VALIDATION OF THE AEROSPACE MEDICAL RESEARCH LABORATORIES 3-CHANNEL PERSONAL TELEMETRY SYSTEM

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THE LAFAYETTE CLINIC

FOREWORD

This study, as Project No. 7222 "Biophysics of Flight," was initiated by the Environmental Stress Branch of the Biophysics Laboratory of the Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio, and carried out under Contract No. AF 33(657)-9352 by The Lafayette Clinic at 951 East Lafayette Avenue, Detroit, Michigan. Albert F. Ax, PhD, Head of the Psychophysiology Laboratory, served as principal investigator for the Lafayette Clinic. Under his supervision the following persons served as co-investigators: L. Andreski, R. Courter, C. DiGiovanni, S. Herman, D. Lucas and W. Orrick. B. Tyler supplied electronic technical help and D. Baer and W. Simson served as regular experimental subjects. About 20 additional subjects served for shorter intervals. Electronic engineering help when needed was supplied by G. Zachary.

The contract monitors for the Air Force were Dr. George Barnard, now at the Department of Psychiatry, University of Florida, Gainesville, Florida, and Major Victor H. Thaler, USAF, MSC, of the Environmental Stress Branch. The period of research was from 24 May 1962 to 28 March 1964.

This technical report has been reviewed and is approved.

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ABSTRACT

The art of physiological telemetry is borderline in three areas: (1) sensors, (2) transmitter, (3) data processing. This study assessed the AMRL 3-channel personal telemetry from all three aspects. Analysis of the records transmitted from men in various graded intensities of physical activity revealed that of the three physiological variables (respiration, EKG and temperature), respiration was the least valid. Torso circumference changes sensed by rubber tube strain gages proved superior to the impedance method for measuring respiration. Some tentative findings on a stress interview study reveal the telemetry method to have promise. It was shown that the major difficulty preventing widespread use of physiological telemetry in significant field situations is the lack of a practicable high-speed data processing system which can distinguish and utilize the occasionally valid physiological signal emersed in artifact or noise produced by movements and changing environmental influences. The solution to the artifact problem is first to sense and utilize movement and environmental influences to gate out and to correct the physiological data and second to develop automatic editing apparatus and computer programs for recognition and selection of the valid signal patterns.

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I. INTRODUCTION

The autonomic nervous system (ANS) as an important mediator of the vital processes of homeostasis is intimately involved in motivation, emotion and adaptation to stress. Observation of the ANS by means of measuring its peripherally available target organ responses has defined a new investigatory area called psychophysiology. Its contemporary confinement to the laboratory restricted by umbilical linkage between subject and recorder tends to influence and distort the emotional processes under observation and thus seriously limit the generality of the findings.

Telemetry now offers a new dimension of freedom from such influence. All sorts of real-life stress situations would be open for investigation. This desired freedom at the same time introduces two new sources of variance; namely, rapid changing behavior of the subject and many influences from the environment which would be controlled in a typical laboratory experiment. These two new sources of variance must be investigated and evaluated before the advantages of telemetry can be safely realized in studies of the ANS.

The state of the art of physiological telemetry is borderline in three areas: (1) sensors, (2) transmitter and (3) data processing. This study investigates the 3-channel model of personal telemetry developed, built and supplied by AMRL with respect to these three areas. Our experience with psychophysiological research supports the viewpoint that not less than 7 physiological variables are required for an adequate assessment of the emotional state (and more are highly desirable). The seven physiological variables proven most informative for studies of emotion are heart rate, palmar sweating, respiration, blood pressure (systolic and diastolic), vascular constriction in the fingers and face and frontalis muscle tension. For a freely moving subject, several additional channels would be required for sensing the subject's movements and positions and such environmental variables as temperature, humidity and air flow as they influence the specific skin sites on which the physiological sensors are located.

Although such as 12-15 channel system was conceived of as essential, we nevertheless undertook to evaluate the 3-channel system supplied by AMRL with the expectation that a 6-channel model would be forthcoming during the study. If a 3- or 6-channel model can be demonstrated to be sufficiently reliable, sensitive, and portable, there would be justification for expansion to more channels.

The plan of the study was first to evaluate the sensitivity, reliability and practicability of the system during various types of human activity such as reclining, sitting, standing, running and various graded arm and torso movements. If the results of these studies justified the effort and cost of substantive studies, they would be undertaken.

II. METHOD

A. Apparatus.

Each of the two identical units supplied by AMRL has three input channels, for transmitting EKG, respiration and temperature (5). The radio receiver used was a Fisher model 100 B. The output of the receiver was recorded by a Magnecorder Model 728-4 operating at 7 1/2 inches/second. The pulse position modulation signals being recorded on the tape were visually monitored by a Tektronix oscilloscope model 310 A. Oscillograms for detailed analysis were prepared by reproducing from the magnetic tape through the decoder (Systems Research Laboratory model 406) and recording on paper chart by a 24-channel Minneapolis-Honeywell visicorder model 1108.

B. Procedure.

The EKG and the impedance changes across the chest caused by respiration were both sensed by one pair of electrodes on the sides of the chest. The temperature sensor was a thermistor and could be placed anywhere on the body. Since the temperature channel could be easily calibrated by standard methods and the problems of measuring internal and surface bodily temperatures are well known, no specific research was done on the temperature measurements. It was quickly determined that most any of the electrodes and placements suitable for the impedance respiration measurements produced an EKG satisfactory for recording the heart period or its reciprocal heart rate. Thus the chief research effort was directed to the measurement of respiration. It was also determined to what extent the telemetry units could be adapted to transmit three other variables, palmar skin resistance (GSR), finger pulse, and respiration by the rubber strain gage method. Four studies were done to clarify the problems and solutions for the indirect measurement of respiration.

III. SPECIFIC RESPIRATION STUDIES

A. Comparison of 4-Electrode Impedance and Chest-Abdomen Strain-Gage Measure of Respiration.

It is highly desirable to have a measure of respiration that does not require oro-nasal instrumentation. In order to choose the best method, comparisons were made with the direct closed system spirometer as the criterion.

