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A Note on the Effect of Electric Fields on *Gadus virens*

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PREFACE

Some preliminary experiments with marine fish in electrical field were made in Bergen in 1953 by Mr. GUNNAR SÆTERSDAL. He used interrupted d. c. and the pulses were obtained from a mechanical pulse-generator. In 1954 the generator was exchanged with an electronical pulse-generator, designed by Dr. HARALD ENGE and Mr. GUNNAR SÆTERSDAL and built at Institute of Physics, University of Bergen. This electronic generator was used in the experiments described here.

The authors are much indebted to Mr. GUNNAR SÆTERSDAL for encouragement and advice of the present work. Thanks are also due to Mr. KÅRE FLØISAND for helpful advice with the statistical treatment of the material, and to Mr. PER ØINES for technical assistance.

INTRODUCTION

The conductivity of sea water is several times greater than that of fresh water. In seawater it is necessary, therefore, to use considerably greater effects than in fresh water to maintain a certain electric field. When interrupted current is used, however, conditions in sea water are not as unfavorable because the smaller resistance permits shorter pulses, which means smaller average effects (MEYER—WAARDEN, 1957).

In fresh water a series of experiments have been performed in fields of a.c., d.c. and interrupted d. c. to study the different responses of fish, especially electrotaxis and electronarcosis (SCHEMINZKY, 1924; HOLZER, 1931; HALSBAND, 1956; and others).

Although some practical applications of electric current in fresh water fishing have taken place (Mc. MILLIAN, 1928; HOLMES, 1948; BURNET, 1952; and others), it seems necessary to carry out controlled, small-scaled experiments in sea water prior to large scale practical applications.

In sea water the two degrees of electrical control of fish, electrotaxis and electronarcosis, are possible, and the present work is particularly concerned with the first of these reactions. Electrotaxis of marine fish has been studied both in d. c. and pulsed d. c. fields. GROODY, LOUKASHKIN and GRANT (1952) used pulsed d. c. in their tank experiments with *Sardinops caerulea* (Pacific Sardine). The most effective of the pulses they used, was one which increased slowly from zero and decreased rapidly. The pulse was repeated at 5 c/s. and had a duration of 133 ms. and an off period of 66 ms. MORGAN (1953) has carried out tank experiments with *Kuhlia sandvicensis* (aholehole). He demonstrated the electrotaxis both in d. c. and interrupted d. c. fields, and the effects of different on-off ratios of interrupted current were studied. He found that interrupted d. c. current had better electrotactive and electronarcotic effects on fish than continuous d. c. current. From the observations of the effect of the various interruptions he came to the conclusion that the lower frequencies were not as effective as those in the middle range (15—20 c/s). This was particularly so when pulse duration was short. BARY (1956) studied the different responses of *Mugil auratus* (Risso) in fields of 50 c/s. a. c., d. c. and pulsed d. c. To elicit electrotaxis in field of interrupted d. c. for a given pulse duration, he found an optimum frequency of pulsing below which the voltage gradient increased and above which no detectable change with frequency was observed. As the pulse duration was decreased, the optimum frequency and the voltage gradient increased. The range of optimum frequency lay between 3.5 and 5.0 c/s., and the corresponding voltage gradients between 0.12 and 0.52 V/cm. for a range of pulse durations of 0.12 to 9.00 ms.

EXPERIMENTAL

The material used was young *Gadus virens* of a length ranging between 38—55 cm. Prior to the experiment the animals were kept in big concrete tanks where smaller wounds due to catching and transportation would be discovered. Only completely healthy animals were used for experiments.

The stimuli were obtained from a pulse generator (Fig. 1) and the pulses were produced by discharging a bank of capacitors through a thyratron. The capacitors were charged from a d. c. source through a second thyratron. The d. c. supply was obtained from a full-wave rectifier, which was supplied with 50 c/s a. c. through a transformer.

The thyratrons were fired alternatively by pulses from a master-pulse generator, which made it possible to repeat the pulses at frequencies between 5—50 c/s. The peak value of the pulses could be varied from 0—15 amps., and the pulse duration was varied by switching capacitors into or out of the bank. The form of the pulses could also be changed, but in general they all rose sharply from zero and decayed exponentially (Fig. 1, B). Pulse duration, defined as the time between start of pulse and the point where the voltage falls to 1/e of the peak value, was measured by a cathode ray oscilloscope. The rise-time, i. e. time between 10 and 90 per cent of the peak value from base-line, was also measured.

A wooden test tank was used, five meters long, one meter broad and the depth of the water was half a meter. The electrodes consisted of two zink plates at the ends of the tank and covering the entire cross section, thus giving rise to a homogeneous field. To retard the contamination of the water by the products of electrolysis a diffussion barrier consisting of two layers of felt were put in front of the electrodes. The animals' behaviour was observed from above.

