TELEMETERING PHYSIOLOGIC DATA FROM ATHLETES

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Summary
Employing a team composed of physicians, electrical engineers, and specialists in physical education, significant dynamic physiological data has been gathered by means of radiotelemetry from athletes undergoing strenuous effort, participating in team sports, and from spectators viewing football games. Using a transistorized A.M.-F.M. transmitter carried in a padded compartment strapped comfortably onto the low back and weighing 30 oz. complete, ECG, pulse, temperature and respiration signals have been transmitted for distances up to 500 yards. The multiple technical problems surrounding distance telemetering of physiological information during active and vigorous muscular effort are discussed. Somatic muscle interference, the most troublesome artefact in dynamic electrocardiography, has been successfully circumvented by instantaneous recording of data from the momentarily inactive subject. Application of computer techniques to the analysis of exercise electrocardiograms must await procedural improvement and standardization and collection of adequate data on which to base valid programming.

Introduction
The acquisition of dynamic physiologic data from active subjects imposes demands upon technique and instrumentation not usually encountered in static studies. Thus, accumulation of meaningful information is frequently fraught with problems which are unique to each area of study. Holter\(^1\) expressed the problem very clearly when he suggested three variables which influence the type of equipment needed for any given study. These were (a) duration of observation period, (b) activity of physiological subject and (c) data storage requirements. By permuting these variables he came up with eight possible combinations of data acquisition and storage systems. The possible variables, however, can be extended almost infinitely. For instance a fourth can be suggested concerning the location of the test subject, be he or it beneath or in the sea, on the land, in atmospheric space or in stellar space. A specific example is the limitation placed on direct Mars to Earth telemetry by Martian atmospheric argon. The limitation demands a dual system, Mars to orbiting Martian satellite and satellite to Earth.

In our own specific area, dynamic physiologic studies in swimmers has been limited by the milieu in which they perform, although attempts are being made to circumvent this
environmental factor. Even more important to us is the degree of physical activity involved. Holter has listed two sub-variables, active and inactive. Yet activity of a subject performing a Master’s 2-step electrocardiogram is significantly different from that of a 440 yard sprinter running a 48-second race. Therefore, activity itself must be subdivided, and the method used to obtain significant data must be modified to meet the demand. Thus, variables vary by degree, “and so on into infinity”.

For four years we at the University of Nebraska have been applying radiotelemetering techniques to the study of various problems in athletics. How this technique is being applied to an investigation of pulse, temperature, respiration and electrocardiographic changes in male and female athletes and in spectators is the subject of this paper. Particular attention is directed toward problems in Methods and instrumentation, especially at the transducer level, dictated by the demands imposed by a vigorously active, moving, distant, muscular, perspiring subject.

**Material and Methods**  
Spencer et al., discussing the impact of electronics on medicine, listed the components of electronic diagnostic instrumentation. Fig. 1, extracted from their paper, suggests three domains in any physiological study, that of the patient, that of instrumentation and that of the physician. In actual practice, however, domains interlock and responsibilities converge. A closely oriented multidiscipline staff is important in any research project but particularly where disciplines, by their very nature, are so widely divergent in training, nomenclature and interest, as those involved in the application of medical electronics to a study of athletic physiology. We have rediscovered this by bard experience. Our present staff consists of a physician as principal investigator; a physician who is both a cardiologist and an electronics expert as co-principal investigator; a biophysical engineer for equipment support; an instrument maker; a track coach, a chairman of the Department of Physical Education for men; an assistant professor of physical education for women; graduate and undergraduate assistants in physical education as research assistants; and ancillary medical laboratory and x-ray technologists. Frequent interdisciplinary meetings help to solve the numerous technical problems related to gathering of significant data.

Figure 2 is a block diagram of the equipment complex employed in these studies. The transmitter will be discussed later. Signals are picked up on a simple multi-directional antenna, although for routine short-distance use it has been found that a small strip of 300 ohm TV lead wire suffices for distances up to 300 yards. Two Citation Model III F.M. tuners are used, both mounted firmly on a metal rack and grounded through the central ground. One is tuned to 102.2 mc and the other to 104.2 mc. The 2000, 2800 and 5200 cps band pass filters are custom built. Signals are passed through an RCA program.

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amplifier and fed to Sanborn Twin-Viso electrocardiograph amplifiers where they are passed to the direct writer for real time recording or through the appropriate Jack to a Tektronix Type 502 Dual Beam oscilloscope for monitoring. Tape storage is not a part of our present program for reasons which will be discussed later.

Figure 3 shows the instrument complex mounted for transport. The forward wheels are caster-mounted, the rear wheels are stationary mounted. With the antenna pole slung beneath the cart, the equipment is moved about the campus from building to building and athletic fields with ease. Removable wheels render it easily transportable from city to city by land or air. In Fig. 4 the antenna pole is mounted. It is extended to its maximum of 20 feet during cross-country experiments where intervening land masses may interfere with signal reception. A rear view (Fig. 5) shows, from left to right, the central ac input and ground box, pre-amplifier, band-pass filter bank and the F.M. receivers.

