Effect of Electric Stimulation on Heart Beat and Body Muscle in Fish

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The effect of AC and DC electric stimulations on the heart-rate and the entire body of *Heteropneustis fossillis, Tilapia mossambica* and *Macrobrachium rosenbergii* were studied and presented in kymograph tracings. The reaction of spinal cord in *Puntius ticto, Heteropneustis fossilis* and *Tilapia mossambica* to D.C. field was obseived to find out its role in electric shocks. A test-check of the electrical resistance of a few species was also conducted. The effect of D. C. and A.C. on the body muscle was found to be the same as that in the case of frog. Different degrees of cardiac slowing were observed in AC and DC. Unbalanced galvanotropic movements were also noticed in spinal fishes.

Electric shock response in man (Dalziel & Lee, 1968) has shown that electric current is the best measure of the strength of the sensible shock effect. Similar results were observed in fishes also (Cuinat, 1967). The primary function of the electro fishing system is to establish an electric current in water near the fish. Depending on the ratio of fish and water conductivity a portion of this current will pass through the fish and elicit the desired response. The skin of fish with the numerous sensory organs is an important receptor for physical and chemical stimuli (Brett, 1957). In this paper the authors report their attempts to measure the electrical resistance of the skin and body of fish, the contraction of fish body by direct currents and also the effect of electrical stimulation on the heart beat in fishes.

Materials and Methods

The electrical resistance of the skin and body and also between different points of the body were measured by using a dermometer described by Whelan (1950) which had a range of 1,000 to 4,50,00,000 ohms and about 5% accuracy. Live fishes were measured for length and maximum width and kept in between the folds of filter paper to remove water from the surface. One end of the silver electrode was connected to the instrument and the other end pressed against the fish, the instrument switched on and adjusted to 2μA. The resistance of the fish was directly read from the voltmeter and multiplied by 10 or 100 depending the range selected. The resistance between different body parts, namely, mouth to top of head, mouth to mid-dorsal fin, mouth to caudal peduncle and mouth to vent were measured with platinum electrodes. To record the contraction of the body in *Hetropneustics fossilis,* its peduncle was clamped firmly, upper jaw connected through a thread to a lever provided with a writing pen. The writing pen touched the black surface of a smoked paper wound round a cylindrical drum moving at constant speed. The pen drew a horizontal line (abscissa) on the smoked paper when the drum rotated. The brain together with a portion of spinal cord was destroyed by inserting and rotating a needle. The lever turned on the fulcrum, jerked up and the pen drew a curve on the smoked paper. The time was furnished by a tuning fork vibrating at 100 times per second.

The effect of electrical shock on the heart rate by the applied underwater field was recorded graphically on a constant slow moving drum. The fish after destroying the brain and spinal cord was firmly clamped upside down at the bottom of the experimental tank, where a homogenous electrical field was created by two copper plates, placed vertically along the tank extremeties. The heart of the animal was then exposed and the ventricle was connected to a lever, fitted with a writing point, which in turn touched the blackened surface of a tracing paper wound round a drum. After recording normal heart beat for some time, the animal as a whole was subjected to electric shocks of different intensities and the heart rhythm was recorded for some time. The recordings continued even after switching off the current till the heart came to normal rhythm. Currents of different forms and stimulations of different types were tested on *H. fossilis* and *Tilapia mossambica*. Visual observations of the effect of electrical shock on the heart rate of *Macrobrachium rosenbergii* were also made. The spinal cord of *Puntius ticto*, *H. fossilis* and *T. mossambica* were severed first behind the supraoccipital and were allowed to rest for two hours before exposing them to electric shocks. The experimental set up and the procedure were similar to that already described. Observations were made for the sensitivity and response in these animals and the minimum field strength required to elicit response in them.

Results and Discussion

The resistance of *Mystus aor* was the lowest (6×10^3–7×10^3 ohms) and of *M. rosenbergii* the highest ($24\times10^3-25\times10^3$ ohms) as shown in Table 1. The result of tolerance test showed 100 per cent mortality in *M. aor* and *Cirrhina mrigala* within 25 to 35 and 65 to 75 min after exposure to current. 60% of *Notopterus notopterus* and 40% of *M. rosenbergii* died after 85 to 105 and 92 to 120 min respectively. 25 per cent of *Labeo rohita* and *Catla catla* were found dead within 115 to 135 and 218 to 255 min respectively after exposure to current (Table 2). An increase in the latent period by 20 milliseconds under 3 volts was recorded over that of 8 and 17 volts in *H. fossilis*. A sharp rise (contraction) with two peaks and a gradual fall (relaxation) were observed at all the shock intensities tested. The contraction phase lasted for 80, 160 and 180 milliseconds for 3, 8 and 17 volts respectively. The corresponding relaxation phases were 120, 140 and 110 milliseconds. In *T. mossambica* two distinct curves with double peaks and a latent period of 90 milliseconds were recorded for D.C. 3, 8 and 17 volts. At 3 volts the amplitude of the second curve was more than the first one. But the amplitude of the first curve increased with the intensity of current (8 and 17 volts). The contraction phase lasted for a higher period in 7 volts than the relaxation period.