Methods

The chest and abdomen circumference changes were measured by a mercury filled elastic tube strain gage and two types of impedance measurements. The 4-electrode impedance method as described by Nyboer (6)* and Allison (1)* and the 2-electrode system similar in approach to that of Geddes (3)* were used. Only one impedance method was used at a time but the chest and abdominal strain gages and the spirometer were always used. Thus the experiments may be divided into two parts enabling correlation for part 1 between the spirometer, 4-electrode impedance and the strain gage and for part 2 the spirometer, 2-electrode impedance and the strain gage.

The spirometer was a Collins 13 1/2 liter size. The 4-electrode impedance apparatus is manufactured by S. Bagno. The 2-electrode system is the impedance respiration channel of the AMRL 3-channel personal telemetry system. The strain gages for measurement of chest and abdominal circumference were Dow Corning Silastic flexible tubing 9 1/2 inches long with .025" bore. Each tube, filled with mercury and with platinum wire electrodes, had a resistance unstretched of about 1.0 ohm. The strain gage functioned as one leg of a low impedance bridge fed by a 400 CPS, 25 MV current which, after rectification and biasing, served as input to the recorder amplifier. Linearity of the system is within $\pm$ 2%. The chest and abdominal measurements were kept separate. The abdominal strain gage was positioned at the level of the umbilicus,and the chest either at the level of the fourth or the eighth dorsal vertebra.

A four-point electrode system (6)* was employed with the Bagno unit. The electrodes were thin malleable copper disks one inch in diameter applied with a saline paste fixed to the skin with tape. The members of each pair were placed on either side of the vetebral column: I_1 at C_{3-4}, E_1 at C_7-D_1 (the members of the E_1 pair were 20 cm apart), E_2 30 cm below E_1 (with its members also 20 cm apart), and I_2 8 cm below E_2. The base line resistances varied from 8 to 25 ohms between subjects. However, for each subject, the variation with respiration was less than two ohms. A Minneapolis-Honeywell Visicorder served as the end recorder for the strain gages and impedance measurements.

After the electrodes and strain gages were applied and the subject was breathing into the spirometer, he was asked to take 30 breaths in various experimental profiles, to be described. His respiratory pattern was recorded simultaneously on the spirometer chart and by the oscillograph. The maximum height of each of the strain gage and impedance curves on the oscillogram was measured in 16th of an inch, and the actual volume of each breath was computed

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*See Reference section.

from the spirometer. Product moment correlations were then computed using each of the following as separate variables: (a) chest, (b) abdominal, (c) chest plus abdominal strain gage values, and (d) the impedance measurements, with the spirometer values as the criterion.

The first tests (employing the 4-electrode impedance method along with the spirometer and strain gages) were made by L. Andreski, C. DiGiovanni and W.P. Orrick, healthy men aged between 23 and 27, alternately serving as subject and experimenter. The experimental situations were (1) recumbent, (2) sitting or (3) standing each without movement or with arms moving so as to simulate manipulation of controls of an instrument panel or more active exercise consisting of arm movements simulating swimming or stationary running. During the more active exercises neither the respiration rate nor amplitude could be reliably determined by either the strain gage or impedance methods, hence no correlations could be computed for the active exercise conditions.

Results

The correlations obtained for breathing without movements and for mild arm movements are tabulated in Table 1*. These results appeared inconclusive so additional tests were made without exercise and with more natural breathing with results in Table 2.

Discussion of Study A.

The correlations from the later trials (in Table 2) were consistently improved over the earlier trials in Table 1. In addition, the later trials were made on more subjects, and with a larger N of 30 for each profile. That the later trials were consistently better than the earlier trials, we believe, is due primarily to increased experimental care and familiarity with the techniques on the part of the personnel.

Repeated trials indicate that neither the strain gage nor the impedance technique is reliable for any exercise more vigorous than mild arm movements. For more vigorous exercises, differentiation between movement artifacts and the respirations needed for determining respiratory rate and tidal volume is impossible.

The location of the chest strain gage was varied in the later trials from D_4 to D_8 levels in order to determine the optimal position for this gage, that is, over the fixed upper rib cage or over the non-fixed lower ribs. For the recumbent position, the D_8 level was superior (t test, $p + 0.001$). For the sitting and standing positions there was no significant difference between the two strain gage positions ($p = 0.4$ and 0.9 respectively).

An analysis of the more accurate second run indicates four-electrode impedance plethysmography on the average to be inferior to the chest plus abdomen strain gage measurements. Although the chest strain gage was more reliable than the abdominal gage the sum of the two correlated better with the spirometer than either separately.

B. Study of 2-Electrode Impedance and Strain Gage Methods.

In this second study, the 2-electrode impedance method using the AMRL telemetry system and the chest + abdominal strain gages were correlated with the

*Tables are located in the Appendix.

spirometer as the criterion. The experimenters and subjects for this study were Leo Andreski, Donald Lucas and Bernard Tyler. The telemetry signal was first recorded on magnetic tape, then played back and recorded on the polygraph chart for visual measurements.

Four sequences were run on each subject: (a) recumbent, (b) sitting, (c) standing doing a standard exercise of moving right arm through a 90° arc in the horizontal planes at shoulder level and (d) standing motionless.

The telemetry electrodes were 15-millimeter nickle-silver disks applied with EPSCO adhesive plasters. Placement was at the 6th intercostal space, mid axillary line bilaterally. The abdominal strain gage was positioned at the level of the umbilicus, and the chest strain gage at the level of the 6th rib. The quality of the telemetry signal was considerably improved when low capacitance shielded "microdot" leads were used on the electrodes. Filtering improved the decoder output so as to produce a clean respiration signal.

Since the previous study had shown the simple sum of the abdominal and chest strain gage to have the higher correlation than either one separately, the strain gage score used is the sum. The correlations for the three subjects for the four conditions are in Table 3.

Discussion of Studies A and B.

These results are considered tentative and to be used as leads for further experiments. The comparison between the sum of chest and abdominal strain gage with the four-electrode impedance methods indicate that the strain gage method has about 26 percent more accuracy. The accuracy is estimated by r^2 which for chest gage position D_8 is .940; and for the four-electrode impedance method measured simultaneously for the same 270 respirations on three subjects, r^2 is .680. An accuracy superiority of 94% over 68% is worthy of serious consideration.

