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by *Yu. A. Kholodov*

From *Trudy Soveshchaniya po Fiziologii Ryb*  
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No. 8, 1958

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TO A MAGNETIC FIELD IN FISH**

**By Yu. A. Kholodov**

**Translation of "Obrazovaniye uslovnykh refleksov  
na magnitnoye pole u ryb"**

**From Trudy soveshchaniya po fiziologii ryb, Akademiya Nauk SSSR  
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# FORMATION OF CONDITIONED REFLEX RESPONSES TO A MAGNETIC FIELD IN FISH

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The question of whether magnetic fields have an effect on animals still remains open, although certain investigators have attempted to answer it affirmatively. It is commonly supposed that birds are affected by the earth's magnetic field during long-distance flights, but this has not been reliably confirmed.

We decided to verify by the conditioned reflex method the possibility that fish may be affected by a magnetic field, on the assumption that the earth's magnetic field may play some part in the complicated procedure by which fish follow definite migratory routes. The project was begun in 1953 at the Institute of Biophysics, Academy of Sciences USSR, under the direction of G. M. Erdman and is being continued at the Chair of Physiology of Higher Nervous Activity, Moscow State University, under the direction of L. G. Voronin.

The experiments were performed on carp. Conditioned reflexes were formed by defense and feeding methods. Using Yu. P. Frolov's (1938) defense method, the action of a conditioned stimulus was reinforced by an electric shock. The two electrodes were placed on the walls of the fish tank. Current from a storage battery flowed through an induction coil and thence to the electrodes. The movement of the fish was registered on a kymograph with the aid of two Marey tambours. A thread was attached to the dorsal fin of the fish at one end and to the lever of a Marey tambour at the other. The lever of the other capsule, which is connected to the first air line was fitted with a stylus.

In using the feeding method suggested by N. V. Prazdnikova (1953), the effect of the conditioned stimulus was reinforced with a bloodworm if during the period of action of the stimulus the fish tugged at a bead suspended in the tank by a thread. By tugging at the bead the fish closed an electric circuit and, by means of an electromagnetic marker, this food response of the fish was recorded

on a kymogram.

The magnetic field was provided by permanent horseshoe cobalt magnets and variously shaped electromagnets supplied with direct or alternating (50 cps) current of different strengths. Most often the conditioned stimulus was the magnetic field of a solenoid (500 turns) with an inside diameter of 15 cm and 9 cm in height. The jar of water in which the fish were placed was inserted into the solenoid.

In addition to conditioned responses to a magnetic field, we produced in the fish conditioned responses to the light of a 40-watt bulb and to the sound of an electric bell. When the defense method was used, the unconditioned reinforcement was applied 5 to 7 seconds after the conditioned stimulus began to operate. When the feeding method was used the conditioned stimulus was withdrawn if after 30 seconds the fish still did not tug at the bead. The conditioned stimulus was considered established if five successive responses to the conditioned stimulus were observed.

In the beginning, the question of the unconditioned effect of the magnetic field was investigated. We did not notice any orientation of the fish in the magnetic field, although fields with an intensity of as high as 10,000 oersteds were created. We also failed to detect any effect of the magnetic field on the respiration of the fish.

The next stage of the work was to establish a positive conditioned response to a magnetic field. To do this we used the feeding on 3 fish and the defense method on 12 fish. Positive conditioned reflexes were thus developed in all 15 fish (Table 1).

The rate of formation of the conditioned response to a magnetic field varies sharply. The reflex appeared after 2 to 25 combinations of the magnetic field with unconditioned reinforcement and became established after 12 to 102 combinations. Compared with the conditioned responses to other stimuli (light, bell), in fish a positive response to a magnetic field appears more slowly and takes more time to become established. Once the reflex has developed, a clear-cut response is observed nearly every time the magnetic field is applied.

Fig. 1 shows clearly that the fish tugs at the bead only when a magnetic field is present. The perception of a magnetic field by fish is just as convincingly demonstrated by another kymogram (Fig. 1, B), illustrating the experiments in which the defense method was used. When this method is used, the conditioned reflex persists for a long time even when no reinforcement is given. The kymogram shows that the conditioned response to a magnetic field

TABLE 1

Rate of Formation of Positive Conditioned Reflexes  
to a Magnetic Field in Fish

No. of Fish	Appearance of Reflex (Number of Combinations)	Establishment of Reflex (Number of Combinations)
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Feeding Method

1	5	20
2	4	37
3	5	12

Defense Method

11	12	97
12	17	79
13	20	37
15	11	24
16	12	87
17	9	102
20	11	24
38	25	47
39	11	53
41	2	55
42	2	55
51	3	40

recurs four times in a row without reinforcement.

