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Development in recent years of subdermally implanted radio, transmitters has widened the scope of physiological research. The advantages of the telemetry method are that the animal is unrestrained in a large enclosure and can carry on its accustomed daily activities unhampered by wires, external sockets, or restraining lines. (Fig. 1, 2, 3.)

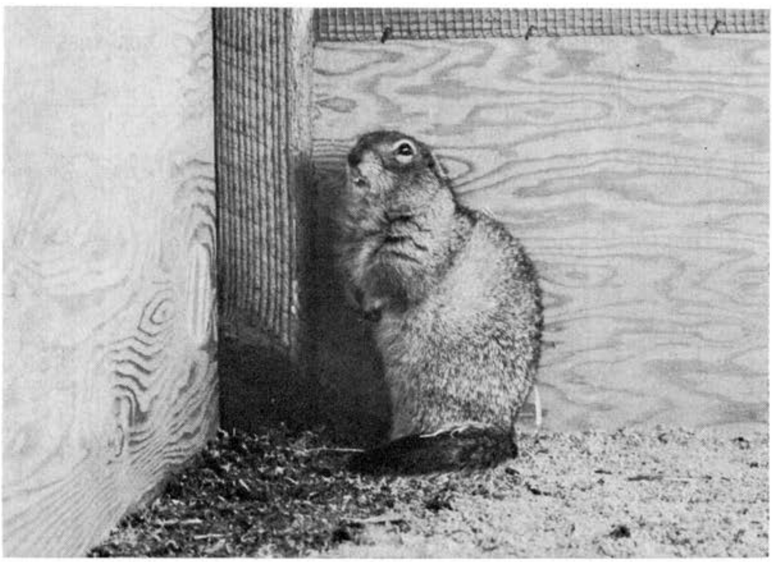

Fig. 1. Arctic ground squirrel carrying a transmitter potted in Marine resin Apoxy which has been functional from Oct. 20, 1965 to time of writing. Note that the transmitter does not affect the normal alert stance of the animal. In fact, there have been no cases of an influence of body-cavity transmitters affecting the health or behavior of the animal.

Via this method, data may be obtained in several areas: (1) determination of day-night activity patterns and rhythms; (2) records of the basal resting heart rate of unrestrained and unexcited mammals; (3) measurement of the accuracy of biological clocks (Folk, 1964); (4) recording of heart rate during activity of normal life such as courtship and mating.

The primary instrument in this method is the implantable transmitter. Former designs have been along a rectangular form (Fig. 4). The transmitters were packaged in a machined, polystryene plastic box or tube (1.1 mm thick) sealed at joints by fusing with plastic solvent and then dipped in tygon, usually 7

[1] Supported by the National Science Foundation. Illustrations by Mary A. Folk.

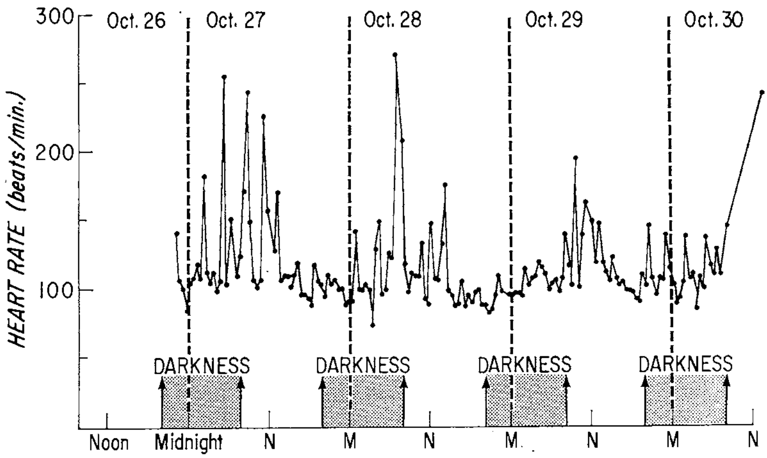

Fig. 2. Type of data obtained with the Iowa radio capsule. Heart rates of an Arctic ground squirrel A maintained under controlled conditions in a 12-hour light-darkness cycle. Note the conspicuous day-night rhythm of physiological activity.