The comparisons between the strain gage and two-electrode impedance method indicated a much smaller difference. The mean coefficient of determination (for non-exercise) for the strain gage method is .886; whereas for the two-electrode impedance method, r^2 is .860, a difference of only 2.6% in favor of the strain gage method. Since this evaluation of the two-electrode determinations is based on a smaller sample of respirations, without exploration for optimum electrode or strain gage placement and other considerations such as inexperience in handling the telemetry equipment, we cannot conclude there is a superiority of one method over the other. Additional experiments were done exploring all these considerations with special effort on determination of the effects of graded exercise for different electrode and strain gage placements. The degradation of the A.C. coupling of the telemetry system was also determined and found not to be a significant source of error for the respiration patterns employed.

Other considerations include the possibility of improving the strain gage method, especially during movements by additional strain gages properly placed and with optimum electrical weighting in the circuit so as to compensate for movements. To the degree that such an arrangement approaches the actual torso volumetric displacement, the estimate of tidal volume by the strain gage method should approach perfection. The limiting factor will no doubt be the practicable one of how much complication and tailoring for individual physique and type of exercise.

Another approach that ought to be considered is an inflated vest which could possibly average out the movement artifacts and reflect the actual volumetric changes due to respiration.

We wish to point out that under ideal conditions the strain gage method can monitor respiration volumes with a substantial (over 90%) accuracy. This fact has not been widely known.

C. Electrode Comparisons and Placements.

The Cordis-type rubber cup with the imbedded nickel silver mesh was employed in 3 ways: (1) cup filled with electrode paste by hypodermic needle after application, (2) cup filled with sponge then filled with either zinc sulphate or (3) sodium chloride electrolyte. All three applications demonstrated signal deterioration after wearing 4 to 9 hours. The signal was useless by 24 hours of continuous application. In addition, the Davol surgical appliance cement, No. 262, recommended by Cordis containing natural rubber, zinc oxide and N-Hexane caused painful skin irritation after a few hours.

It was also found that excessive electrical noise produced by clothing friction could be eliminated by replacing the wire leads to the electrodes with shielded "microdot" wire.

Next the conducting cloth (silver on nylon) was used as electrodes. It was applied with Bentonite saline paste backed by Readi-spot plasters further secured with centerless cork plasters. After 50 hours continuous wearing, through 2 baths, profuse sweating during vigorous exercise and 2 nights sleeping, essentially undegradated signals were transmitted.

Similar tests on additional subjects showed less longevity. It was concluded that the nylon-silver-mesh cloth was the best electrode for short-term recording but there were still difficulties in long-term sticking to the skin and leads coming loose from the mesh electrode.

The study on electrode placement was done by testing five lateral locations and three dorsal-ventral locations during reclining, standing without movements, standing with fore-and-aft arm movements and standing with arms rotating in a horizontal plane (the latter being the most disturbing to the impedance measurements of respiration). By constant visual inspection of the polygrams during these maneuvers, it was judged that the lateral placements at approximately the sixth intercostal space was the best average location for the impedance measurement of respiration. It should be made clear, however, that even with this optimum location, often the more intensive arm movements (swinging through a 180° arc) would completely obscure the respiration excursions, preventing even a count of respiration from being made. The largest EKG signals were obtained from the back and front electrode placement, although ordinarily the EKG survived more intense exercise from any chest electrode placement than did the impedance measure of respiration.

D. Further Comparisons of 2-Electrode Impedance and Strain-Gage Methods.

In this study, 56 experiments on two subjects were done for various degrees of activity during recumbent, sitting and standing positions. The three methods, (1) abdomen + chest strain gage, (2) impedance, and (3) telemetry strain gage were each compared with the spirometer criterion by product moment correlations on about 35 breaths for each condition for each subject. An inspection of Table 4 shows the strain gage method to be superior to the impedance method (both via telemetry) in the majority of instances (38 of 45). For subject D. L., the strain gage method was superior in 18 of 24 cases and, for subject L. A., in 19 of 20 cases. Once more the comparison of the telemetry strain gage ($CuSO_4$) with the directly recorded chest and abdominal Hg strain gage showed very little choice. In 23 instances, the Hg SG (C + A) was superior and in 22 the $CuSO_4$ (telemetry) was superior. In order to see if improvement could be made over a simple addition of abdominal plus chest respiration values, stepwise, regression equations were computed on the G-15 digital computer for 25 samples of respiration data. The purpose of the computation was to determine whether there was sufficient consistency in the ratio of chest to abdominal circumference changes as measures of respiration tidal volume so as to establish a standard ratio for optimum accuracy of tidal volume. The ratios of the chest/abdomen coefficients ranged from 2.26/.182 to .265/.628 with no apparent consistency either for position (recumbent, sitting or standing) or for the subject. Apparently the style of breathing changes from time to time and from one subject to another in regard to the relative contribution of chest and abdomen such that no consistency may be found. Accordingly, this particular approach to the optimization of tidal volume measurement by chest and abdominal circumference changes is being postponed until larger samples of data can be analyzed via the total data processing system. At that time further comparison of chest and abdominal circumference changes versus chest impedance changes will be made.

There are several features of the strain gage method which makes it preferable to the impedance method. These are: 1. Higher average validity during movement. 2. The problem of electrode placement on the subject's skin required for the impedance method. (a) Reliable long-term application becomes irritating. (b) Non-irritating application of metalized cloth tends to dry out and become inoperable after several hours. (c) This drying out changes the resistance and requires frequent adjustment of the telemetry range. (d) Finding the optimum placement for the impedance electrodes is difficult and varies for different positions. The bodily conditions which determine the optimum placement of the impedance electrodes are relatively unknown and nonvisible, whereas the optimum placement for the strain gage is relatively constant from one subject to the next, and can readily be seen by simply observing the torso for a few breaths.

The electrodes for EKG and impedance, although they may not be used for impedance, may still be used for EKG since the EKG input circuit can tolerate relatively wide ranges of impedance without failure. (To implement this separation of respiration and EKG channels, however, requires changes in the internal circuitry of the transmitter which we have not done).

