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A nonobtrusive heart rate telemetry system for rats

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A harness for recording heart rate (HR) from unrestrained rats and an inexpensive FM transmitter for broadcasting high-resolution EKGs are described. The harness, which employs surface electrodes rather than skin pins or implanted electrodes, is especially valuable for recording HR over extended periods of time. Because it is comparatively free of noise generated by the animal's activity, the system is applicable to a wide range of experimental conditions. Sample HRs obtained from three strains of rats while engaging in different behavioral categories are presented.

For recording heart rate (HR) in unrestrained animals, telemetry has a number of advantages over alternative techniques which require the use of connecting wire leads. Apart from the fettering caused by direct wiring, there is evidence that telemetry leads to faster adaptation and, therefore, lower HRs in rats tested in the home cage or in an open-field apparatus (Bohus, 1974). In attempting to adapt telemetry to long-term HR conditioning in rats, the present authors found that the available techniques for obtaining the EKG signal from the animal, which involved either attachment of pins to the animal's skin or implantation of electrode wires to the rib cage, were inconvenient, obtrusive to the animal, and frequently were the cause of subject loss. A nonobtrusive electrode harness was consequently developed, which eliminates the need for implanted electrodes or skin pins and is essentially nonobtrusive. An FM transmitter was also developed, which, in conjunction with the harness, produces a strong, clean EKG signal under a wide range of experimental conditions, including classical aversive conditioning, escape and avoidance leverpress conditioning, and appetitive HR conditioning.

HARNESS

The harness, shown in Figure 1, is constructed from a BRS/LVE "rat saddle" originally designed as an infusion tube mount. The saddle is modified by attaching two Beckman miniature skin electrodes (No. 679157) to the saddle cinch. The electrodes are of sufficient depth to be inserted through the sponge

rubber pad, leaving the electrode surface flush with the sponge pad surface. Each electrode is attached to the Velcro cinch by cementing (with nylon cement or epoxy) a small nylon screw to the back of each electrode. The screws are then inserted through the Velcro and tightened with hexnuts, as shown in Figure 2. Attaching the electrodes with screws allows them to be positioned closer together or further apart (2-2.5 cm) to accommodate smaller and larger animals, respectively. Once the electrodes are in place, the wire lead from each electrode is sewn or taped to the outside of the cinch, terminating at the saddle. Gold pin connectors insure a durable connection between the electrodes and the transmitter. Finally, a screw is inserted through the copper frame on the saddle for mounting the transmitter.

Figure 1. Photograph of rat wearing electrode harness with mounted transmitter. The harness was fabricated from a two-piece rat saddle manufactured by BRS/LVE (5301 Holland Dr., Beltsville, Maryland 20705).

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Figure 2. Cut-away illustration detailing the construction of the electrode harness from the cinch (lower) portion of the rat saddle.

Instead of surgically implanted electrodes, or skin pins, the external electrodes simply require that the rat's chest be shaved. A small amount of electrode paste is applied to the electrodes before installing the harness on the animal. (If shorting of electrodes due to smearing of electrode paste becomes a problem, a small piece of sponge rubber may be sewn between the electrodes on the sponge rubber pad.) Clean EKGs have been obtained for as long as 2 months between shavings in animals tested over a 6-month period. The harness is remarkably insensitive to movement artifacts during such activities as walking, rearing, and grooming. The only situation in which the harness has not performed satisfactorily is on hardware cloth floors, where the wire mesh has a tendency to become caught in the hexnuts which secure the electrodes to the cinch. This problem has been avoided by using dowel or rod floors; however, the problem can also be solved by securing the electrodes to the harness cinch in some other fashion.

TRANSMITTER

The harness has been used with a commercially produced transmitter with acceptable results.¹ However, our transmitter produces a QRS signal which is of greater magnitude and more highly resolved, and it broadcasts this signal with a greater field strength. The improved QRS signal is obtained by using a high-performance operational amplifier with filtered input to detect and amplify the EKG. The greater field strength is due to the relatively large diameter of the broadcast coil. These improvements are gained through greater power consumption, hence shorter battery life. This is an advantageous tradeoff for us because the improved signal facilitates automated data collection, and, with our harness arrangement, batteries are easily replaced. Our unit has the additional advantage of costing \$25 in components, while commercial transmitters typically cost from \$150 to \$300. The transmitter broadcasts on the standard FM band

(88-108 MHz), and is compatible with any good FM receiver. We have used an old tube-type tuner (c. 1963), with results comparable to our \$700 biotelemetry receiver. A band-pass filter (10-300 Hz) inserted between the tuner and the amplifier helps block high-frequency noise and prevents shifts in baseline dc caused by the animal's movement and other factors (see Swinnen, 1968, for simple filter designs).