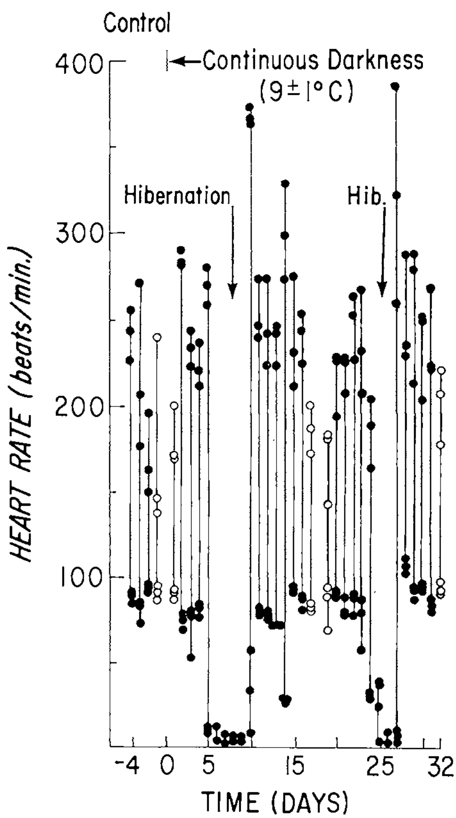

Fig. 3. Heart rate records obtained when ground squirrel A went into and out of hibernation. The three lowest and highest heart rates for each day are graphed.

For several days before each hibernation bout, the lowest heart rates were successively reduced each day; *i.e.*, the animal demonstrated physiological test-drops.

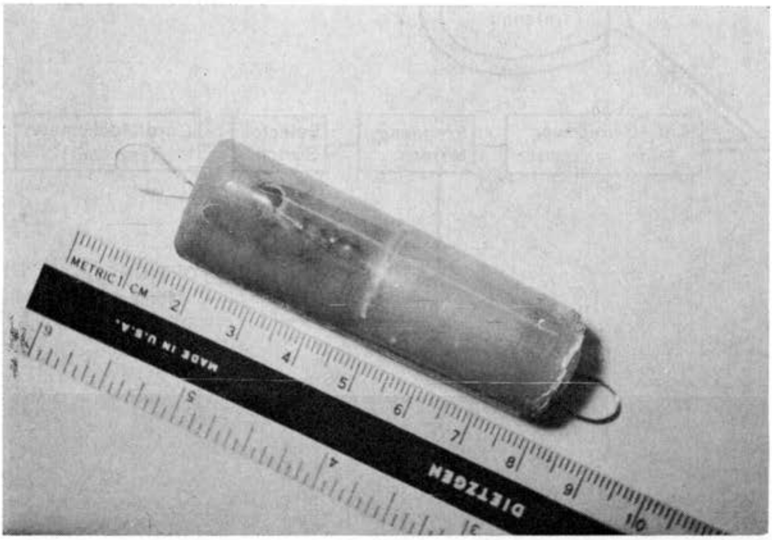

Fig. 4 View of typical implantable Iowa radio transmitter for recording heart rate and EKG.

times (Shook and Folk). The capsule consisted of 3 main parts:

(1) a single transistor oscillator, operating in the 200 to 500 KC band

(2) a two transistor amplifier which amplifies the pulsating voltage received by the electrodes.

(3) a voltage sensitive capacitor (varicap) which converts the output of the amplifier to capacity variations.

The capacitor is connected to the oscillator in such a way that capacity variations cause pulsating changes in output frequency or frequency modulation (Folk, 1964). The normal method of recording heart rate involves reception of the signal and conversion into the original pulsating voltage received by the electrodes. This pulsating voltage is then applied to a standard EKG recorder (Fig. 5).

