PART II

SCIENTIFIC AND TECHNICAL

RESPONSE OF FISHES TO THE UNDERWATER D. C. FIELD

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Response to external electric field (D. C.) of three different varieties of fish namely *Puntius ticto, Heteropneustis fossilis* and *Tilapia mossambica* having different anatomical and behavioural characteristics were studied.

Clearly distinguished reactions occurred one after another in all the varieties of fish with the increase in field intensity with minor specific variations. These reactions can be broadly classified into initial start (first reaction), forced swimming (galvanotaxis), slackening of body muscle (galvanonarcosis) and state of muscular rigidity (tetanus).

The orientation of the organism (projection of nervous element) to the surrounding field has been found to have important bearing on the behaviour reactions. Clearly differentiated anodic taxis and true narcosis set in when fish body axis was parallel to the lines of current conduction. But with greater angle between the body axis and the current lines, fish did not show well marked reactions. Fish body, when perpendicular to current lines responded for anodic curvature and off balance swimming followed by tetanus.

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Introduction

Scheminzky (1936) stated that the opposite effect of descending galvanic current (paralysing) and of ascending galvanic current (exciting) in aquatic vertebrates and crayfish could be explained respectively by the action of the anelectrotonus and of the catelectrotonus occurring in every nerve cell. According to Scheminzky and Kollensperger (1948) galvanonarcosis would be caused by a sedative produced in the medulla by smooth direct current. When the current is switched off, the sedative disappears.

Nusebaum and Faleeva (1961) agreed with the theory that the casual analysis of the anodic reaction in fish is impossible without the help of data on the different actions of fish in a descending current (fish facing the anode) and ascending current (fish facing the cathode); and what is particularly important is that such an analysis needs a deep comprehension of the phenomenon provoked by polarity of the electric current on the entire fish system.

According to Holzer (1932) the conductivity of fish body being greater than the surrounding media (fresh water) all the current lines were directed towards the fish body and the organism is thus satisfactorily influenced by electricity. According to Halsband and Meyer-Waarden (1960), with the progressive increase of density of the current there were three phases of reaction shown by fishes namely jerking of the body, swimming towards the anode (Galvanotaxis) and cessation of all movements with their muscles relaxed. Regarding the behavioural changes, Houston (1949) observed the tendency of fish to place themselves with their head pointing towards the increasing potential. Cod and herring were observed to swim to the anode when released in an electric field (Meyer-Waarden, 1952). Cattley (1955) described the reactions of fish in an electrical field in three definite stages which correspond to the first reaction, galvanotaxis and galvanonarcosis as described by Halsband *et al.* (1960). But Lamarque (1963) reported about thirty identifiable reactions of the fish depending on species and their position in the field, that is, across the field or facing the anode or cathode.

Rommel and Mc Cleave (1972) have reported the sensitivity of *Anquilla rostrata* in a uniform field of direct current.

The present paper details the electrosensitive responses of *Puntius ticto*, *Heteropneustis fossilis* and *Tilapia mossambica* in an uniform D. C. field.

Materials and Method

A homogeneous field was created in an insulated glass tank (90 x 10 x 10 cm.). Potential was increased by 1 volt steps between the tank extremities. The electrodes consisted of two copper plates (10 x 9 cm.) fixed vertically along the tank extremities. They were connected to the output terminals of a D. C. rectifier which in turn was connected to A. C. mains through a variable resistance. A voltmeter connected parallel to the terminals of the electrodes indicated potential tension between the electrodes during the experiment. The field intensity was monitored by a microameter connected in series with the tank electrodes.

The test animals after being acclimatized to laboratory conditions for seven days, were measured for total length and then released in the experimental tank where they were allowed to settle. The field intensity was then increased from zero potential till the organism could perceive the surrounding exernal field and react to it.

A single fresh fish was taken for each experiment and the used specimens were never reused before a rest period of at least forty eight hours after the trial. The effective period for narcosis was determined for every fish on trial.

The temperature, resistance of the water and the light in it remained constant for each set of experiments.

TABLE I

Occurrence of identifiable reactions in fishes

Temperature of water media — 30° - 27°C.

Resistance of water media — 18×10^3 to 10×10^3 ohms/cm².

Nature of current — Continuous D. C. with gradual rise.