At 20 volts the curve of muscle twitch in *H. fossilis* showed a sharp rise and fall with two small peaks at the top. When raised to 40 volts, two peaks along with a wide valley at the top was noticed. At 60 volts, a single peak of highest amplitude was drawn. The contraction phases remained for 190, 450 and 425 milliseconds for 20, 40 and 60 volts respectively. The corresponding relaxation phases however lasted for 20, 30 and 185 milliseconds respectively. The contraction of body muscle of *T. mossambica* due to A.C. 20, 40, 60 and 80 volts revealed the formation of two curves during each stimulus. The height of the second curve was more than the first and a double peak was noticed in the second curve at 80 volts.

The latent period was prolonged by 15 to 50 milliseconds from the third stimulation onward. The length of contractions were also increased irrespective of D.C. and A.C. After an initial rise during the the first few contractions, the height of the curve reduced uniformly. The relaxation phase was prolonged with the number of stimuli and after 30 to 40 contractions, the writing lever took several milliseconds to return to the baseline.

The heart rate of *M. rosenbergii* when exposed to field intensity of 0.0792 to 0.2376δ for 15-180 seconds, showed a decrease of 10-12 per min during the shock. But heart beat decreased under current intensities of 0.792 to 1.98δ till the heart stopped during narcosis. Increasing shock intensity suppressed heart beat (61-116 per min) but accelerated to 146-212 per min immediately after recovery from narcotic condition

Table 1. *Electrical resistance of the body of different species of fish**

Species	Length mm	Animals tested	Electrical resistance in ohms: Mouth to top of head	Mouth to middorsal fin	Mouth to caudal peduncle	Mouth to vent	Electrical resistance of body ohms/cm
Macrobrachium resenbergii	95–115	14	—	—	27×10^3 29×10^3	—	24×10^3 -25×10^3
Labeo rohita	180–205	16	11×10^3 12×10^3	13×10^3 18×10^3	15×10^3 21×10^3	12×10^3 16×10^3	7×10^3 -9.5×10^3
Catla catla	160–195	12	10×10^3 13×10^3	15×10^3 16×10^3	15×10^3 18×10^3	13×10^3 15×10^3	10×10^3 -11×10^3
Cirrhina mrigala	90–100	16	12×10^3 12.5×10^3	16×10^3 21×10^3	22×10^3 25×10^3	15×10^3 16×10^3	75×10^3 -8×10^3
Notopterus notopterus	100–120	12	10×10^3 13×10^3	15×10^3 16×10^3	22×10^3 25×10^3	15×10^3 16×10^3	8×10^3 -9×10^3
Mystus aor	153–184	10	12×10^3 21×10^3	15×10^3 20×10^3	26×10^3 30×10^3	15×10^3 20×10^3	6×10^3 -7×10^3

*Air temperature 33°C, water temperature 32.5°C

Table 2. *Effect of D.C. shocks (direct contact) on animals**

Species	Size range mm	Animals tested	Contact voltage in volts	Effect of direct shock Immediate effect	Percentage death	Time required for death after shock treatment min
Labeo rohita	180–205	12	1.4–2.0	No narcosis	25	115–135
Catla catla	160–195	12	1.4–1.8	No narcosis	25	218–255
Cirrhina mrigala	90–100	12	2.1–2.4	Narcosis for 12–22 sec	100	65– 75
Mystur aor	153–184	10	2.1–2.3	Narcosis for 56–84 sec	100	25–35
Notopterus notopterus	100–120	10	1.4–2.1	Narcosis for 5–7 sec	60	85–105
Macrobrachium rosenbergii	95–115	10	2.6–2.8	No narcosis	40	92–120