Although this experiment was done using a $CuSO_4$-filled rubber tube as the strain gage for measuring torso circumference by telemetry, other methods for measuring the circumference should be re-evaluated. We used the $CuSO_4$ strain gage so as to obtain an impedance to match the approximately 100,000 ohms input impedance of the temperature channel of the telemetry. The $CuSO_4$ transducer becomes inoperable after several days or weeks due to water loss through the rubber and due to chemical contamination. Mercury-filled "Silastic" tubing is superior but has very low impedance of from 1 to 2 ohms. If the telemetry input can be made to readily handle this low impedance, it would appear to be the method of choice. The Hg strain gage can be made very small and soft so as to require no noticeable effort in breathing. It would be very desirable if the transducer or amplifier could be logarithmic so as to emphasize the small normal breaths and compress the larger ones so as to encompass the very large dynamic range into more practical limits.

E. Activity Studies.

Although the previous studies indicated the superiority of the strain gage method for measuring respiration, there was still need to determine what percentage of the record could be considered valid during various degrees of activity. The following experimental procedure was used in testing 16 subjects:

1. Five minutes of rest.

2. Exercises (First group).

Activity	Duration	Rest
Pushups	1 min	3 min
Walking	2 min	2 min
Waist Twist, Arms Out	2 min	2 min
Jumping Jack	2 min	2 min
Knee Squat, Arms on Hips	2 min	2 min

3. Five minute rest period.

4. Exercises (Second group).

Activity	Duration	Rest
Toe Touching	2 min	2 min
Lifting Chair	2 min	2 min
Sit Ups	1 min	3 min
Leg Lift Lying on Floor	2 min	2 min
Running in Place	2 min	2 min

The variables recorded are EKG and respiration by the impedance method and respiration by the copper sulfate strain gage method. Visual inspection during recording and careful editing of a few of the polygrams gave the following results with regard to percent good data,which was the purpose of the study.

The EKG is good about 40% of the time for the jumping jack, 60% good for pushups and running, and better for the less active exercises. For the whole hour, including the rest periods, the EKG is good for about 98% of the time. The respiration records were almost completely bad for the pushups, waist twist and jumping jack, and essentially all of the second group of exercises. In general (as previously reported), the strain gage method was superior to the impedance method; but neither method was useful for the more strenuous exercises -- especially those involving total arm movements and major trunk movements. Over all the exercises, the best respiration record could be used for respiration rate about 47% of the time.

Conclusions are (1) that EKG is pretty good but could be improved for long-term recording by better electrodes; (2) Respiration by the impedance method is useless during major bodily movements; and that for the milder movements or near rest conditions, the strain gage method of measuring changes in circumference of the chest and abdomen is superior to the impedance method for both respiration rate and tidal volume.

IV. SUMMARY OF RESPIRATION STUDIES

Considering all aspects, our investigations on indirect measurement of respiration suggest the following recommendations:

A. The present telemetry set can be used to measure respiration best by using a $CuSO_4$ rubber-tube-type strain gage operating into the temperature channel.

B. It is believed that a redesign of the respiration channel would permit the use of low-impedance, mercury filled strain gages.

C. During very active movements, neither torso impedance nor circumference measurements provide a valid measure of respiration; not even for counting the number of breaths.

Some method of sensing the air flow is surely required to monitor respiration during intense activity. Sensing the temperature change at the nostril or in a breathing tube has been used. For this method, the chief problems to be overcome are (1) proper placement and its maintenance for long periods of time, (2) nose and/or mouth breathing, (3) variations in external air temperature, and (4) slow and rapid flow rates as related to the thermistor time constant.

Our expectation is that whereas an innocously placed thermistor in the nostrils and in the air flow from the mouth may never be as valid a measure of tidal volume during little or no movement, it may nevertheless provide a second measure which becomes the more valid one during intense activity. Ideally, then, respiration would be monitored by both torso circumference strain gages and by a thermistor flowmeter. Corrections for variations in external air temperature can probably be achieved by utilizing the ambient temperature as indicated by the values of the minima in the temperature excursion during inspiration. The position of the thermistor and its method of mounting is very difficult and will require considerable experimentation.

It may be thought that it is not worth while to pursue further the indirect measurement of respiration during intense activity, since the respiration characteristics of a given individual during activity can be determined in the laboratory setting using standard spirometer methods. The problem remains, however, to determine how various stresses summate in real-life situations. For this purpose it is highly desirable to test many of the physiological systems simultaneously under field conditions, many of which would not tolerate masks or mouth tubes.

V. APPLICATION OF THE 3-CHANNEL TELEMETRY APPARATUS TO THE MEASUREMENT OF PALMAR SWEATING

From the results of the studies described, it was concluded that the 3-channel unit was sufficiently reliable and practicable to employ in a modest substantive study. It was decided, however, that a measure of palmar sweating and finger pulse pressure would be very desirable if they could be measured. Possibly the two telemetry units could be applied to the same subject so that one unit would measure EKG and respiration with a strain gage sensor and the other unit would measure palmar skin resistance on its temperature channel and finger pulse on its EKG channel if a suitable sensor could be found. As already described, the temperature channel was used without modification with a 100,000 ohm strain gage (rubber tube filled with $CuSO_4$) for the measurement of chest and abdomen circumference changes of respiration. Our standard GSR electrodes (1/4" disks in a plastic cup filled with sponge saturated with $ZnSO_4$) on two adjacent finger pads have a resistance of about 100,000 ohms. With a resistor in series (or parallel) as needed, it was possible to adjust the total resistance sufficiently close to 100,000 ohms for the temperature channel to accept. Even though the skin is not a pure resistance (having at times up to 2 microfarads of capacitance), and the output current of the telemetry is not a pure D.C., it still did measure GSR changes such that parallel determinations done on two adjacent fingers of the same hand with a pure D.C. calibrated recording skin resistance meter produced correlations of .78 and .81 on two samples of GSRs each on the same subject. Correlations across a population of subjects would probably be lower since the capacitance component is relatively greater across subjects. Accordingly, it has been recommended (and incorporated in the AMRL 7-channel model (5)*) that two channels be used for the measurement of skin resistance., One a pure D.C. measure of base level resistance, and an A.C. measure for the specific GSR changes. Thus the required dynamic range is achieved without any base level adjustments being required.