The dynamic physiology evaluation modules (Dypem) are shown in Figure 6. They also are custom built and the basic specifications have been described by Dunn & Beenken in the published literature. From left to right “A” is a twin-channel A.M.-F.M. transmitter shown mounted to transmit two bipolar electrocardiographic leads. The signal amplitude-modulated sub carriers at 2800 and 5200 cps frequency-modulate the RF broadcasting at 102.2 mc. Any of the other transducers shown (C, D and E) may be “piggyback” mounted to permit ECG-peripheral pulse, ECG-respiration or ECG-oral temperature transmission respectively. “B” is the single channel 2000 cps module capable of transmitting one bipolar lead only. RF is adjustable from 100 to 105 mc. Each transmitter has a patient-standardization switch and a 1 mv standardization button. The range is 500 yards over open terrain. The weight of the instrument mounted, including elastic belt, electrodes, lead wires and batteries is two pounds. (Fig. 7) It is comfortably carried in the hollow of the sacrum and has been used in races as long as five miles.

The peripheral pulse module (Figs. 8, 6C) is a custom built photoelectric cell transducer. It can be used successfully only when the subject is not swinging his aims. This limitation is circumvented by signalling the subject to hold his arm steady when a recording is desired. At rest no problems are encountered. An ear lobe transducer of similar design, if lighter weight, would be more acceptable.

The respiration sensor (Figs. 9, 6D) is simply a thermistor bead held in a thin plastic shell, and records only respiratory rate. Attempts have been made by others to monitor respiratory volumes in athletes by use of B.M.R.-type equipment containing a thermistor bead, but this method defies accurate calibration, especially in the running athlete whose breathing amplitude is often times quite erratic. The traditional method of measuring oxygen consumption and carbon dioxide output is applicable to treadmill experiments but impossible in active sports studies, thus we have been satisfied with the measurement
of rate only. An excellent tracing can be obtained even on a mouth-breathing subject, sufficient nasal flow of air occurring to activate the thermistor.

The oral temperature sensor weighs less than 10 grams and consists of a U-shaped tubular wire with a disc-imbedded thermistor so placed that it fits snugly against the buccal mucosa when inserted. (Figs. 10, 6E). It is accurately standardized from 37° to 40° c. Mouth breathing results in no air temperature artefacts. The “piggyback” module has a graduated switch for instant calibration. A rectal probe (not shown) can be used for measurement of internal body temperatures. We have encountered oral temperatures up to 43° C. during running, suggesting that our original standardization range was unrealistic.

**Electrodes and Electrode Placement**  
The subject to electrode interface is by far the most important but troublesome link in the telemetering chain for it is here that the artefacts occur. Even the most sophisticated laboratory-tested transmitting, receiving and recording equipment is of little value if the signal is lost or distorted at the electrode interface. It is here that most workers founder. Therefore, I would like to spend a little time discussing this most important area.

**(a) Electrode Placement**  
Blackburn and co-workers tested 22 known heart patients, with typical ST depression somewhere in their standard ECG, against 15 electrode placements reported in the world literature as being used in exercise electrocardiographic studies. The leads were compared in regard to optimal sensitivity to display of ST depression, signal to noise ratios, and base-line shift with exercise, all important considerations in exercise electrocardiography.

CM₅₆ (reference electrode at the manubrium sterni and exploring electrode at the left 5th or 6th rib interspace at the anterior axillary line) rated superior to all the rest. CR₅C₅ (reference and exploring electrodes at right and left 5th interspace at the anterior axillary line) rated next in overall efficiency. For maximum significant S-T depression sensitivity the exploring electrode must be at C5 or 6. At C4 (over the cardiac apex) much of the ST depression noted was of the “J” or junctional type, the significance of which is in question. Exploring leads over the sternum are of little value in obtaining significant or ischemic-type segment shifts. This is important since the “distorted” central lead sternal applications are being used in physiological studies and are being highly recommended for their freedom from motion artefact. I use this example in order to caution you that ultimate purpose can be lost in the compulsion for technical excellence.

After 4 years of experience we have settled on the CR₅C₅, or biaxillarly, bipolar lead application as the one most suited to our needs. Figure 11 shows that the area selected, at the anterior axillary line, is below the origin of the pectoralis major muscle, anterior to the insertion of the serratus anterior muscle, and at the level of the maximum left
ventricular mass. It is in a region low in, but not free from, somatic muscle mass. How we circumvent the ever-present somatic muscle artefact problem will be discussed under technique.

(b) Electrode Types  Inevitably, every worker in the field of radio-telecardiography spends much if not most of his time testing various electrodes to determine the one best suited to his use. Five of the six we have tested are shown in Figs. 12 and 13 along with tracings taken of a subject during a sprint race. The electroencephlographic needle electrode has negligible mass and bypasses the skin interface. It is electrode artefact-free but has two very real drawbacks. It must be inserted hypodermically, and it is difficult to keep in place during extensive effort. Volunteer subjects just prefer not to have needles inserted in their skin. We have concluded, therefore, along with Blackburn\(^6\) and Master and Rosenfeld\(^7\) that the bandaid type patch, when properly applied, is the best currently available electrode. We may modify our conclusion after testing some of the newer silver electrodes currently on the market.