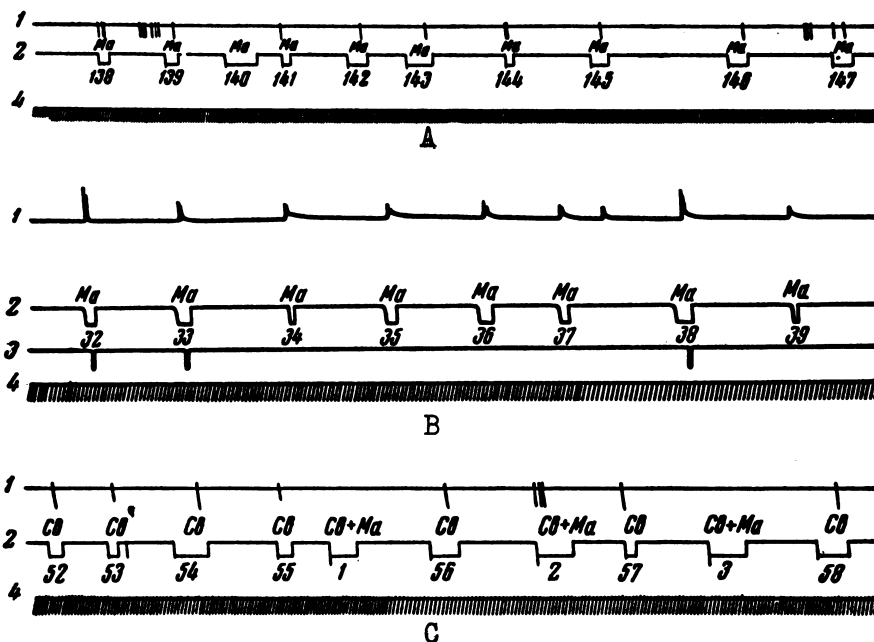


Fig. 1. Kymograms of experiments in producing temporary connections associated with a magnetic field in fish. A. Development of positive conditioned reflex response to a magnetic field by feeding method (fish No. 2, experiment No. 13); B. The same, but by the defense method (fish No. 20, experiment No. 2); C. Development of conditioned inhibition with respect to a magnetic field by the feeding method (fish No. 5, experiment No. 7); 1. Conditioned response; 2. Conditioned stimulus; 3. Reinforcement; 4. Time mark (5 sec.).

[CS = Light; Ma = Magnetic Field]

The graphs of the formation of positive conditioned responses to a magnetic field in fish (Fig. 2) show that these kymograms are typical rather than reflecting isolated, unusually successful experiments. The same graphs also show that the appearance of a response every time a conditioned stimulus was applied was observed only in a few of the experiments. This is yet another proof that a magnetic field is a weaker stimulus than light or sound.

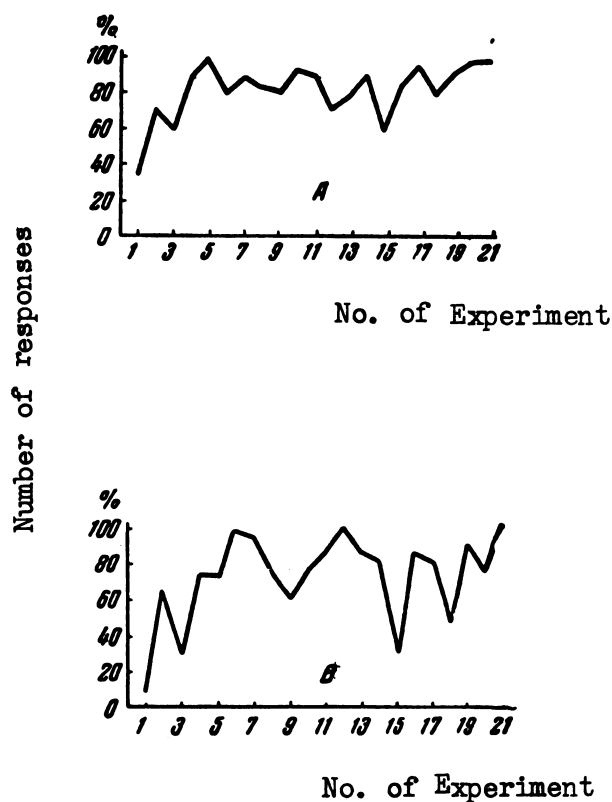


Fig. 2. Curves of Formation of Positive Conditioned Reflex Response to a Magnetic Field in Carp.  
A. By feeding method (fish No. 2);  
B. By defense method (fish No. 20).