Our attempts to measure finger pulse pressure as an index of vasodilation and constriction on the EKG channel of the 3-channel telemetry unit were not successful. We tried first a piezoelectric and secondly a differential-transformer type transducer, but apparently insufficient impedance matching prevented sufficient sensitivity. Had the EKG and respiration channels been separated within the telemetry unit, the EKG channel could no doubt have been so used. At about this time it was discovered that one of the telemetry units on its temperature channel had become extremely sensitive to movement and acceleration, thus unusable for strain gage respiration measurement. Time allotted to the study had nearly expired, so we decided to go ahead with one unit and measure only GSR, EKG, and respiration by the impedance method on the interviewer as described next.

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*See Reference section.

VI. STRESS INTERVIEW STUDY

The 3-channel telemetry was applied to the interviewer (a senior psychiatrist) as he interviewed a patient over a 40-minute period. Each interview was divided into eight 5-minute epochs, one block of 20 minutes being a stress interview, during which the patient's sensitive areas of personality adjustment were actively probed; the other block of 20 minutes was a non-stress interview during which maximum reassurance was given and non-sensitive topics discussed. Each patient had two interviews, 2 days apart with the order of the stress and non-stress periods reversed. During the interview, the patients were instrumented with our full set of 14 physiological variables, which are recorded on oscillograph and magnetic tape recorders.

The EKG and GSR on the interviewer were recorded via the telemetry onto magnetic tape and subsequently decoded and displayed on an oscillograph. Due to a lack of high-speed machine analysis for either set of data, only a partial manual analysis of results can now be reported.

The heart rate and GSR have been analyzed for both the interviewer and patient for 6 interviews. Ratings were made of emotional arousal for 9 patient variables and 10 therapist variables (see Tables 5, 6 & 7) made by a psychiatric observer and the interviewer in conference as they together reviewed the magnetic tape recording of the verbal transaction immediately after the interview. The observer's continuous verbal account of both the patient and interviewer is recorded on a second channel of the tape of the interview. Neither the interviewer nor the observer had seen the physiological recording when they made their ratings.

By an inspection of these tables, the ratings of the patient's anxiety, hostility and negative arousal are seen to be all clearly higher during the stress epochs than they are during the non-stress epochs. The interviewer's aggressivity is likewise consistently rated higher during the stress epochs; thus at the clinical judgment level the purpose of the interview is being carried out.

In Table 8 are the mean physiological scores for the stress and non-stress periods for three patients. For patient number 1, a male, all physiological scores suggest differences which probably are not statistically significant. In marked contrast, for patient number 2, a female, all physiological scores are substantially higher for the stress periods. In patient number 3, also a female, all but one (# GSR) show a tendency to be higher for the non-stress period.

For the interviewer, from the telemetry data in Table 9, we find very much the same picture with regard to the physiological variables. For all the interviews, the skin conductance, mean heart rates, and minimum HR are higher for the non-stress epochs. Only during the interview of Subject 3 did the maximum heart rate reach a higher level during the stress period. The heart rate range in the interviewer, however, was consistently greater for the stress periods for all sessions. Maximum GSR was also greater in the interviewer during the stress interviews for two of the subjects, and the number of GSR is greater for every interview.

With only this small amount of data analyzed, it would be premature to draw any conclusions but it is interesting to speculate how such findings, if they hold up on the total group, might be explained.

First consider the interviewer. This experienced psychiatrist was not at all anxious in the situation. He merely behaved more aggressively (not with hostility) during the stress portions and with a feeling of confident accomplishment. Much research, including Silverman and Cohen's studies on G tolerance done at Wright-Patterson Air Force Base supports the prediction that this type of confident aggressivity is a norepinephrine type of arousal which we (2)* and others (4)* have shown is often associated with a decrease in heart rate but with greater variability of HR and with no increase in amplitude of palmar sweating but with a greater number of GSR. In every interview, this is exactly what we find for the interviewer. Thus we would speculate that these physiological findings are appropriate for the emotion being manifested in the interviewer. Although the patients 1 and 2 were rated higher on anxiety than on hostility or aggression, these patients reported to their regular therapist that they resented having to submit to this grilling by other people. It is very likely that the chief emotion felt by the patients, though maybe not openly expressed, was also hostility. In the case of subject number 2, possibly the anxiety was more intense than the hostility. Her clinical rating of anxiety was 33 to a total hostility rating of 22. Whereas patient number 3 had a clinical rating of 21 for anxiety to 52 for hostility along with a substantial decrease in HR and increase in number of GSR during the stress. Only patient number 1 fails to strongly support this position, but both the clinical impression and the physiological results suggest that he was not very successfully aroused by the interview. When the BP, ballistocardiogram, finger pulse and respiration rates are analyzed for the patients, the type of arousal should be considerably better specified.

The purpose of reporting this preliminary examination of the interview data was to show that in a laboratory situation with the AMRL 3-channel telemetry apparatus it was possible to obtain data of sufficient validity to demonstrate a rather subtle differentiation of emotion by physiological responses. With the modifications incorporated into the new 7-channel AMRL personal telemetry set, quite valuable research studies can probably be done. In the laboratory situation of clinical interviewing, however, umbilical recording is even more practical. For physiological telemetry to become practicable in really free and active situations, considerable research and development will be required.

***See Reference section.**

VII. GENERAL CONCLUSIONS AND RECOMMENDATIONS

This study of physiological telemetry from humans in action supports our chief concern at its inception; namely, that before physiological telemetry can be used efficiently in the field, effective and economical methods of automatic editing must be developed. The significant signals are lost in the noise of movement artifacts to such an extent that only very effective automatic high-speed procedures for identifying the "good" signals when they are present can be considered. Human editing by visual inspection is simply too slow and costly for any but very special and limited research purposes.

We believe there are several fruitful approaches to this problem. First we shall discuss the methods applicable generally to all variables and secondly approaches specific to each variable are taken up.

