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INVESTIGATION OF ELECTRIC FISHES

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1. INTRODUCTION

In a previous proposal, it was stated that the relationship between electroreceptors in the pattern recognition process of electric fish would be studied. In a Midterm Report of September 1972, the phasic tuberous asynchronic electroreceptors and the synchronous tonic ampullary electroreceptors of the Sternarchus albifrons, a freshwater South American weak electric fish were described. The tonic asynchronous ampullary electroreceptors of the same fish species were described previously. Measurements were made and reported.

The studies on Gymnarchus niloticus, a freshwater African weak electric fish, were continued, as were studies of the effect of different anaesthetics on the electrical activity of electric fishes. The effect of D-tubocurarine and the countereffect of neostigmine on Sternarchus albifrons were also assessed.

Three mormyrids (Gnathonemus petersii) were obtained, a freshwater African weak electric fish supposed to be the most intelligent fish (sic). The brain/body weight ratio is close to that of human beings. Previously, one fish of this species was trained to jump through a circle over the water in order to get its food. Studies of the electric activity of these fishes will yield added information on pattern recognition ability of electric fishes. Based upon data generated by these studies, we now propose to generate design and test concepts for physical analogs of the electroreceptors of electric fish to be used in subsequent studies of underwater object detection, identification, and position. These sensor analog simulation tests will be planned to be performed in a plastic water tank of 18 feet diameter.

2. TECHNICAL DISCUSSION

From previous and ongoing investigations, it was determined that Sternarchus albifrons, a South American freshwater high-frequency weak electric fish, has three kinds of electroreceptors:

1. synchronous tonic ampullary electric sensors
2. asynchronous tonic ampullary electric sensors
3. asynchronous phasic tuberous electric sensors

Microelectrode recordings were made from these receptors. The fish was anaesthetized with tricaine methanesulfonate (Finquel "Ayerst") and curarized with D-tubocurarine. Subsequently, neostigmine was used to counteract the long-term effect of curare. A search for an anaesthetic that will not affect the frequency and amplitude of the electric signals emitted by electric fish has been made. This study is in progress and preliminary results indicate that thiopental sodium may not affect the electric signal of Sternarchus albifrons. Both ampullary and tuberous electric sensors are autorhythmic. Two out of three kinds of electric sensors act independently of the main electric organ. This means that we deal with three transmitting systems: a main organ and two secondary represented by the autorhythmic activity. There are also three kinds of electroreceptors, two of which are transmitters and receptors at the same time, and each of them may have some finer subdivisions with regard to sensitivity, amplitude, frequency, latency and habituation.

These electroreceoptors are part of the "lateralis system" of the fish and the other organs related to this system like the lateral line receptors and the free neuromasts are certainly playing an important role in pattern recognition.

The difference between the lateral line sensory receptors and free neuromasts is that the first ones are connected to a common lateral line canal and the last ones not. With all the research devoted to both of these sensory receptors, the difference in the role of the one or the other kind of sensory receptor has not been clarified. However, both sensors are related to water displacement, the fish's own movement, schooling behavior, and avoidance of objects or enemies.

The electric fish's other "lateralis system" sensory organs that the electric organs have not received too much attention. [redacted] demonstrated that on one and the same elasmobranch, Negaprion brevirostris, (Lemon shark), two kinds of ampullary sensory organs exist: one that is sensitive to water displacement, and another one that is sensitive to electric stimuli. Anatomically they looked very much the same, but not biochemically. This indicates the complexity of the sensory system of certain fishes to provide the required functions required for navigation, location of prey, identification of enemies, social interaction in the same species, and communication.

Gymnarchus niloticus, an African freshwater medium-frequency weak electric fish, has one ampullary type of electric sensors and two tuberous types of electric sensors. These electric sensors have to be investigated in relation to their autorhythmicity and their role in navigation and object location. Previous studies have demonstrated the ability of Gymnarchus niloticus to communicate with members of their same species.

Gnathonemus petersii, an African freshwater low-frequency mormyrid electric fish, can be obtained and study is planned after the usual stabilization stage. Studies by Agalides and others of electric fish sensory systems as cited above provided a basis for describing the physical analogs of tonic ampullary electroreceptors and of phasic tuberous electroreceptors in a midterm report. Continuation of this work can establish physical analogs for other electroreceptors and sensory receptors of the "lateralis system" of electric fishes.

Microelectrode recordings, histology, light microscopy, electromicroscopy, and scanning electronmicroscopy can be used to clarify the establishment of the physical analogs.