* Intensity of shock 25 μA, duration 10 sec, temperature of water 32.5°C

Table 3. *Effect of D.C. shocks on heart rate of Macrobrachium rosenbergii**

Current density in which the animal was narcosed	Animals tested	Heart rate per minute: Before shock Normal	During shock taxis	After recovery from narcosis	Electric shock sec
0.0792	12	124–128	114–116	—	150– 180
0.2376	10	126–130	96–104	—	25– 24
0.7920	12	104–109	83– 87	146–150	27– 31
0.9900	12	172–176	75– 80	194–198	23– 28
1.9800	12	176–180	61– 64	200–212	30– 34

* Electrical resistance 22.5 x 10^3 ohms/cm^2, length of fish 120-170 mm, weight 25-55g, water temperature 29°C

(Table 3). *T. mossambica* showed slowing of heart beat soon after exposition at D.C. 0.8δ and 1.2δ caused momentary cardiac slowing, but afterwards came back to normal rhythm prior to shock treatment. *H. fossilis* when subjected to increasing intensity of A.C., its heart curve showed initial rise during first few contractions followed by uniform decrease till the current intensity reached 0.55δ. At a field intensity of 0.75δ irregular fluttering of heart was recorded which regained normal rhythm when the current was switched off. Gradual cardiac slowing was observed when *H. fossilis* exposed to sharp current rise of 0.35 and 0.55δ and heart stopped in the relaxing phase after 35 and 11 contractions respectively. Exposure at higher current intensity (0.75δ) caused stoppage of heart beat after 3 contractions.

Stimulating the heart with current intensities at 0.7δ and 1.1δ in a media of calcium chloride (1:1500) having a resistance of 8×10^3 ohms/cm^2, the relaxation after each contraction became more and more incomplete, until finally the heart stopped in a tonically contracted condition. In potassium chloride solution of identical concentration and resistance, the tonic condition of the heart increased with 0.2 to 0.75δ current and the contractions lasted as long as the current flow continued. During treatment with current intensities of 0.2δ and 0.35δ, however, the amplitude of heart beats was more when compared to shocks of higher intensities.

When *P. ticto* was stimulated with the increasing field intensity, they responded for first reaction (sensing of surrounding electric field) vibration and leap frogging movement towards the anode and strong swimming movement towards the positive electrode at times accompanied by anodic curvature with head turning towards the anode at currents of 0.4 to 0.048δ 0.08 to 0.096δ and 0.112 to 0.16δ, respectively. 80 to 90% fishes reached for anodic movement in the second and third stage of reaction, while 10 to 20% exhibited vibration of fins accompanied by anodic curvature turning their heads towards the positive electrode in varying current intensities (Table 4).

Table 4. *Response of Puntius ticto to D. C. shocks**

Classification of reaction	Response with the increasing intensity	Current density in μA required to bring out the response	Percentage responded
Stage–I	Expansion of dorsal, pectoral, pelvic fins accompanied by tremour of caudal fins	0.04–0.048	100
Stage–II	Leaped towards the +ve electrode a little with jerk of body	0.08–0. 96	90
	Vibration of pectoral fins and turn its head to the +ve electrode	0.08–0. 96	10
Stage–III	Moved towards the +ve electrode with jerks of body	0.112–0.16	80
	Bending of body turning its head towards +ve electrode	0.112–0.016	10
	Anodic curvature of the body and turned to anode with movement towards the +ve electrode	0.112–0.16	10

* Electrical resistance of water 16 x 10^3 ohms/cm^2, size of fish 72-90 mm, temperature 24°C, number of animals tested 20

Table 5. *Response of Heteropneustis fossilis to D.C. shocks**

Classification of reactions	Response with the increasing intensity	Current density in μA required to bring out the response	Percentage responded
Stage–I	Vibration of barbels and occasional bending of the body	0.016–0.04	100
Stage–II	Forced swimming towards the anode with bending of body and sideward movement of head till they reached the electrode	0.096–0.12	81.4
	Bending of body turning its head towards the anode till their body became parallel to current lines, when they moved violently towards the +ve electrode in that condition	0.12–0.16	8.6
Stage–III	Immobilized with expanded fins and maxilla facing +ve electrode	0.16–0.176	64.4
	Curvature of body pointing their head and tail towards the anode	0.16–0.176	35.6

* Resistance of water 19 x 10^3 ohms/cm^2, size of fish 100-124 mm, temp. 25°C, fishes tested 18

Subjecting *H. fossilis* to increasing field intensity, their reactions were observed at three stages in the current densities of 0.016 to 0.04δ, 0.96 to 0.16δ and 0.16 to 0.176δ respectively. Forced swimming towards the positive electrode and immobilization near the anode were observed in 81.4 and 64.4% cases, whereas, initial bending of the body during second stage and the anodic curvature during third stage were noticed in 8.6 and 35.6% of fishes. All the organisms responded for vibration of barbels and bending of body during the first reaction (Table 5).