The general approach for detection of a complex signal emersed in noise of similar amplitude and frequency characteristics cannot be done by filtering but only by pattern recognition methods. Specified patterns can be recognized either by digital or analog computing methods. The approach is essentially the same for both. A signal, such as an EKG, is identifiable by its pattern, that is, the relative amplitude, slope and interval of its component branches. Limits or tolerances for each parameter must be established for acceptable signals. The limits of these criteria can be successively narrowed and thus made more critical when the characteristic pattern of the specific individual and of his specific activity are known. The criteria of parameter tolerances can be re-established as frequently as necessary. The virtue of digital computer editing is its flexibility by parameter modification. But the high sampling rate required necessarily increases the cost of analysis a great deal. For example, to analyze heart rate changes from a cardiotachogram requires a sampling rate of not more than 3 samples per second (SPS) whereas to analyze the EKG wave pattern for editing purposes requires up to 300 sps. Since digital computing is approximately proportional to number of bits being processed, a 100-fold increase in analysis cost might be expected.

In contrast, analog computing is done on line (possibly on line during A/D conversion) without additional computing time or cost unless more than one pass is required. The problem is well worthy of parallel solutions by digital and analog methods to see which is the more successful, economical and practicable.

Another method of detecting signals to known stimuli is by correlation. In spontaneous responses of physiology, however, only the cardiovascular variables such as pulse pressure, pulse wave velocity and ballistocardiogram are correlated within narrow time limits to the EKG which may be used to gate the signal detecting circuitry. This can eliminate possibly 90% of the noise but cannot, of course, prevent artifacts occurring at the critical times from contaminating the signal.

A more generally useful method of automatic editing is to provide simultaneous measurements of the artifacts and environmental conditions responsible for signal corruption. For example, accelerometers at critical positions on the body can operate the gating of the signal acceptance circuitry so as to prevent movement artifacts from being mistaken for physiological response signals. Complete dependence on this latter method might eliminate the few good signals that would be available for analysis during some activity, hence cannot be the preferred method.

Another type of environmental influence that must be taken into consideration in such a variable as skin temperature or peripheral blood flow as an index of emotional response is the local ambient temperature, humidity and air flow situation. Unless these are recorded at a position very close to the site being observed, skin temperature and sweating measurements of a man in action may be relatively meaningless. Consider the thermistor readings on the face when it is alternately exposed to shade or sun, wind or no wind and is sweating or is not sweating. Skin temperature or the plethysmogram has been a useful measure in the laboratory by virtue of the fact that the environment is controlled very closely. But for field work, at least one environmental thermistor, an air flow meter (possibly a heated thermistor) and probably a sweating measure as well, must be supplied so as to enable meaningful interpretation of the temperature reading at each skin site. Or, for another example, consider the problem of measuring the sweating response on the feet while a man walks (the feet may be the site of choice so as not to encumber the hands). Pressure sensors could be placed on the soles of the feet and circuitry designed to gate out the skin resistance reading during the pressure pulses with interpolation provided to fill in the lost sections of the GSR curves.

We are confident that evermore sensitive and appropriate transducers and ever smaller transmitters are being developed. There is less evidence, however, that the problem of physiological signal detection drowned in the sea of behavioral and environmental noise has been recognized as the major nemesis of physiological telemetry of the free subject. A substantial R & D program should be directed to the solution of this problem.

APPENDIX

Table 1

Correlations Against Spirometer

Recumbent, W/O Ex.*, Normal Breathing	Chest	Abdominal	Chest + Abdominal	Impedance
C. D.	.850 (n=30)	.914 (n=30)	.936 (n=30)	.935 (n=30)
W. O.	.863 (n=24)	.836 (n=24)	.837 (n=24)	.568 (n=24)
Recumbent, W/O Ex., Variable Breathing				
C. D.	.861 (n=30)	.919 (n=30)	.972 (n=30)	.750 (n=30)
W. O.	.888 (n=27)	.698 (n=20)	.934 (n=20)	.748 (n=27)
Recumbent, W mild arm movements, Normal Breathing				
C. D.	.422 (n=12)	.780 (n=23)	.855 (n=12)	.903 (n=23)
W. O.	-.088 (n=29)	.021 (n=29)	-.066 (n=29)	.190 (n=29)
Sitting, W/O Ex., Normal Breathing				
C. D.	.807 (n=29)	.969 (n=29)	.948 (n=29)	.829 (n=29)
W. O.	.814 (n=27)	.664 (n=27)	.815 (n=27)	.588 (n=14)
Standing, W/O Ex., Normal Breathing				
C. D.	.014 (n=29)	.371 (n=30)	.381 (n=29)	.365 (n=30)
Standing, W/O Ex., Variable Breathing				
C. D.	.876 (n=30)	.312 (n=30)	.646 (n=30)	.751 (n=30)

*W/O Ex = Without Exercise

Table 2

Correlations Against Spirometer

	Chest		Abdominal	Chest + Abdominal	Impedance
Recumbent Chest S. G. at D_4					
C.D.	.980	N=30	.920	.986	.976
W.O.	.835	"	.814	.873	.693
L.A.	.931	"	.660	.924	.879
Recumbent Chest S. G. at D_8					
C.D.	.968	N=30	.958	.983	.782
W.O.	.920	"	.830	.987	.769
L.A.	.976	"	.942	.986	.909
Sitting Chest S. G. at D_4					
C.D.	.961	N=30	.844	.954	.751
W.O.	.980	"	.674	.916	.906
L.A.	.960	"	.858	.944	.813
Sitting Chest S. G. at D_8					
C.D.	.987	N=30	.869	.972	.890
W.O.	.955	"	.866	.949	.982
L.A.	.938	"	.648	.951	.671
Standing Chest S. G. at D_4					
C.D.	.883	N=30	.702	.887	.964
W.O.	.948	"	.851	.966	.952
L.A.	.934	"	.630	.965	.905
Standing Chest S. G. at D_8					
C.D.	.973	N=30	.979	.985	.608
W.O.	.968	"	.696	.959	.969
L.A.	.961	"	.640	.958	.841