Sl. No.	Nature of identifiable reactions	Presence of identifiable reaction in *P. ticto* (61-100 mm.) out of 154 fishes %	*H. fossilis* (106-170 mm.) out of 312 fishes %	*T. mossambica* (91-200 mm.) out of 144 fishes %
1.	Inhibition of normal swimming	46—65	40—52	70—85
2.	Jerks of head	78—98	58—82	44—54
3.	Straightening of fins	50—56	58—75	75—84
4.	Quivering of body and tail	43—56	58—72	67—78
5.	Anodic galvanotaxis	50—66	48—65	3—6
6.	Cathodic galvanotaxis	2—8	5—9	54—61
7.	Sustained anodic curvature	26—48	26—47	36—40
8.	Galvanonarcosis	52—74	53—74	26—34
9.	Pseudo-forced swimming	15—38	25—36	42—63
10.	Tetanus	15—38	88—96	11—24
11.	Change in body pigmentation	—	100	100

Results and Discussion

Classification of Reactions

With a steady rise in the density of current and potential gradients of the field, the following stages of reaction of fish were identified.

Stage I (First reaction)

P. ticto could feel the current and the co-ordinated forward swimming of the fish retarded and came to a halt when parallel to current direction and facing the positive electrode. The opercular beat slowed down to 34 to 42% of the normal rate and the fish did not react sharply to external stimuli.

Occasionally the fish oriented itself almost perpendicular to the field lines. The movement of fish still remained voluntary.

On facing cathode, the fish could perceive the external field by raising of the median dorsal fin. The ventrals were spread out. Semicircular movements were observed accompanied with short jerks of the body (when parallel to the field lines) followed by placing its body axis almost perpendicular to current lines without showing any further movement till the current was switched off.

H. fossilis in this stage perceived the surrounding electric field by stretching its barbels, and vibrating its caudal fin and posterior portion of the ventral fin. The subsequent reactions with increased field strength facing positive and negative electrodes were similar to that of *P. ticto.* Response to external stimuli was reduced to a considerable extent and the rate of gill movement slowed down to 62 to 70% of the normal.

T. mossambica on facing the positive electrode exhibited its response to the increasing field intensity by 42 to 55% increase in pectoral beats, expanding the pectoral, ventral and the dorsal fins and orienting itself perpendicular to the current lines. Not only did it become less responsive to external stimuli, but also occupied the same perpendicular position even though the fish was placed parallel or in any position other than perpendicular to current lines.

Stage II *(Galvanotaxis)*

The reaction in this stage concerned with forced involuntary movements of the fish under the influence of increased intensity of the surrounding field. On facing anode, *P. ticto* rushed towards the positive electrode at a speed of 18 to 34 cm. per second. The opercular beat increased to 58 to 71%. Occasionally individuals jumped out of the water and a few manoeuvred to stay without much movement at right angles to the direction of current flow.

When the fish was facing the cathode, it swam with short undulations in an elliptical path to a certain distance and manoeuvred to turn towards the positive electrode and move fast towards it. The gill movements slowed down with irregular beats and the fish tended to stay perpendicular to current lines.

The fish across the field lines curved towards the anode and remained there till it received a new stimulus of increasing intensity. The extremities of the body

TABLE II

Occurrence of identifiable reactions in fishes

Temperature of water media — 29° - 27°C.

Resistance of water media — 18×10^3 to 14×10^3 ohms/cm².

Nature of current — D. C. with sharp rise.

Sl. No.	Nature of identifiable reactions	Presence of identifiable reactions in *P. ticto* (51-90 mm.) %	*H. fossilis* (106-170 mm.) %	*T. mossambica* (91-200 mm.) %
1.	Inhibition of normal swimming	6—12	14—22	68—84
2.	Jerks of head	87—94	92—96	24—33
3.	Straightening of fins	84—88	58—66	56—65
4.	Quivering of body and tail	85—91	58—64	8—14
5.	Anodic galvanotaxis	91—95	93—96	3—8
6.	Cathodic galvanotaxis	—	—	38—42
7.	Sustained anodic curvature	5—9	3—7	20—29
8.	Galvanonarcosis	91—95	93—96	38—42
9.	Pseudo-forced swimming	5—9	3—7	3—8
10.	Tetanus	4—8	93—96	7—12
11.	Change in body pigmentation	—	No appreciable change	No appreciable change

bent towards the electrode in the shape of an arch. Gill movement increased to 58 to 63% of the normal.