All the *T. mossambica* showed quivering of pectoral, pelvic and caudal fins followed by the curvature of body in current intensities of 0.08 to 0.096δ. With the rise of field densities of 0.144 to 0.16, 75% of them remained either perpendicular or at 45° to the field lines without any movement. The remaining 25% glided towards the cathode in an unbalanced manner. Change of body colour and discharge of milt after cease of current flow were noticed in 12.5% animals at this stage. Momentary muscular rigidity in up side down condition occured in case of 12.5% fishes at current intensities of 0.16 to 0.24δ (Table 6).

In order to control fish by electricity in freshwater, a high field strength is required because the conductivity of the fish is higher than that of the water (Bary, 1956). When a fish comes to an electric field, the charge induced on the fish is proportional to the cube of its body length (Kuroki, 1952). According to Holzer (1931), when the conductivity of animal body is higher than the surrounding water (fresh water) all the potential lines are directed towards the body with better conductivity and the fish is thus satisfactorily influenced by electricity. The knowledge of electrical resistance of the animal body is thus important in initiating

Table 6. *Response of Tilapia mossambica to D.C. shocks**

Classification of reactions	Response with the increasing intensity	Current density in μA required to bring out the response	Percentage responded
Stage–I	Curvature of the body, quivering of tail, pectoral and pelvic fins	0. 08–0.096	100.0
Stage–II	Un-co-ordinated movement towards the negative electrode	0.144–0. 16	25.0
	Remain either perpendicular or at 45° to the field lines	0.144–0. 16	75.0
	Body colour darkens deep black during current flow and discharge of milt after stoppage of current flow	0.144–0. 16	12.5
Stage–III	Momentary muscular rigidity and stayed at the bottom with ventral surface up	0. 16–0. 24	12.5

* Resistance of water 15 x 10^3 ohms/cm^2, size of fish 90–122 mm, temperature 23.5°C, number of fishes tested 24

the responses and determination of reaction thresholds.

Halsband (1968) measured the electrical resistance of trout body through water media. In the present study the electrical resistance was determined directly by the dermometer and represented as ohms/cm^2 of body and between different points of body as studied by Denzer (1956) for rainbow trout. The electrical resistance (ohms/cm^2) was found to be lowest in case of *M. aor* (devoid of scale) and highest in *M. rosenbergii* (with a chitinous shell). As observed by Denzer (1956) the resistance between mouth to caudal peduncle of all the test animals was highest than between any other part of the body which is due to the largest body extremities of the animal. It is observed that the order in which fishes affected by electric shocks are *M. aor, C. mrigala, N. notopterus, L. rohita* and *C. catla*. A fixed amount of current (25μA) was allowed to pass through their body by direct contact for a period of 10 seconds. The contact voltage varied from 1.4 to 2.4 volts depending on the species. The severity of shocks (as observed by the percentage of death and the time required for death) indicate that the test fishes are sensitive to D.C. as described earlier.

The skeletal muscle, or its nerve when stimulated by a single induction current resulted in a single short sharp contraction followed immediately by a relaxation (Starling, 1947). To determine the time relations of muscle contraction it was necessary to employ the graphic method. The mechanical changes that the fish as a whole had undergone by D.C. and A.C. were represented by kymograph tracings along with a time record.

Starling (1947) demonstrated that the simple muscle twitch in frog consists of three main phases, namely, the latent period (during which no apparent change takes place in the muscle), contraction (a phase of shortening) and a phase of relaxation. When the whole body of *H. fossilis* and *T. mossambica* were stimulated by D.C. of varying intensities, the latent period was delayed in currents of low intensities. According to Meyer —Waarden (1957) the effective period inducing narcosis (relaxation of muscle) in fishes is inversely proportional to the intensity of the field. The occurrence of second contraction before attaining complete relaxation in both the test fishes can be explained by Pfluger's principle (Pfluger, 1853), that is, the closing of the circuit has a stimulating effect on the nerves or muscles within the range of the cathode and the opening of the circuit has also a stimulating effect within the range of the anode and the reaction to the opening of the circuit is much smaller than the reaction to the closing of the circuit. But in case of D.C. on *T. mossambica*, the amplitude of the second curve (due to opening of the circuit) was found to be greater than 3 volts when compared to currents of 8 and 17 volts.

