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SHORT COMMUNICATION

AN ACOUSTIC TELEMETRY SYSTEM FOR MONITORING THE HEART RATE OF PIKE, *ESOX LUCIUS* L., AND OTHER FISH IN THEIR NATURAL ENVIRONMENT

BY J. D. ARMSTRONG, M. C. LUCAS, I. G. PRIEDE AND L. DE VERA
Department of Zoology, University of Aberdeen, Tillydrone Avenue, Aberdeen, AB9 2TN, UK

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Heart rate can be telemetered from fish using FM radio transmitters (Nomura & Ibaraki, 1969), FM acoustic transmitters (Wardle & Kanwisher, 1974), acoustic pulsed transmitters (Priede & Young, 1977), electromagnetic transmitters (Priede *et al.* 1985) and acoustic transponders (Storeton-West *et al.* 1978). Most of these systems transmit only over short distances or cannot be used with the standard equipment used in animal-tracking studies. This paper describes an acoustic transmitter which emits a high-power pulse triggered by the R wave of the electrocardiogram (ECG) and is compatible with normal field equipment for tracking fish.

The design is based on the concept of Priede & Young (1977) but has a 75 kHz output usable in fresh or salt water, modern integrated circuits with low power consumptions, and lithium batteries. The circuit (Fig. 1A) is made on a miniature printed circuit board using chip-type surface-mounting components. Power is provided by a two-cell lithium battery (Duracell PX28L) which is centre-tapped to provide a nominal ±3 V supply. For safety reasons, care should be taken not to heat the battery excessively during soldering. One input is connected to the earth (IP2) and the other to IP1. A1 amplifies the ECG signal. C1 in the feedback circuit filters out most high-frequency noise such as muscle activity. C2 provides a.c.-coupling to the second amplifier stage A2. Values of C1 and C2 can be adjusted for different rise-times of ECGs of fish living at different temperatures. A3 is configured as a comparator, the output of which changes polarity whenever the input exceeds a threshold set by adjusting R9. A negative-going transition triggers a pulse from the acoustic output stage of 5 ms duration at 75 kHz and source level 174 dB re 1 μPa at 1 m.

The circuit was enclosed in a polypropylene tube (52 mm long, 16 mm diameter) filled with oil to protect the components and provide acoustic coupling to the surrounding water. The mass in air was 19 g and life under test at 60 beats min^{-1} was 28 days. The PVC-insulated electrode leads (RS Components 357-154) were threaded through a flexible rubber seal in the end of the casing using a hypodermic

Key words: heart rate, telemetry, fish.

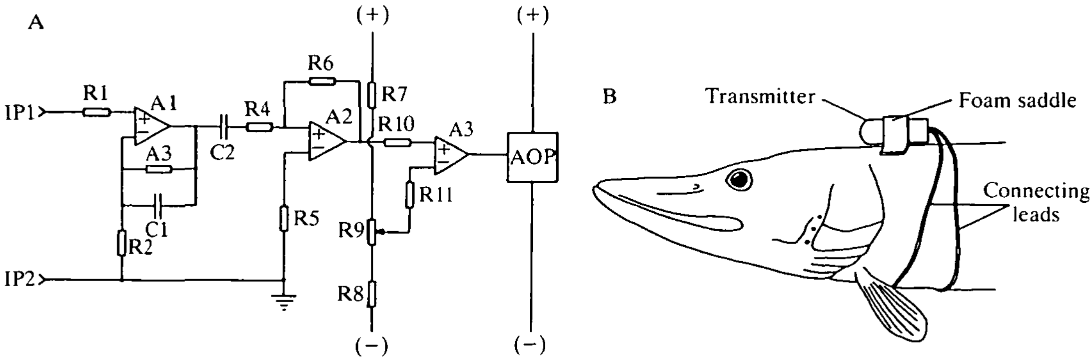

Fig. 1. (A) Circuit diagram. A1,A2,A3, amplifiers (ICL7611, Intersil); power connections on the amplifiers are not shown, positive pin 7, negative pin 4, pin 8 (Iq set) normally connected to positive (see Intersil manuals). AOP, acoustic output module. C1, 1000 pF; C2, 4·7 μF; IP1,IP2, electrode inputs; R1,R2, 100K; R3, 1M; R4,R5, 10K; R6, 330K; R7,R8, 220K; R9, 470K linear potentiometer Siegert TPHG; R10,R11, 10K. All components are surface-mounted leadless-chip types. (B) Transmitter mounting. The acoustic heart-rate transmitter was held by a foam saddle which was sutured to the dorsal surface of the fish. Leads were connected to ventrally implanted electrodes which detected the electrocardiogram.

needle. The transmitter was mounted on a flexible neoprene foam saddle (Fig. 1B) which, on pike, was sutured in a medial position on the anterior dorsal surface by four sutures (Ethicon W328), one at each corner. Removal of one or two scales at each suturing site was necessary. The ECG electrodes were epoxy-insulated stainless-steel wires (0·8 mm diameter) bared at the tips and held in position with sutures, ventrally, close to the heart. Optimum lengths (cm) of the electrode leads for pike were: signal lead 0·029L+3·88, reference lead 0·023L+2·89, where L is fish fork-length (in cm).