The capsules were dipped in tygon coating, but moisture from the body yet gained entry. On many occasions, transmitters removed from the body cavity were wet inside. Minor corrosion was present on metal parts and the paper battery wrappers were soft and soggy. According to manufacturer's information, the mercury batteries used in these transmitters absorb all of the products that they generate so they should not be the source of dampness and corrosion (Shook and Folk, 1966). This mositure leakage continued despite use of new plastics.

Moisture leakage, coupled with problems of electrode breakage, led to the development of the "Super Radcap." This newest

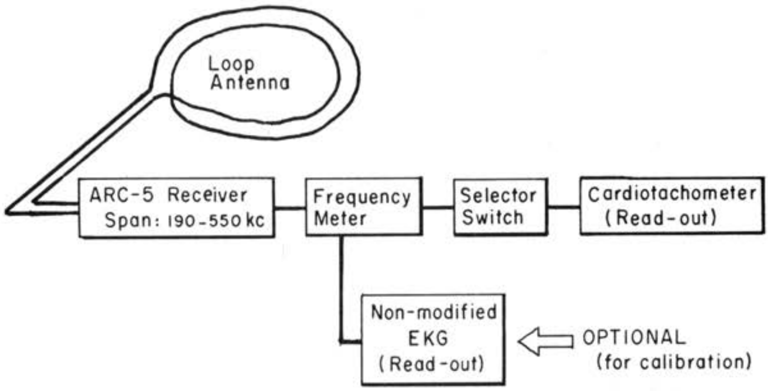

Fig. 5. Block diagram of recording circuits.

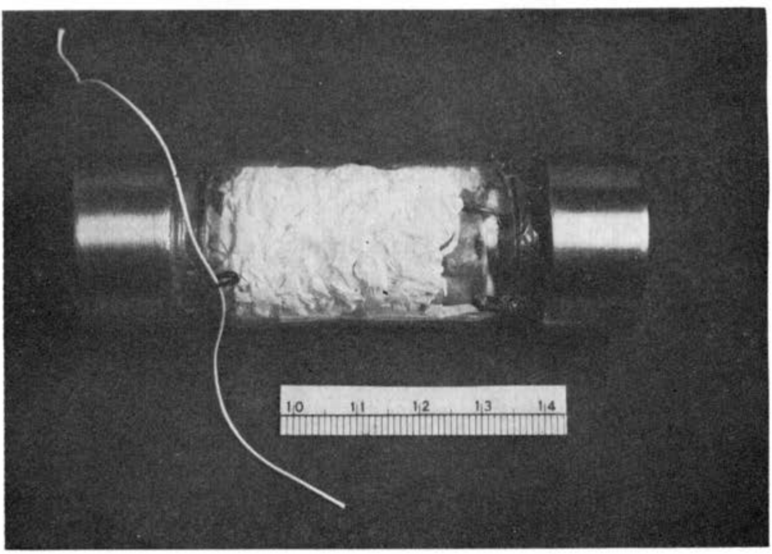

Fig. 6. View of new form of Iowa radio capsule with stainless steel caps acting as electrodes on glass container.

capsule is protected with glass and stainless steel (Fig. 6). The cover is formed from the fusion of the upper ends of two pyrex tubes, retaining the threads to allow stainless steel electrode-caps to be screwed on. The internal mechanism is of the type designed by Essler (1961). Total weight is 110 gms.

This capsule was successfully, temporarily implanted in a rabbit prior to implantation in a raccoon for environmental studies. At necropsy the incision of the rabbit showed no stress nor impariment of healing due to the weight resting upon it. The "Super Radcap" was implanted in the same fashion as all others (Folk, 1964).

Transmission performance from the Super Radcap surpasses other models. A clear, recordable signal may be obtained with a 12′ square (144 sq. ft.) single-wire loop-antenna. With other recording systems, signals have been received with a 25 yard corral (Folk, 1964). It is certain that the Super Radcap would equal this performance.

The Super Radcap design gives the advantages of longer life due to battery capacity, leakage control, and increased electrode contact.