Averages

Recumbent Chest	C + A	Imped
S. G. at D_4	.928	.849
S. G. at D_8	.985	.820

Standing Chest	C + A	Imped
S. G. at D_4	.939	.940
S. G. at D_8	.967	.806

Sitting Chest		
S. G. at D_4	.938	.823
S. G. at D_8	.957	.848

Total Positions	C + A
Chest S. G. at D_4	.935
Chest S. G. at D_8	.970

Table 3

Correlations Against Spirometer

	Strain Gage Chest + Abdominal	2-Electrode Impedance
A. Recumbent W/O Exercise		
Subj 1 (B.T.)	.943	.913
2 (L.A.)	.968	.954
3 (D.L.)	.926	.929
B. Sitting W/O Exercise		
Subj 1	.971	.965
2	.943	.922
3	(Invalid)	.433
C. Standing W Arm Movement		
Subj 1	.653	.104
2	.893	.741
3	.826	.005
D. Standing W/O Exercise		
Subj 1	(Invalid)	.945
2	.844	.878
3	(Invalid)	.522

Table 4

Correlations Against Spirometer

	Subj	No Breaths	Hg Strain Gage Chest	Abd	C+A	Telemetry Imped	$CuSO_4$
Recumbent-15° vert. arm movement (1 arm)	D.L.	35	.870	.849	.935	.932	.941
	L.A.	38	.795	.793	.967	.248	.874
Recumbent-45° vert. arm movement (1 arm)	D.L.	35	.947	.952	.957	.973	.946
	L.A.	35	.858	.914	.962	.521	.961
Recumbent-150° vert. arm movement (1 arm)	D.L.	35	.928	.237	.964	.963	.926
	L.A.	35	.711	.785	.785	.346	.807
Recumbent-15° vert. arm movement (2 arms)	D.L.	35	.914	.857	.946	.953	.958
	L.A.	35	.936	.900	.982	.594	.973
Recumbent-45° vert. arm movement (2 arms)	D.L.	35	.791	.913	.932	.922	.846
	L.A.	35	.931	.838	.934	.209	.858
Recumbent-45° horiz. arm movement (1 arm)	D.L.	35	.850	.950	.971	.912	.979
	L.A.	35	.901	.930	.974	.595	.973
Recumbent-150° horiz. arm movement (1 arm)	D.L.	35	.883	.942	.959	.911	.978
	L.A.	35	.964	.962	.977	.746	.933
Sitting-45° vert. arm movement (1 arm)	D.L.	35	.939	.971	.965	.949	.974
	L.A.	33	.793	.902	.929	.477	.507
Sitting-150° vert. arm movement (1 arm)	D.L.	35	.804	.891	.877	.959	.907
	L.A.	33	.654	.947	.937	.736	.869
Sitting-45° vert. arm movement (2 arms)	D.L.	35	.861	.939	.936	.940	.944
	L.A.	35	.350	.416	.599	.100	.400
Sitting-150° vert. arm movements (2 arms)	D.L.	35	.619	.849	.788	.915	.791
	L.A.	35	.306	.556	.616	.422	.592
Sitting-45° horiz. arm movement (1 arm)	D.L.	35	.845	.864	.892	.896	.902
	L.A.	35	.854	.959	.978	.710	.817
Sitting-150° horiz. arm movement (1 arm)	D.L.	35	.564	.887	.628	.895	.846
	L.A.	35	.152	.566	.414	.403	.482
Sitting-45° horiz. arm movement (2 arms)	D.L.	35	.912	.909	.949	.808	.930
	L.A.	35	.692	.977	.968	.700	.936
Sitting-150° horiz. arm movement (2 arms)	D.L.	35	.890	.882	.933	.910	.927
	L.A.	35	.210	.769	.618	.454	.539
Standing-45° vert. arm movement (1 arm)	D.L.	35	.928	.965	.969	.967	.979
	L.A.	35	.737	.897	.921	.716	.811

Table 4 (contd)

	Subj	No Breaths	Hg Strain Gage Chest	Abd	C+A	Telemetry Imped	$CuSO_4$
Standing-150° vert. arm movement (1 arm)	D.L.	35	.872	.968	.968	.961	.984
	L.A.	34	.231	.385	.361	.124	.174
Standing-45° vert. arm movement (2 arms)	D.L.	35	.807	.963	.966	.963	.972
	L.A.	20	.747	.897	.943	.581	.930
Standing-150° vert. arm movements (2 arms)	D.L.	35	.648	.930	.920	.903	.919
	L.A.	35	.030	.183	.100	.120	.102
Standing-45° horiz. arm movement (1 arm)	D.L.	39	.667	.772	.840	.289	.843
	L.A.	35	.441	.576	.576	.558	.649
Standing-150° horiz. arm movement (1 arm)	D.L.	35	.646	.887	.907	.929	.949
Standing-45° horiz. arm movement (2 arms)	D.L.	35	.530	.790	.749	.261	.780
Standing-150° horiz. arm movement (2 arms)	D.L.	35	.254	.676	.654	.642	.850
Recumbent with no exercise	D.L.	35	.874	.486	.916	.875	.933
	L.A.	40	.461	.539	.567	.178	.525
Mean r via Z'					.906	.783	.890

LEGEND

The table reflects the correlation of various simultaneous measurements of respiration with respect to a spirometer. The measurements were taken from two subjects, aged 25, in various positions. Two telemetric measuring devices were used - the impedance method as heretofore reported using Cordis conformal electrodes with paste positioned at the junction of the 6th dorsal interspace and the mid-axillary line, and a $CuSO_4$ strain gage positioned across the 5th dorsal interspace and transmitted across the temp. channel of the telemetry transmitter. The mercury strain gages were positioned across the umbilicus (abd) and across the 4th dorsal interspace (chest) respectively. C+A in the table represents the sum of these two values. The t test for paired observations of the difference between the two telemetry methods via the Z' transformation of r produce a t of 4.96 for the 45 pairs which is significant at less than .001 level of null probability demonstrating the superiority of the strain gage method.