On facing the positive electrode, *H. fossilis* moved fast towards it with long undulations of its body. The speed of this forced movement was 42 to 54 cm. per second. The opercular movement slowed down to 17 to 58% of the initial rate. A few individuals oriented themselves perpendicular to the lines of current conduction and did not move from that position.

Jerky swimming of fish with its head turned a little towards the anode was noticed on facing the cathode. This forced movement continued till the fish could orient itself perpendicular either to the field lines or to the bottom plane. The head and tail of the fish body curved towards the positive electrode it being perpendicular to the field lines. The extent of curvature increased with the increase in potential.

A higher rate of pectoral undulations (up to 320 to 450% per minute) followed by tremor of the body and expansion of fins was observed in case of *T. mossambica* when it headed towards the anode. On facing cathode, it exhibited jerky movements with a curvature of the body resulting in short circular movements in the field. The rate of gill movement slowed down to 15 to 40%. Being across the field lines, an increased pectoral beat up to 155 to 230% accompanied by bending of body extremities towards the positive electrode was observed.

TABLE III

Occurrence of identifiable reactions in *P. ticto* in relation to their orientation in the field.

Temperature of water media — 27°C.
Resistance of water media — 18 x 10^3 ohms/cm^2
Nature of current — D. C. with sharp rise
Size group — 61—90 mm.
Total Nos. — 99

Sl. No.	Nature of identifiable reactions	Presence of identifiable reaction in %				
		Parallel to current lines		45° to current lines		Perpendicular to current lines
		Facing +ve	Facing —ve	Facing +ve	Facing – ve	
1.	Inhibition of normal swimming	15—22	24—35	23—38	43—47	—
2.	Jerks of head	100	—	49—58	—	—
3.	Straightening of fins	—	38—42	—	23—27	—
4.	Quivering of body and tail	—	38—42	—	23—27	—
5.	Anodic galvanotaxis	100	—	43—58	—	—
6.	Cathodic galvanotaxis	—	4—16	—	2—7	—
7.	Anodic curvature	—	—	—	—	100
8.	Galvanonarcosis	100	42—56	47—62	45—55	—
9.	Pseudo-forced swimming	—	4—16	10—16	12—17	—
10.	Tetanus	—	4—16	—	—	—

TABLE IV

Occurrence of identifiable reactions in *H. fossilis*

Temperature of water media — 29°C.
Resistance of water media — 14 x 10^3 ohms/cm^2
Nature of current — D. C. with sharp rise
Size group — 111-260 mm.
Total Nos. — 93.

Sl. No.	Nature of identifiable reactions	Presence of identifiable reactions in %				
		Parallel to current lines		45° to current lines		Perpendicular to current lines
		Facing +ve	Facing −ve	Facing +ve	Facing —ve	
1.	Inhibition of normal swimming	21—26	34—38	27—33	41—46	—
2.	Jerks of head	100	—	41—47	—	—
3.	Straightening of fins	—	41—45	—	23—26	—
4.	Quivering of body and tail	—	41—45	—	23—26	—
5.	Anodic galvanotaxis	100	32—46	44—48	38—51	—
6.	Cathodic galvanotaxis	—	2—5	—	—	—
7.	Anodic curvature	—	—	—	—	100
8.	Galvanonarcosis	100	58—62	61—75	44—53	—
9.	Pseudo-forced swimming	—	—	—	2—3	—
10.	Tetanus	—	94—96	—	—	—

Stage III *(Galvanonarcosis)*

This reaction occurred in all the species studied when the fish lost their stability and rolled over to one side, or turned on their back incapable of any voluntary movements. The gill movements were irregular and the amplitude of each opercular beat became larger initially and later there were sudden rapid beats of the opercle with an interval of a few seconds.

The curvature of the body in all cases were more sustained even after the rise of field intensity without any movement on the part of the fish.