Data Reduction

As stated earlier, data is recorded by conversion of the signal to pulsating voltages which are recorded on standard EKG machines. Records are made automatically every 15 or 30 minutes for 30-sec. duration. These tapes, which show the standard EKG wave form, are then counted by hand and graphed (Fig. 7, 8).

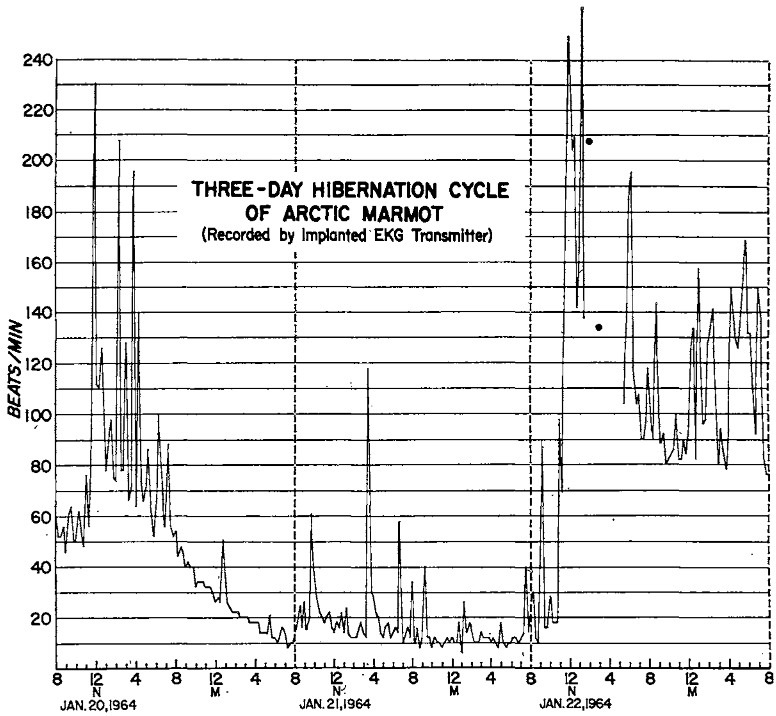

Fig. 7. A second example of the cardiac physiology during entering and coming out of hibernation. The animal is an Arctic marmot maintained under constant conditions.

The ease of using telemetry methods in research and the ability to program collection of data from a series of animals has increased the quantity of raw data which must be reduced by hand. In an effort to find a method for mechanical reduction of data the cardiotachometer was developed with the aid of Professor Harold W. Shipton of the University of Iowa.

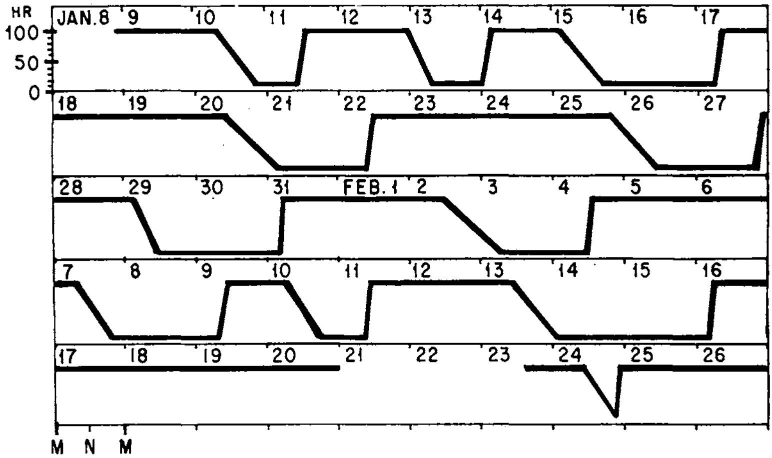

Fig. 8. Cardiac record of Arctic marmot B obtained from recording throughout the winter. Note the slow drop into hibernation and the rapid awakening from dormancy. These data illustrate the problem of counting heart rates since four marmots were recorded 48 times daily throughout the winter.