In A.C. also, double curves for each stimulation was obtained in case of *T. mossambica*. But in *H. fossilis*, two peaks at 20 and 40 volts and a single peak of highest amplitude during 60 volts could be explained by summation effect of two stimuli during closing and opening of the circuit. When the intervals between two currents were shortest, a greater response was observed with a single peak. But during longer intervals between the first and second shocks, as in case of 20 and 40 volts, the excitatory condition of muscle was maintained, so that instead of forming two isolated muscle twitch a second contraction occurred before the fading of the effect of previous stimulus forming two peaks in one curve. The effect of repeated stimulation by both D.C. and A.C. on *H. fossilis* showed that the latent period was prolonged, with the length of contractions. The A.C. and interrupted D.C. caused heavy stimulation of the central nervous system which led to tetanic condition of the muscles (Meyer-Waarden, 1957). According to him, this state of immobility is the consequence of cramp occurring in the muscles caused by the superposition of numerous individual contraction as observed in the present test with *H. fossilis* for A.C. William (1885) demonstrated in the eel that almost any sort of peripheral stimulation caused inhibition of the heart beat and this appeared to be generally true in unanesthetized fish. Cardiac slowing in *M. rosenbergii* was observed during the application of D.C. depending on the current intensity. A slight hyperactivity of the heart was noticed after recovery from narcosis. Momentary cardiac inhibition of *T. mossambica* was also observed in D.C. of varying intensities

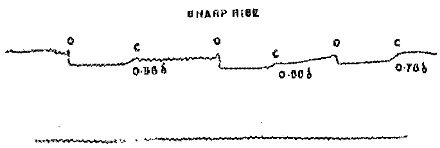

Fig. 1. Effect of sharp increase in A. C. current on heart beat of *H. fossilis*

(0.12 to 1.2δ). Studies in man and animals with A.C. indicated the occurrence of ventricular fibrillation (Novotny & Priegel, 1974). The heart of *H. fossilis*, when exposed to A.C. with slowly rising intensity, exhibited staircase phenomenon (Starling, 1947) at current densities of 0.1δ cardiac slowing at 0.55δ and irregular fluttering at 0.75δ. In sharp current rise, cardiac arrest occurred in relaxation phase even at 0.35δ. Switching off current flow immediately after stoppage of heart beat, regained the normal rhythm once again indicating that the period of exposure in relation to current intensity is responsible for inhibition of heart rate (Fig. 1). The inhibiting effect of $CaCl_2$ solution and the accelerating effect of KCl on heart muscle (Starling, 1947) was confirmed from the present tests also, where the heart of *H. fossilis* stopped in a tonically contracted condition, when stimulated through $CaCl_2$ solution and continued to contract in the tonically contracted state even during the current exposure while stimulating through KCl solution (Fig. 2).

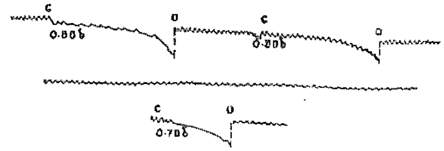

Fig. 2. Effect of A. C. current on heart beat of *H. fossilis* (Medium - Potassium chloride 1:1500)

In the nervous control of locomotion and of movements, the spinal cord clearly plays an important role. Pfluger (1853) severed the spinal cord of eel *(Anguilla anguilla)* immediately behind the medulla oblongata and described various reflexes shown by the posterior portion. Von Holst (1934) concluded that after the spinal section only the anterior part of teleosts *(Carassius auratus, Carassius carassius* and *Cyprinus carpio)* showed rhythmical swimming movements, the hind part being motionless excepting when stimulated.

The fishes *(P. ticto, H. fossilis* and *T. mossambica)* after spinalization behaved in the similar way as described by Von Holst (1934) when exposed to D.C. shocks of varying intensities. The occurrence of anodic taxis, anodic narcosis and anodic curvature in *P. ticto* and *H. fossilis* were observed in a much lower thresholds as that of intact animal (Biswas, 1974). The un-co-ordinated movement of *T. mossambica* towards the negative electrode in lower threshold than the intact animal (Biswas, 1974) confirmed the findings of Cuinat (1967) that the sharp spinal section allowed the persistance of galvanotaxis at the threshold of the intact animal which became unbalanced through the functional suppression of the cerebellum (spinalization).

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