Schematically diagrammed in Figure 3, the transmitter consists of a Colpitts oscillator which is modulated by an amplifier unit. The basis of the amplifier section is a high-performance operational amplifier wired as a noninverting feedback amplifier. An R-C band-pass filter on the input passes the major frequency components of the QRS waveform complex. The positive half of the bipolar power supply required by the amplifier is obtained by rectifying voltage from the oscillator circuit with a "hot carrier" diode, which is faster than silicon diodes.

Constructing the transmitter from parts is a relatively simple matter, requiring several hours for the average technician. The circuit can be assembled on 1/32-in., P-pattern perforated board that is compatible with the pin placement of the op-amp and transistor. The components should be assembled around the two semiconductors using a minimal amount of solder and a low-wattage soldering iron. A magnifying lens or dissection scope is useful for inspecting each connection after it is soldered. The transmitter circuit can be assembled in a package only 2 cm (diam) x .5 cm.

Tuning the transmitter is accomplished by adjusting the number of turns on the coil, and does not require special alignment equipment. Once the circuit is completed except for the coil, a temporary coil can be formed by winding 2½ turns of 28-gauge enameled copper wire around a 1.8-cm form (about the size of a dime). The leads to the coil should be left long enough to add an additional half turn to the coil. When working properly, the transmitter draws 4-6 mA (which results in about 16-h operation with two R13 batteries). The transmitter frequency is trimmed by adding or

Figure 3. Schematic diagram of transmitter circuit. Capacitors C1 and C2 are miniature axial lead tantalum (Corning). All other capacitors are miniature axial lead ceramic (Mucon). All resistors are carbon, 1/8 W, 1%.

subtracting fractions of a turn on the coil, until the desired frequency (which should lie on a quiet spot on the FM band) is obtained. The coil should then be dipped in epoxy or wrapped tightly in wax string to prevent deformation from sudden impact.

The entire circuit should be encased in a nonconductive material. Rather than potting the entire unit in epoxy, we have encased our transmitters in machined Plexiglas, so that the unit may be disassembled for circuit modifications.

APPLICATIONS

It has been well documented (see Obrist, Black, Brener, & DiCara, 1974) that HR is correlated with activity level. In order to demonstrate that our harness arrangement produces orderly data from otherwise unrestrained animals, 12 subjects, four male albino rats from each of three strains (Sprague-Dawley, Charles Rivers, and Blue Spruce), were allowed three 45-min sessions, one session per day, to adapt to an observation chamber and the telemetry apparatus. The observation chamber consisted of a 46 x 25 x 38 cm chamber enclosed in a larger sound-attenuating box with a one-way mirror. During 2 test days (Days 4 and 5), an experimenter monitored the subjects' behavior on a keyboard event marker, classifying behavior according to one of six categories: still (motionless), head movement only, walking, rearing, grooming, and other. The keyboard event marker was interfaced to a PDP 8/e

computer, which also received the square-wave output of a comparator circuit set to respond to the voltage change produced by the EKG signal. The computer was programmed to time 10 consecutive "valid" interbeat intervals (IBIs) and to store the data according to the corresponding behavioral category. An invalid IBI (one that, because of noise or a "dropped" heart beat, fell outside of a predetermined time range) aborted the sample currently in progress and initiated a new 10-IBI sample. Overall, valid samples accounted for approximately 80% of a session's duration. Although unnecessary for present purposes, a substantially higher percentage could have been obtained by employing samples comprised of fewer than 10 IBIs.

As can be seen from Figure 4, there was excellent correspondence between HR and behavioral category among the three strains. There was also an overall difference in HR among strains; however, this difference may have been due to age or weight variations among the three samples. The important feature of the data is that, despite differences in HR level and strain, the relationship between HR and behavioral category (and, therefore, presumably, activity level) remained invariant.

One major advantage of our harness arrangement is that it can be introduced into an ongoing behavioral paradigm with minimal disruption. Subjects easily adapt to the harness, and applying a dummy harness overnight is usually sufficient to inhibit any resistance to the device. Thus, the harness can be introduced at

Figure 4. Mean heart rates during selected activities for three strains of rats (S, Sprague-Dawley; C, Charles Rivers; and B, Blue Spruce).

an advanced stage of training to assess differences in HR between different experimental conditions. We have introduced the harness in the final stages of a long-term

preference for signaled shock study without disrupting the subjects' patterns of responding.

The transmitter is economical and produces a highly resolved EKG. It is easily assembled and does not require sophisticated shop facilities. Although the harness was designed for telemetry purposes, it can also be used to advantage for direct wire recording of HR.

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NOTE

1. The transmitter was manufactured by Narco Bio-Systems, Inc., Houston, Texas, and cost \$310.

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