The cardiotachometer is constructed in two units: (1) Burdick electrocardiograph modified to give a slow paper speed (app. 1 mm/sec.), and (2) a selector box, a description of which follows. Located on the front side of the box are, proceeding first across the upper half from left to right:

(1) the gain control,
(2) the heart rate range selector rotating switch; ranges are 20-300, 150-300, 340-570, 480-715, 715-1000,
(3) an operating light (on, when the box is functioning), and
(4) just under this light, a fuse cap.

Continuing the description by proceeding across the lower half from left to right:

(5) input lead-in from the frequency meter,
(6) an external filter socket, which is not used,
(7) output lead-out to the modified EKG,
(8) discriminator switch to select the "average line output" or "rate output",
(9) power switch.

(The last two are toggle switches.)

Though not given here, a block diagram of the selector box and a diagram of the modifications to the standard electrocardiograph instrument will be provided upon request.

To record with this equipment, the signal is led through the arc-5 receiver, converted in the frequency meter and led into the selector box; readout is from the cardiotachometer. The antenna may be either (1) a single or double loop or (2) a sinusoidal shape over or under the animal cage (Folk, 1964). The "gain" control on the frequency meter is set at a point for a clear reading or a standard EKG. The "gain" on the selector box is set at

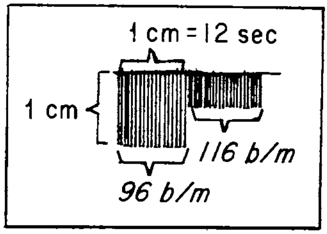

Fig. 9 Explanation of the patterns of spikes recorded by the cardiotachometer.

the minimum point, then increased until the instrument spike is triggered; it is left at a point just beyond the trigger point. This is critical, as a setting too high (toward maximum) will not allow filtering out of noise and movement.

The record itself is a series of single spikes, one for each heart beat. The length of the spike, and the space between each varies with the speed of the heart rate (Fig. 9, 10, 11, 12). An averaging device to automatically draw a line of "best fit" to the spikes is developed; however, it will not be discussed in this presentation.

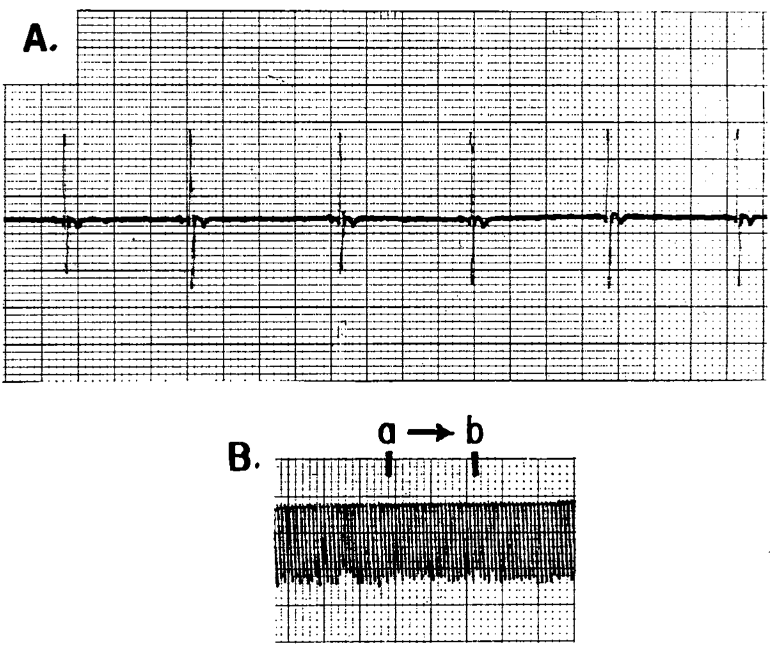

Fig. 10. Simultaneous records from the cardiotachometer and an electrocardiogram instrument.