Body pigmentation in *H. fossilis* darkened to deep yellow from a lighter shade during this stage and in *T. mossambica* it deepened to black from greyish white, when heading towards the anode. But on its turning the

TABLE V

Occurrence of identifiable reactions in *T. mossambica*

Temperature of water media — 29°C.
Resistance of water media — 14 x 10³ ohms/cm²
Nature of current — D. C. with sharp rise
Size group — 91-200 mm.
Total Nos. — 99

Sl. No.	Nature of identifiable reactions	Presence of identifiable reactions in %				
		Parallel to current lines		45° to current lines		Perpendicular to current lines
		Facing +ve	Facing −ve	Facing +ve	Facing −ve	
1.	Inhibition of normal swimming	38—44	41—47	52—57	64—72	—
2.	Jerks of head	—	36—41	—	26—37	—
3.	Straightening of fins	—	68—72	—	40—51	—
4.	Quivering of body and tail	—	68—72	—	40—51	—
5.	Anodic galvanotaxis	8—12	—	3—7	—	—
6.	Cathodic galvanotaxis	—	55—62	—	28—35	—
7.	Anodic curvature	—	—	—	—	100
8.	Galvanonarcosis	—	27—34	—	37—44	—
9.	Pseudo-forced swimming	5—9	—	13—15	—	—
10.	Tetanus	—	3—5	—	—	—

head towards the cathode, the body colour faded to white. No visual change in body pigmentation was noticed in the case of *P. ticto*.

Stage IV *(Pseudo-forced swimming)*

All the three species of fish under study, during their states of narcosis, at times, started swimming again in an unbalanced manner. They rolled and swam often in an elliptical path between the two electrodes.

Stage V *(Tetanus)*

Followed by pseudo-forced swimming, the muscular rigidity of jaws and gill cover was observed without any respiratory movement, in all the fishes. In *T. mossambica* the cathodic galvanotaxis was replaced by a quivering tetanus with cessation of all its movements including respiration.

IDENTIFIABLE REACTIONS

Identifiable reactions occurring in all the three species of fish in gradually rising D. C. potential are given in Table I while similar reactions occurring in abruptly created potential are given in Table II. Response to reactions in relation to orientation in the electrical field of *P. ticto*, *H. fossilis* and *T. mossambica* are presented in Tables III, IV and V respectively.

In homogeneous D. C. field used in the experiments, *P. ticto, H. fossilis* and *T. mossambica* responded for ten recognizable reactions depending on their position in relation to lines of current conduction and facing the positive or negative electrode. These visible reactions, as described earlier had a close similarity with those defined by Faleeva (1961). The occurrence of these reactions, however, were not uniform in all the three of the above mentioned species (Table-I). The predominance of anodic galvanotaxis in case of *P. ticto* and *H. fossilis* over that of *T. mossambica* can be explained as due to their varied nervous structures and behavioural peculiarities. *T. mossambica* reacted for the cathodic galvanotaxis better than the anodic ones. The results are in agreement with the observation of Denzen (1968); where he has observed the *T. nilotica* to react cathodically in 60% of cases in low impulse frequencies of 20 per second and at a temperature of 25°C. Lamarque (1963) reported the absence of anodic galvanotaxis in case of skate, plaice and sole and the presence of cathodic galvanotaxis in them.

In an abruptly established potential difference, unmistakable anodic taxis followed by true narcosis has been observed in fishes during closure of the circuit with a lesser percentage of anodic curvature across the field and off balance swimming followed by tetanus (Tables I and II).

Halsband *et al.* (1960) stated that a steady direct current had no effect on fish at low potential values. Stimulation of nerves occurs only in response to a change in circuit.

The present findings support Halsband's statement that current with a slow rise has no stimulating effect. The nerves become accustomed to the current when it rises slowly (Nervous accommodation) and consequently a lower percentage of fishes show specific movement.

Another important factor regulating fish behaviour in the electric field is its orientation in the field. An electric field affects fish more strongly when head-tail potential is high. If the fish finds itself just along the equipotential lines, the voltage drop between head to tail equals zero, and the fish hardly feels any electric stimulus even if the electric field is very strong. Thus according to Chmielewski (1965), in order to get uniform results on the reaction of fish with various electrical, biological and environmental parameters, it is necessary to place the fish exactly along the lines of current conduction.

The determined reactions were more specific when they were parallel to equiflus. Anodic taxis and true narcosis occurred in all the fishes irrespective of their size, except in the case of *T. mo-*

ssambica where anodic taxis was replaced by cathodic galvanotaxis (Tables III to V).

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