Some studies on the sensitivity threshold of electric fishes to electric stimuli were made by

This proposed study intends to extend this work. An extensive study of the sensitivity of different species of electric fishes to electric stimuli in the presence of noise and without noise will be made to find out which of the different types of sensory systems of the different species is most effective in locating and identifying objects underwater.

For these experiments, we will use an instrumented pool facility. The distance at which an electric fish can identify moving and stationary objects and to communicate with specimens of its own species can be deducted from the distance, the composition and size of the objects presented to the subject and of the distance of back-playing electrodes and the applied attenuation to the signal. By adding specific kinds and amplitudes of noise, we will be able to find out how well the fish can extract the signal from noise.

Having all of the previously mentioned data, we can proceed to the establishment of an underwater pattern recognition diagram. The established physical analogs of electric sensors and cross correlation will be proposed as a means for identifying objects.

3. STATEMENT OF WORK

[redacted] will provide the personnel, services and material necessary to conduct an investigation of electric fishes. The tasks for Phase I and Phase II will be performed as outlined below.

PHASE I

1. Investigate the ability of freshwater electric fishes to recognize patterns under water and how effectively they can differentiate between different parameters when navigating. It is proposed to use three or four of the following kinds of freshwater weak electric fishes:

   a. Sternarchus albifrons, high signal rate electric fish with its frequency influenced only by change in the tank water temperature; region of origin - subtropical, tropical and equatorial South America.

   b. Gymnarchus niloticus, medium fixed signal rate electric fish with its frequency not influenced by change of tank water temperature; region of origin - subtropical, tropical, and equatorial Africa.

   c. Gymnotus carapo, variable medium signal rate electric fish, region of origin - subtropical, tropical, and equatorial South America.

   d. Gnathonemus petersii, a variable low signal rate electric fish of the mormyridae family; region of origin - subtropical, tropical, and equatorial Africa.

2. Microelectrode recording, histology, light microscopy, electromicroscopy and scanning electromicroscopy will be used as necessary to elucidate and establish the interrelation of electric receptors.

3. Report. A report of the six months' study will be submitted at the end of Phase I.

PHASE II

1. The threshold of electric signal stimuli eliciting a behavioral response in electric fishes will be investigated for:

   a. fishe's own signal recorded on magnetic tape and played back and attenuated.

   b. same species but another subject fish's electric signal recorded on magnetic tape, played back and attenuated

   c. sinusoidal electric signal with same repetition rate as the fish's own signal or slightly changed and attenuated

   d. signals as in (1) and (2) but with a noise source like gaussian noise and varying amplitude will be added through another pair of electrodes in the same water tank.

   These experiments will be carried out in a special round tank of 18 feet diameter by 2 feet high and placed in a special tank facility.

2. From all these results, the distance will be calculated at which an electric fish could detect its own or another electric signal considering the attenuation, the distortion of the signal in water, and eventually the added noise.

3. Physical analogs will be established for some of the electro-receptors, displacement receptors, and other lateral line type of receptors.

4. A diagram for an underwater pattern recognition simulation of the electric fish's electric sensors system, using their physical analogs and a special cross-correlation data processing, will be submitted. A special instrumented underwater pool facility and computer simulating equipment will be considered for use for this proposition.

5. Reports. Financial monthly reports will be submitted. A final report will be furnished one year after contract award. The schedule for the proposed research is outlined in Fig. 5 with the estimated time for carrying out each phase.