Technique  Each individual test requires from 1 1/2 to 2 hours, thus accumulation of data is slow. The subject is first instrumented by the application of biaxillary electrodes. The skin is cleansed with a non-polar solvent, usually 95% alcohol or ether. A 1 cm. square is marked at the 5th interspace bilaterally at the anterior axillary line. The skin is prepared by gentle abrasion with emery paper followed by excoriation with electrode jelly. Currently we are using Telectrode paste and find it satisfactory. The peripheral areas are painted with Ace adherent, a necessary precaution in our active subjects to assure continued electrode adhesion. A small amount of jelly is added to the electrode mesh and it is applied with a sliding motion. The edges are taped down and the lead wire clips applied. With the subject standing, a resting tracing is recorded. All of the equipment is then disconnected with the exception of the electrodes, and the athlete allowed to go through his usual stretching and warm up exercises. The instrument is then mounted in its sponge-rubber padded belt and reconnected to the electrodes and other sensing devices.

After a post warm-up record is made the subject undergoes the prearranged test. Somatic muscle artefact makes recording of a clinical quality ECG impossible during vigorous running. However, should the subject sense anything unusual he slows immediately and an instantaneous recording is obtained. As the runner slows at the termination of his race, the record is started, and 15 seconds of record is obtained every minute for 10 minutes and then every 2 minutes for an additional ten minutes. (Fig. 14) Subjects participating in team sports are watched closely and short bursts of tracing are taken at intervals of relative inactivity (Fig. 15). Spectators at football games are monitored from the field house overlooking the playing field so that ECG recordings can be correlated with game activity (Fig. 16). Note the sustained excitement tachycardia in this physically inactive football spectator.
The necessity for recording heart rates of the order of 180 to 220 beats a minute has dictated that the usual paper speed of 25 M/sec. be modified. Ten seconds of slow tracing (19 mu/sec) are recorded for electrical pulse rate and 5 seconds of fast tracing (350 mm/sec) are recorded for wave shape and amplitude analysis and for interval measurements. An example of these tracings, along with associated respiration and oral temperature records are shown in Fig. 17.

**Data Analysis**  Analysis of results is still accomplished by what might be termed antequated methods in this day of computers and data analysis, e.g. direct observation and measurement. Respiratory excursion in the heavily breathing subject may produce a significant axis shift such that measurement of peak heights in a single complex can give rise to misleading results. (Fig. 14) We measure, therefore, 10 complexes in each tracing to circumvent this error, accepting the average as a reflexion of the true peak heights. Interval measurements, not being affected by axis shift, require analysis of only a single complex. An average of 18 tracings are taken in a normal sprint test while as many as 70 may be made during a team sport or spectator experiment. This means from 970 to 3700 individual measurements must be made to analyze completely any one record. This is tedious labor and one my wonder why we have not resorted to taping and data analysis.

Eliminating cost as one obvious reason, there are other technical reasons which can be advanced to support the standard method of analysis. Maximum benefit is derived from taped records when analog data thus recorded can be fed to an analog-digital converter and thence to a digital computer for analysis. This pre-supposes (a) a continous, smooth record, and (b) a valid computer program. I will consider these two individually.

(a) **The Record.**  At the present state of our proficiency we cannot produce a tracing adequately free from artefact and base-line shift to make it amenable to computer use. Average transient computing, or ATC analysis, would seem to offer a solution. Rautaharju and Blackburn\(^8\) have spent 3 years studying the application of ATC to smoothing of the exercise electrocardiogram. Problems encountered with “smoothing error” brought about by the usual use of ordinary amplitude triggering, with “blurring error” produced by inconstant dc amplitude of the signal over the sampling interval, and with non-random noise prompted them to caution that the “cleaned up” ECG is in itself a limited statistic. They suggest the resulting analog signal can only “serve as a starting point for more detailed quantitative analysis of information contained in the exercise electrocardiogram.” In essence, ATC analysis of the exercise electrocardiogram eliminates too much valuable information to make it useful in our specific project.

(b) **The Computer Program**  Sound computer programming presupposes the availability of valid normals. Tables of normal values do exist for standard electrocardiographic leads, although even here there is some divergence of opinion.
Unfortunately, no standard values are known for the bipolar leads customarily used in dynamic electrocardiography. Although all who interpret dynamic tracings use criteria evolved from standard lead static studies, “there is no proof that criteria for the post-exercise tracing necessarily apply to the monitored (telemetered) record... A different lead, faster heart rates, upright position, etc. may all require new criteria.”

Within a few years these data may become available. At the present time, however, there is no universal agreement on lead positioning, type or application technique. There has been no attempt at standardization of the available transmitters, although Dunn and Beenken, whose transmitter is used in these studies, have followed closely the specifications on band width, frequency response, time constant, etc. suggested by the Committee on Electrocardiography of the American Heart Association. Interpretation of data significance awaits collection of adequate information on normals and abnormals which in turn awaits the above. Valid computer programming awaits them all. We have chosen, therefore, to continue our analysis by less esoteric methods for the present.

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