Calibration consists mainly of establishing "base lengths" of the spikes for reading, and checking, the record later. This may be accomplished in three ways:

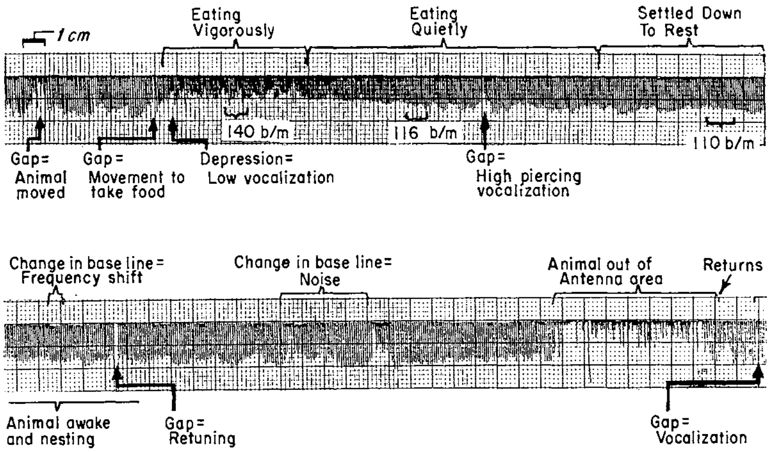

Fig. 11. Effects of animal activities on cardiotachometer records from implanted radio capsule in an Arctic ground squirrel.

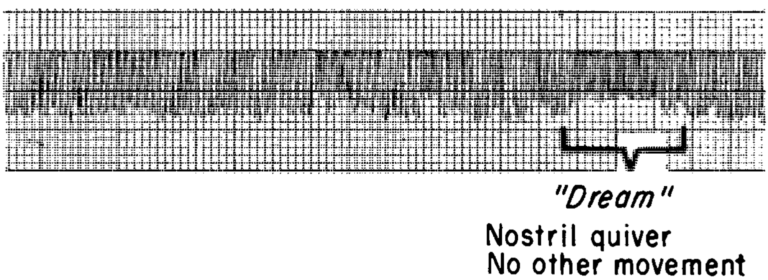

Fig. 12. Cardiotachometer record from an implanted radio capsule in sleeping Arctic ground squirrel. During the period marked "dream," the animal did not show muscular movement except for nasal twitching.

(1) by using an electronic device to feed in a constant rate of impulses of sufficient strength to trigger the spike,
(2) simultaneous recordings of cardiotachometer and a standard EKG,
(3) counts taken either by ear or against the second markings at the top of the paper.

In all three instances, the "standard length" of the spike for use in reading is taken from a line of best fit. A sample calibration graph is provided; for routine work this line can be read to an accuracy of ± 5 beats/minute when the range is from 90 beats/minute to 200 beats/minute (Fig. 13).

Evaluation

There are two main facets to the advantages of this machine—the constant read-out of heart rates and the capabilities of using it as an activity recorder.

In consideration of the former, the constant read-out could be valuable assistance in hibernation studies. Due to slow speed