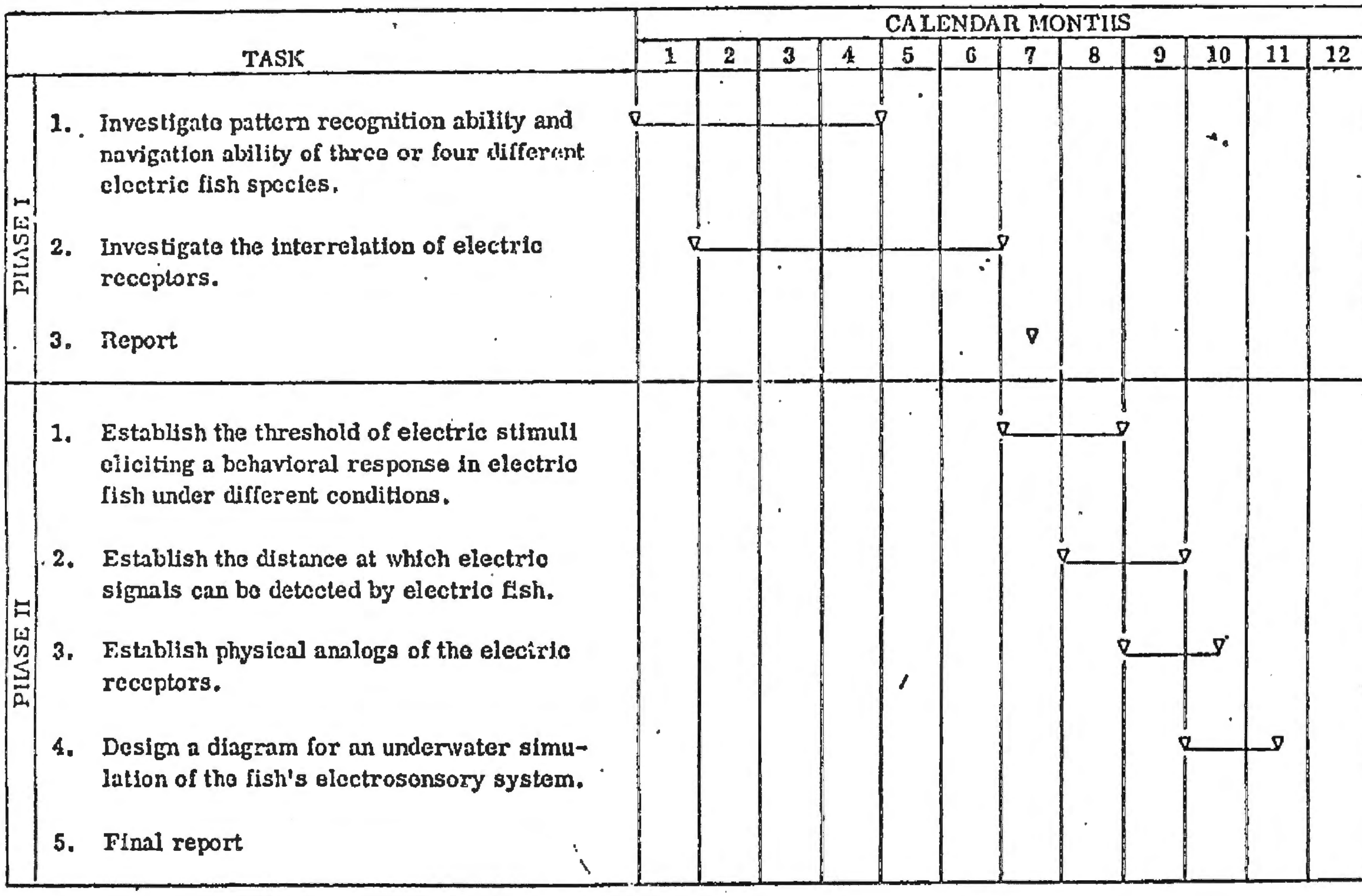

Fig. 5. Program Schedule.

4. PRICE AND CONTRACTUAL INFORMATION

[redacted] suggests that the proposed program be conducted over a one-year period under a cost-plus fixed-fee contract. The estimated costs for this program are shown at the end of this section.

The labor costs used in this proposal are based upon the current average rate of the level of personnel expected to be employed in the proposed effort. No premium for direct overtime expense has been included in this proposal.

The overhead rate used in this proposal is provisional and consists of all [redacted] indirect costs and is adjusted for assumed unallowable costs. Overhead rates will be adjusted at the end of the fiscal year [redacted] to actual costs excluding disallowables, as determined by Government audit.

[redacted] is under the audit cognizance of the Defense Contract Audit Agency, [redacted]

Unless previously withdrawn in writing, this proposal will remain valid for ninety days from the date on the cover.

ESTIMATED COST FOR A TWELVE-MONTH PROGRAM

	Man-Hours	
PERSONNEL COSTS		$
Scientist 41	1210	
Scientist 23	40	
Scientist 12	100	
Technical Typist	96	
OVERHEAD @		
FRINGE BENEFITS @		
TRAVEL: Phase I		
Phase II		
MATERIALS: Phase I		
Phase II		
TOTAL DIRECT COST & OVERHEAD		$
GENERAL & ADMINISTRATIVE EXPENSE @		
TOTAL ESTIMATED COST		$
FIXED FEE		
TOTAL ESTIMATED COST PLUS FIXED FEE		$

5. PERSONNEL