Field trials with the transmitter were carried out at Loch Kinord (57°05′N, 2°55′W). Pike were caught by angling and allowed to recover in aerated water before being anaesthetized in benzocaine ($1\,mg\,l^{-1}$) for attachment of the transmitter. R9 was adjusted so that the transmitter was triggered from the R wave of the ECG. Triggering from other components of the ECG was permitted since amplitude of the pike ECG normally declined following recovery from anaesthesia.

Fish were released close to the point of capture and were followed from boats using a conventional directional hydrophone and acoustic receiver (Mariner, Lowestoft, M471). The audio output of the receiver was recorded on one track of a stereo cassette tape (Sony WM6D crystal-control tape-speed) with a voice commentary and time record on the other track. Alternatively, real-time data could be relayed to shore *via* a radio buoy. The buoy could either be used by the mobile tracking team or, anchored near the fish, could operate remotely by detecting transmitter output *via* an integral omnidirectional hydrophone and acoustic receiver. Recording could thus take place on shore, and during periods

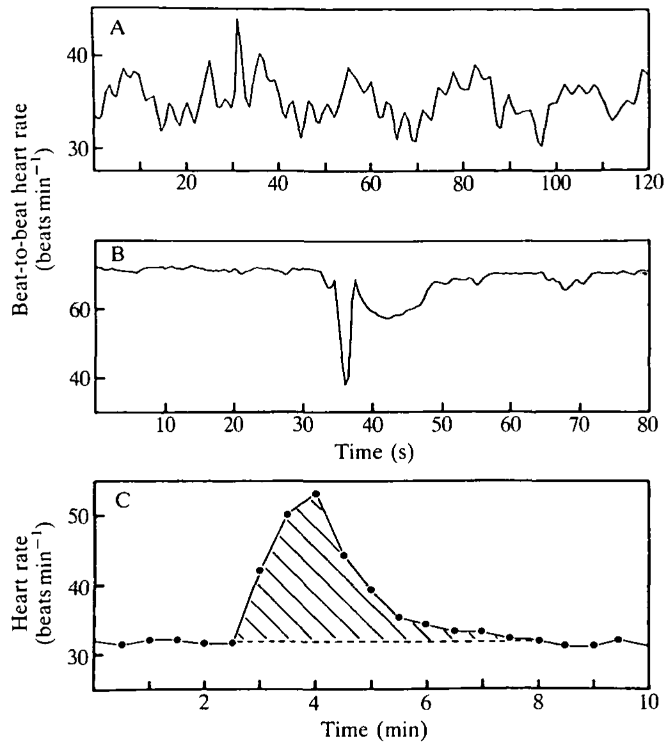

Fig. 2. (A) The heart rate record of a resting pike at night. Heart rate was low with distinct oscillations evident around the mean level. (B) Reflex bradycardia or 'approach reflex'. Heart rate declined markedly as a car approached the shore of the loch. (C) Heart rate change associated with a short burst of activity. Metabolic cost of activity was estimated by integration of heart beats above the baseline level (shaded area).

when the fish was relatively inactive there was no need for a crew to remain on the water.

The range of the transmitter was about 500 m radius depending on water conditions. Within 12 h following release the heart rate settled to apparently normal levels (Armstrong, 1987). Bursts of activity by the fish, accompanied by increased electromyogram (EMG) activity, often caused multiple triggering of the transmitter. This tended to reduce the transmitter life to about half that expected from laboratory tests.

Short-term oscillations in heart rate were recognizable as shown in Fig. 2A for an 800 g pike at 03.00 h on 12 January 1988. This heart-rate variability signal (HRVS) is often found in quiescent resting vertebrates and can be analysed to help understand cardiac control mechanisms (Armstrong *et al.* 1989). The low heart rate with a distinct HRVS serves to indicate that telemetry can provide observations from unstressed pike in the wild.

Two hours after release the heart rate was high and relatively uniform (Fig. 2B).

A distinct bradycardia was shown in response to a car approaching the loch near the fish. This 'approach reflex' (Labat, 1966) is the typical reaction to unusual stimuli and indicates normal levels of responsiveness by the fish to the environment.

Fig. 2C shows a tachycardia typical of that observed during an activity burst. It has been shown that there is a linear relationship between heart rate (fH) and oxygen consumption standardized to a 500 g pike: $V_{O_2,500} = 0{\cdot}81f_H + 5{\cdot}69$, $r = 0{\cdot}885$ (Armstrong, 1986). This gives an estimate of the metabolic cost of this burst of 1·48 mg O_2 which equates with the cost of swimming 34 m at 1 body length s^{-1} or 9 m at 2 body lengths s^{-1}. Often such bursts, confirmed by the presence of distinct EMG interference, could not be discerned using locational tracking. Heart-rate telemetry, therefore, revealed the presence and extent of localized, presumably foraging, movements that might otherwise be missed.

The new transmitter enables continuous field records of heart rate to be made in free-living fish in a range of environments. In fresh water, a VHF radio output (Armstrong *et al.* 1988) could be substituted for the acoustic output stage. This has a lower power consumption and other advantages.

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