However, the development of a conditioned inhibition with respect to a magnetic field reflects a different aspect of the strength of this stimulus. To produce this inhibition, we turned on the magnet 5 to 10 seconds before turning on the bulb by means of which a strong positive conditioned reflex was produced. The magnet and the light operated jointly for 30 to 40 seconds and were simultaneously turned off. We produced a conditioned inhibition to the magnetic field in five fish by the feeding method and in three fish by the defense method (Table 2).

TABLE 2

Rate of Formation of Conditioned Inhibition  
with Respect to a Magnetic Field in Fish

No. of Fish	Appearance of Reflex (Number of Combinations)	Establishment of Reflex (Number of Combinations)
-------------	--	---

Feeding Method

4	5	5
5	1	3
7	2	14
101	1	18
102	1	26

Defense Method

103	1	8
105	3	15
106	1	11

In all eight fish the establishment of the conditioned inhibition required a small number of applications of the conditioned inhibiting stimulus (3 to 26), whereas the number of applications of other inhibiting stimuli is much larger (20 to 60) (Prazdnikova, 1953a). In five fish we observed external inhibition on first applying the conditioned inhibiting stimulus. This is illustrated by the kymogram in Fig. 1. Every application of light evoked a conditioned response in the fish, but out of three applications of the conditioned inhibiting stimulus only one evoked a response, and only upon the action of the magnetic field alone. The presence of external inhibition indicates the considerable strength of the stimulus. This is also attested by instances of successive inhibition. Therefore, the magnetic field is inferior to other stimuli in producing positive conditioned connections, but superior to others in producing inhibiting connections.

The next stage of our project was to determine the threshold of perception of a magnetic field in fish. In this case we performed only qualitative experiments, creating a magnetic field of random intensity which varied over the tank from 12 to 1,500 oersteds, depending on the location of the magnet. The use of a solenoid as the source enabled us to create a magnetic field of relatively uniform intensity throughout the tank, and to vary it by means of a rheostat. The perception threshold was determined in three fish by the feeding method and in three by the defense method. In all cases similar results were obtained. For illustration Table 3 presents the records of two experiments in which reflexes were produced by these methods.

Calculations show that the threshold of magnetic field perception in carp is 10 to 30 oersteds. This is 15 to 50 times greater than the intensity of the earth's magnetic field, but we assume that during their spawning migration the sensitivity of the fish to magnetic fields increases. The verification of this assumption will be the next stage of our project.

Regarding the mechanism of action of the magnetic field, we were anxious to determine whether the effect of this field is a specific one or is exerted on the organism by the induction of an electric current as a result of its variation. The results obtained, though not solving the question completely, indicate a specific effect of the magnetic field. This is suggested by the possibility of developing a conditioned inhibition with respect to the magnetic field when the possible inductive effect (activation) of the magnetic field occurs 5 to 10 seconds before the positive conditioned stimulus -- light -- begins to operate. The persistence of the

TABLE 3

Determination of the Threshold of Magnetic Field Perception in Carp\*

## Experimental Records

No. of Stimulus Applied	Time Magnet Turned On (in hours, minutes, and seconds)	Current in Amperes	Latent Period of Conditioned Response	Reinforcement
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Feeding Method, Fish No. 2  
Experiment No. 51

543	12 hr. 56 min. 15 sec.	0.37	3	+
544	58 " 10 "	0.37	30	+
545	13 " 01 "	0.25	-	+
546	03 " 15 "	0.37	3	+
547	05 " 30 "	0.37	30	+
548	07 " 50 "	0.37	25	+
549	11 " "	0.25	60	-
550	14 " 05 "	0.37	8	+
551	16 " 30 "	0.37	25	+

Defense Method, Fish No. 11  
Experiment No. 27

303	18 hr. 21 min. 30 sec.	0.50	+	-
304	23 " 15 "	0.50	+	-
305	25 " "	0.50	+	-
306	26 " 45 "	0.25	-	-
307	29 " 15 "	0.37	+	-
308	31 " "	0.37	+	-
309	33 " 15 "	0.25	-	-
310	35 " 15 "	0.25	-	-
311	38 " "	1.00	+	-

\*In all cases the magnet served as stimulus.

inhibiting effect throughout the period of operation of the light can be explained only by the existence of a specific effect of the magnetic field. Experiments in which a magnetic field was developed slowly by means of a rheostat have led us to the same conclusion. Although in this case the inductive effect of the magnetic field is virtually excluded, conditioned reflex responses to the magnet were still obtained.