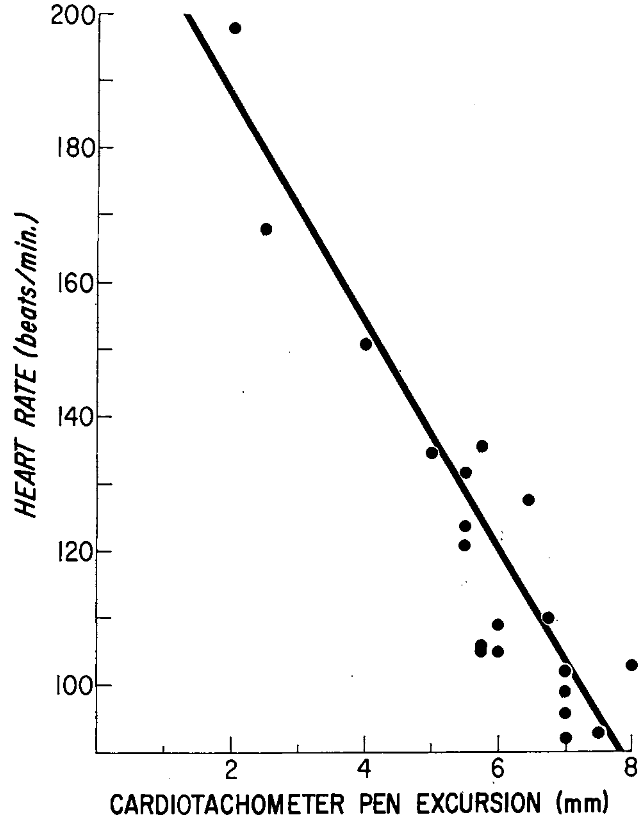

Fig. 13. Calibration of spike height of cardiotachometer record in millimeters and heart rate/min.

of the paper read-out, it would be economically possible to record constantly and not have to depend on random samples of heart rate. If a graph of timed intervals, similar to those made in the past, was wanted, heart rates could be counted off of the tape by the aid of (1) the second slashes on the top of the record and (2) the constant even paper speed of 4.9 cm/min.

The possible application of making timed readings from the tape make the cardiotachometer a useable activity recorder. One could obtain the times of day and/or night activity by the reading. A feasible experiment would be to rig up an antenna of limited range over the feeding area of a large enclosure. From the tape, it could be determined at what time the animal ate and, the heart rate. Then the maximum and minimum heart rates can be counted by hand from the cardiotachometer record. For an example of this type of plotting, see Figure 14.

Further work is being planned to develop a wider range of experiments for the tachometer and the prospect of utilizing the

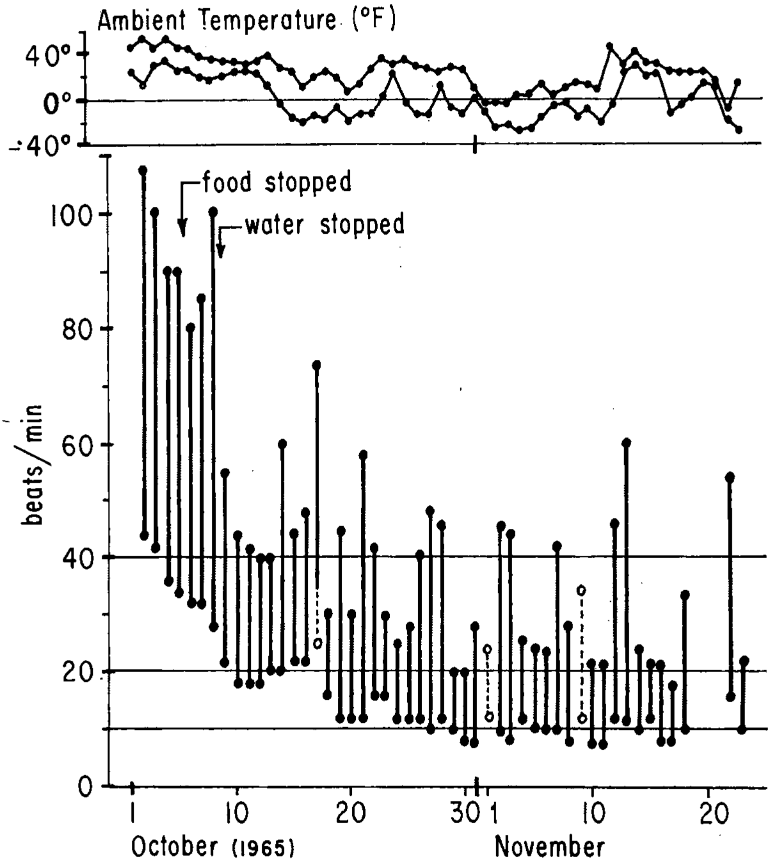

Fig. 14. Example of graphing of minimum and maximum heart rate to represent daily activity of an Arctic mammal (grizzly bear). Note that the animal went into dormancy in the middle of October. To obtain these records, 48 half-minute records were made each day all winter on 4 bears.

"average line read-out" (an automatic line of best fit) is being studied.

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