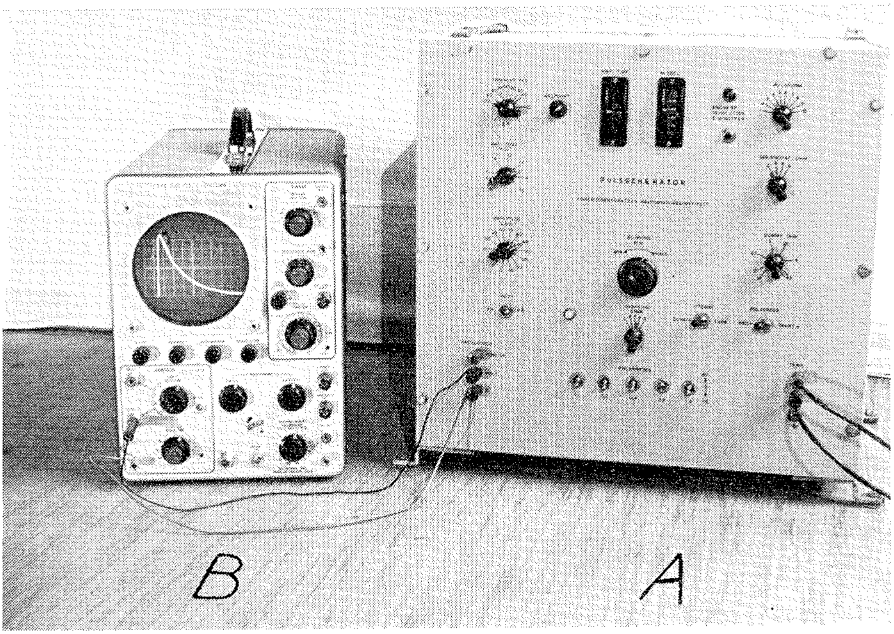

Fig. 1. Electronic equipment.
A: Pulse generator unit. B: Cathode-ray oscilloscope. On the screen is visualized the shape of a pulse.

The procedure was as follows: The animal was captured with a dip-net, the length measured, and the fish transferred to the tank. Ten minutes were allowed for recovery from transfer. Each animal was subjected to a series of five tests, of five seconds' duration each, starting at a subthreshold level and increasing the voltage through the series. A few minutes were allowed for recovery between the tests. An animal was used for one series only. The current was turned on with the animal facing the cathode.

The minimum criterion for electrotaxis was taken as an activation of swimming. Sometimes the electrotactic turn towards the anode would follow immediately upon the closing of the circuit. More often the activation of swimming would first lead to a movement towards the cathode and then the sharp electrotactic turn would follow, leading to a movement towards the anode. Characteristic was also the cramped movements when the length axis of the animal was crossing the field lines.

Table I. The minimum potential difference along the fish (in volts) to elicit electrotaxis for different frequencies and pulse durations. Each value refers to different individuals.

Frequencies in c/s.	Pulse duration and corresponding rise time (in brackets), in ms.		
	1.2 (0.04)	1.4 (0.15)	1.9 (0.50)
10	2.5—1.5—1.5		1.2—1.2
15	2.0—2.7—1.5		1.7—1.0—1.5
20	2.5—1.5	1.5—1.5	1.7—1.7
25	2.5—1.5—1.0	2.0—1.5—1.5	1.5—1.7—1.7
30	2.7—2.5—2.5	1.5—1.5	1.5—1.2
40	2.0—1.7—2.5	1.5—3.0—2.0	1.7—1.2—1.2
45	2.5—2.0—1.7	2.0—1.5—2.7	1.7—1.7
50	2.0	1.5—2.5—3.0—2.3	1.0—1.7

CONCLUSIONS

To test electrotaxis earlier experiments have been performed in relatively small tanks. It was felt, therefore that the arrangement with a comparatively big tank would give greater allowance for a more varied behaviour of the animal. This varied behaviour pattern, however, introduced an uncertainty as to which kind of change in behaviour should be termed electrotaxis. The data have been listed in Table I. As will be seen from the table the spread of data is considerable. A statistical test of the data was tried, therefore, by applying the analysis of variance. For changes in pulse duration there are significant differences ($F = 7.72$; $P < 0.05$). As the pulse duration is lengthened, lower voltage gradients are required to elicit the electrotactic response. This is in accordance with earlier findings. (MORGAN, 1953; BARY, 1956; and others). For changes in frequency no significant differences could be found when the material was treated as a step by step rise of 5 c/s. The number of observations at each frequency is small, and if the material is grouped in higher (30—50 c/s.) and lower (10—25 c/s.) frequencies, a slightly significant difference can be found ($F = 4.52$; $P < 0.05$). The relation this time being that a rise in frequency leads to an increase in the voltage needed for electrotaxis. BARY (1956) showed that the voltage gradient required for electrotaxis does not change with frequencies above 5 c/s.

It was observed during our experiments that a more cramped swimming would be encountered at the higher frequencies, making it difficult to distinguish an electrotactic behaviour. The apparent rise with frequency in the required voltage gradient found by grouping the data, might be caused by this difficulty.

It seems difficult to suggest any reason for the differences in sensitivity between *Gadus virens* and *Mugil auratus*. For a corresponding size and pulse duration BARY (1956) found for *Mugil auratus* a potential difference along the fish of around 7 v., whereas the present investigation yields 2.5 v. for *Gadus virens*.

Many suggestions have been made as to the physiological events underlying the electrotactic behaviour. For the future discussion on the topic, we wish to draw attention to the following observation: Even at voltages higher than the minimum for electrotaxis the effect on the animal was seldom so strong that it overshadowed the animals sensual perseption of the tank walls: The fish would usually turn before hitting the tank wall. Exceptions here are again during the cramped movements accompanying the higher frequencies.

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