At the same time, in the experiments using the defense method, we observed an enhanced conditioned response at the moment the magnetic field was turned off. When the conditioned reflex was first being produced, or when a field of threshold intensity was applied, the response of the fish followed only after the magnetic field was turned off. It may be that the heightened response of the fish at the turning-off moment is attributable to the combined action of the specific and inductive effects of the magnetic field.

Regarding the mechanism of perception of magnetic fields by fish, we first assumed that they are perceived by the entire skin surface of the fish. To verify this assumption, we denervated the lateral-line organ in four fish (Nos. 1 and 2, feeding method; Nos. 11 and 13, defense method). It turned out that the perception of the magnetic field by fish was not disturbed by this operation.

During these experiments we accidentally discovered that the conditioned reflex response to a magnet is generalized when a visual stimulus is present. Special experiments confirmed this fact and demonstrated the possibility of reverse generalization. The generalization of magnetic and visual stimuli is indicated by the presence of a response to the action of the magnetic field alone at the beginning of the development of a conditioned inhibition. The kymogram (Fig. 1) shows that the fish began to tug at the bead before the light was turned on, when only the magnet was active. This fact was also observed in experiments with other fish.

The generalization of visual and magnetic stimuli in fish forced us to assume that a magnetic field, like light, may be perceived by the retina of the eye. However, experiments with fish in which the eyes and part of the optic nerve were removed showed that the perception of a magnetic field remains undisturbed. What is more, a conditioned defense reflex response to light could also be produced in blinded fish, in which it formed almost as rapidly as in seeing fish. Table 4 presents the rate of formation of conditioned reflexes in blinded fish upon simultaneous production of

defense reflex responses to light and a magnetic field by alternating these stimuli. Reflexes were produced in this manner in fish Nos. 44, 46, and 47. In fish Nos. 48 and 49 only the visual reflex was produced, and its generalization to the magnetic field verified.

TABLE 4

Rate of Formation of Visual and Magnetic Conditioned  
Reflexes Produced Simultaneously in Blinded Fish

No. of Fish	Appearance of Reflex Response (Number of Combinations)		Appearance of Reflex Response (Number of Combinations)	
	To Light	To Magnet	To Light	To Magnet
44	11	11	24	64
46	7	7	7	48
47	17	19	22	38
48	8	-	21	-
49	3	-	10	-

The table shows that visual and magnetic reflexes appear simultaneously, but the visual reflex is more likely to become established. Graphs of the development of conditioned reflexes in these fish (Fig. 3) reveal the parallel nature of the establishment of visual and magnetic reflexes. The curve of the conditioned reflex response to a magnetic field nearly duplicates the shape of the curve of the response to light. This similarity of the dynamics of conditioned reflex formation, observed in all three fish, warrants the assumption that a common receptor of light and magnetic fields is present in the blinded fish.

