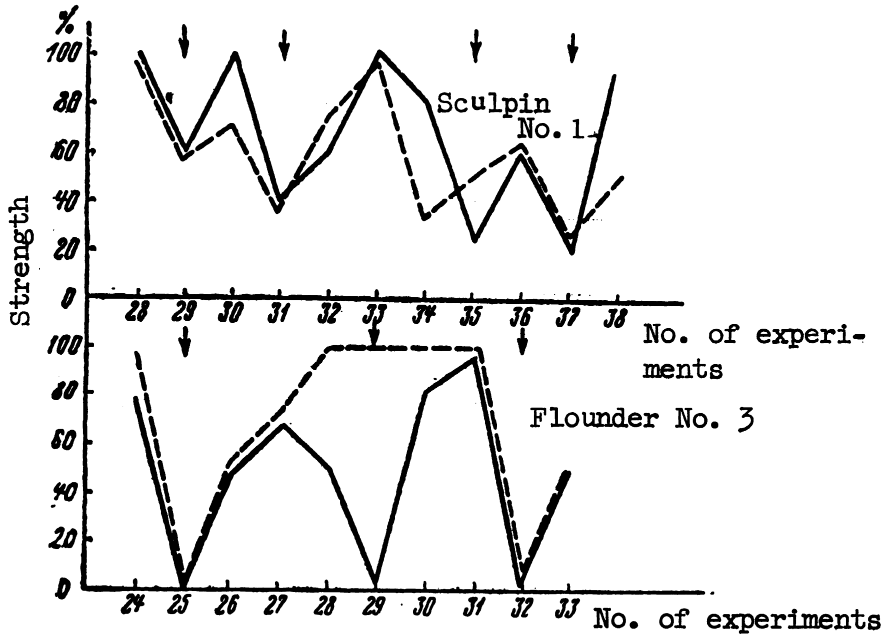

Fig. 1. Effect of a constant magnetic field on visual (solid line) and auditory (broken line) conditioned reflexes in fish. Arrows mark the experiments in which the magnetic field was applied.

that stimulus. The results of an experiment, in which every conditioned stimulus was accompanied by the application of a magnetic field, were compared with the results of the preceding and following experiments, in which all the experimental conditions were identical, except that the magnet was not applied.

The principal indicator of conditioned reflex activity was the strength of the conditioned responses. To illustrate the data obtained in Fig. 1 we have plotted curves of the strength dynamics of the conditioned reflexes in sculpin No. 1 and flounder No. 3 and the effect upon them of the magnetic field.

In the sculpin, in every experiment in which the magnet was applied, the strength of the conditioned responses to light was reduced. The number of conditioned responses to the bell fell in three experiments and rose in one. In flounder, the conditioned visual reflex was also inhibited whenever the magnet was applied. In some experiments the magnet completely destroyed the conditioned reflexes, although the action of every conditioned stimulus was reinforced by the unconditioned stimulus (experiments Nos. 25, 29, and 32). In experiments in which the magnet was applied the auditory conditioned reflex grew stronger in one experiment, remained the same in another, and grew weaker in two (experiments Nos. 25 and 32). The overall results of the experiments on the effect of a magnet on conditioned reflexes in fish are presented in Table 5.

This table shows that in the majority of cases the magnetic field inhibited the conditioned reflexes. The visual conditioned reflexes were inhibited more often (85% of cases) than the auditory conditioned reflexes (70% of cases).

Thus, a constant magnetic field of the given intensity has an unconditioned inhibiting effect on the behavior of fish. On comparing the results obtained with data on the effect on the higher nervous activity of other factors similar in nature to a magnetic field, an analogous picture may be observed. Thus, a UHF electromagnetic field inhibits salivary conditioned reflexes in dogs (Livshits, 1957). The same effect on higher nervous activity is produced by X-rays (Nemenov, 1950). Both factors are similar to a magnetic field in the sense that, while being highly penetrative, they are of low intensity under natural conditions, and animals lack special receptors for detecting them.

In our opinion further investigations of the biologic effect of magnetic fields should be oriented toward clarifying the role of different sectors of the central nervous system in the perception of such stimuli.

CONCLUSIONS

1. In response to a constant magnetic field the stickleback may develop conditioned inhibition of a positive visual reflex.

2. The conditioned inhibition with respect to the magnetic field develops much more rapidly than the positive conditioned visual reflex.

3. The effect of a magnetic field also manifests itself in the inhibition of the conditioned response to succeeding conditioned stimuli.

4. A constant magnetic field applied in individual experiments inhibits visual and auditory defense reflexes developed in flounder and sculpins.

5. These properties of a magnetic field suggest that this stimulus has an unconditioned inhibiting effect on the higher nervous activity in fish.

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