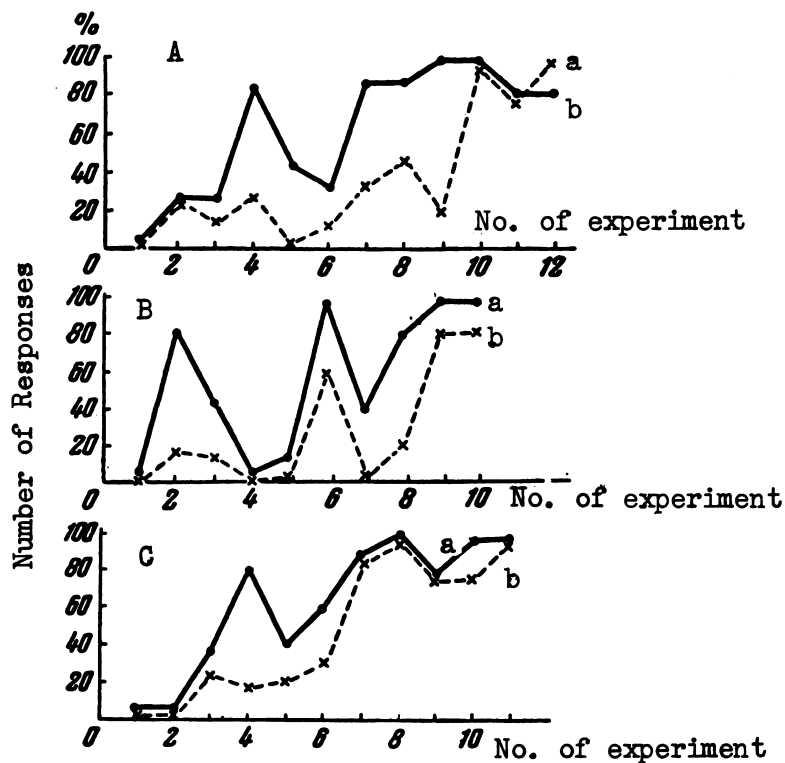


Fig. 3. Curves of Simultaneous Formation of Conditioned Reflex Responses to Light and to a Magnetic Field in Blinded Carp.  
 a. Conditioned reflex response to light; b. Conditioned reflex response to magnetic field.  
 A. Fish No. 44; B. Fish No. 46;  
 C. Fish No. 47.

The literature mentions the perception of light directly by the cells of the diencephalon in fish (Frisch, 1911; Scharrer, 1928; Young, 1935). Our preliminary experiments in extirpating isolated sectors of the fish brain with the object of clarifying their role in the implementation of the conditioned reflex response

to a magnetic field indicate the important role of the diencephalon in the perception of this field. We are continuing our work with the object of elucidating this problem in detail.

### CONCLUSIONS

1. The possibility of forming a positive conditioned reflex and a conditioned inhibition in fish with respect to a magnetic field was established.

2. The threshold of perception of a magnetic field by carp is 10 to 30 oersteds.

3. Preliminary experiments permit the assumption that the magnetic field has a specific effect.

4. Denervation of the lateral-line organs does not disturb the conditioned reflex response to a magnetic field.

5. A close relationship between magnetic and visual stimuli is observed, expressed in the generalization of the conditioned reflex when these stimuli are interchangeably applied.

6. Removal of the eyes did not disturb the conditioned reflex response to a magnetic field.

7. Conditioned visual reflexes can be developed in blinded fish.

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<p>NASA TT F-190 National Aeronautics and Space Administration. FORMATION OF CONDITIONED REFLEX RESPONSES TO A MAGNETIC FIELD IN FISH. (Obrazovaniye uslovykh reflektsov na magnitnoye pole u ryb.) Yu. A. Kholodov. January 1964. 13p. OTS price, \$0.50. (NASA TECHNICAL TRANSLATION F-190. Translation from Trudy soveshchaniya po fiziologii ryb, Akademiya Nauk SSSR, no. 8, pp. 82-89, 1958 (USSR))</p> <p>In experiments performed on carp, the possibility of forming reflexes or inhibitions with respect to a magnetic field was established. The threshold of perception of a magnetic field was from 10 to 30 oersteds. Neither denervation of the lateral-line organs nor removal of the eyes disturbed the condi- tioned response.</p>	<p>I. Kholodov, Yu. A. II. NASA TT F-190 III. Akademiya Nauk SSSR, no. 8, pp. 82-89, 1958 (USSR)</p>	<p>NASA TT F-190 National Aeronautics and Space Administration. FORMATION OF CONDITIONED REFLEX RESPONSES TO A MAGNETIC FIELD IN FISH. (Obrazovaniye uslovykh reflektsov na magnitnoye pole u ryb.) Yu. A. Kholodov. January 1964. 13p. OTS price, \$0.50. (NASA TECHNICAL TRANSLATION F-190. Translation from Trudy soveshchaniya po fiziologii ryb, Akademiya Nauk SSSR, no. 8, pp. 82-89, 1958 (USSR))</p> <p>In experiments performed on carp, the possibility of forming reflexes or inhibitions with respect to a magnetic field was established. The threshold of perception of a magnetic field was from 10 to 30 oersteds. Neither denervation of the lateral-line organs nor removal of the eyes disturbed the condi- tioned response.</p>	<p>I. Kholodov, Yu. A. II. NASA TT F-190 III. Akademiya Nauk SSSR, no. 8, pp. 82-89, 1958 (USSR)</p>
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