Table 5

Clinical Ratings of Subject 1

	SESSION I			SESSION II		
	Stress	Non-Stress	Diff	Stress	Non-Stress	Diff
Patient Variables						
1. Resistance	21	27	-6	20	25	-5
2. Verbal Productivity	27	29	-3	23	28	-5
3. Anxiety	27	16	9	28	22	6
4. Hostility to Therapist	9	4	5	13	5	8
5. Hostility to Others	7	8	-1	15	5	10
6. Depression, boredom, apathy	11	14	-3	14	11	3
7. Negative Arousal	54	42	12	70	43	27
8. Positive Feelings to Therapist	4	12	-8	4	5	-1
9. Positive Feelings to Others	6	16	-10	10	8	2
Therapist Variables						
10. Resistance Interpretation	5	4	1	5	4	1
11. Content Interpretation	9	4	5	17	4	13
12. Transference Interpretation	4	4	0	4	4	0
13. Reassurance and Reward	4	15	-11	4	11	7
14. Drive and Motivation	29	18	11	19	28	-9
15. Directive Statements	4	7	-3	7	4	3
16. Mild Agreement	5	5	0	4	5	-1
17. Verbal Productivity	13	11	2	17	12	5
18. Interview Aggressivity	24	5	19	29	10	19
19. Positive Feelings	5	14	-9	4	15	-11

Table 6

Clinical Ratings of Subject 2

	SESSION I			SESSION II		
	Stress	Non-Stress	Diff	Stress	Non-Stress	Diff
Patient Variables						
1. Resistance	26	28	-2	27	30	-3
2. Verbal Productivity	15	15	0	15	16	-1
3. Anxiety	33	23	10	29	17	12
4. Hostility to Therapist	4	4	0	8	4	4
5. Hostility to Others	18	4	14	16	6	10
6. Depression, boredom, apathy	18	12	6	21	16	5
7. Negative Arousal	73	43	30	74	43	31
8. Positive Feelings to Therapist	4	6	-2	4	4	0
9. Positive Feelings to Others	4	10	-6	4	10	-6
Therapist Variables						
10. Resistance Interpretation	5	4	1	4	4	0
11. Content Interpretation	8	4	4	9	4	5
12. Transference Interpretation	5	4	1	4	4	0
13. Reassurance and Reward	5	9	-4	4	8	-4
14. Drive and Motivation	29	31	-2	31	32	-1
15. Directive Statements	4	4	0	4	4	0
16. Mild Agreement	4	4	0	4	4	0
17. Verbal Productivity	25	25	0	25	24	1
18. Interview Aggressivity	22	10	12	26	5	21
19. Positive Feelings	5	10	-5	4	9	-5

Table 7

Clinical Ratings of Subject 3

	SESSION I			SESSION II		
Patient Variables	Stress	Non-Stress	Diff	Stress	Non-Stress	Diff
1. Resistance	30	30	0	35	31	4
2. Verbal Productivity	10	12	-2	8	8	0
3. Anxiety	21	16	5	22	14	8
4. Hostility to Therapist	26	18	8	24	22	2
5. Hostility to Others	26	16	10	23	20	3
6. Depression, boredom, apathy	13	17	-4	16	14	2
7. Negative Arousal	85	67	18	85	70	5
8. Positive Feelings to Therapist	4	4	0	4	4	0
9. Positive Feelings to Others	4	10	-6	4	5	-1
Therapist Variables						
10. Resistance Interpretation	10	5	5	9	4	5
11. Content Interpretation	7	4	3	7	4	3
12. Transference Interpretation	4	4	0	6	4	2
13. Reassurance and Reward	5	13	-8	5	13	-8
14. Drive and Motivation	25	24	1	22	20	2
15. Directive Statements	5	6	-1	8	11	-3
16. Mild Agreement	4	4	0	4	4	0
17. Verbal Productivity	30	28	2	32	32	0
18. Interview Aggressivity	24	9	15	30	12	18
19. Positive Feelings	5	13	-8	5	15	-10

Table 8

Physiolgical Responses of Patient

Interview of Subject No. 1

Variable	Stress	Non-Stress	Diff
HR			
Mx	101.5	102.2	-0.70
Mn	94.6	94.8	-0.20
Diff.	6.9	7.2	-0.30
SC			
Mx	4.61	5.40	-0.79
Mn	4.20	4.31	-0.11
GSR	.62	.69	-0.07
# GSR	19.6	22.1	-2.5

Interview of Subject No. 2

Variable	Stress	Non-Stress	Diff
HR			
Mx	82.2	77.1	5.1
Mn	71.6	68.8	2.8
Diff.	10.6	8.3	2.3
SC			
Mx	5.04	4.52	0.52
Mn	3.97	3.56	0.41
GSR	.87	.53	0.34
# GSR	15.1	6.4	8.7

Interview of Subject No. 3

Variable	Stress	Non-Stress	Diff
HR			
Mx	85.7	87.9	-2.20
Mn	75.2	75.8	-0.60
Diff.	10.5	12.1	-1.60
SC			
Mx	4.76	5.16	-0.40
Mn	4.01	4.04	-0.03
GSR	.65	.68	-0.03
# GSR	9.20	5.97	3.23

Table 9

Physiological Responses of Interviewer

Interview of Subject No. 1

Variable	Stress	Non-Stress	Diff
HR			
Mean	79.60	80.30	-0.70
Mx	81.50	81.60	-0.10
Mn	74.40	75.80	-1.40
Diff.	7.10	5.80	1.30
SC			
Mx	12.24	12.83	-0.59
Mn	10.28	10.95	-0.67
Diff.	1.96	1.88	.08
Mx GSR	1.04	.95	.09
# GSR	24.60	20.00	4.60

Interview of Subject No. 2

Variable	Stress	Non-Stress	Diff
HR			
Mean	75.46	78.08	-2.62
Mx	82.25	84.17	-1.92
Mn	72.31	74.90	-2.59
Diff.	10.94	9.27	1.67
SC			
Mx	11.82	12.33	-0.51
Mn	10.82	11.21	-0.39
Diff.	1.00	1.12	-0.12
Mx GSR	.35	.36	-0.01
# GSR	6.70	5.50	1.20

Interview of Subject No. 3

Variable	Stress	Non-Stress	Diff
HR			
Mean	77.36	77.41	-0.05
Mx	83.16	82.05	1.11
Mn	73.41	74.01	-0.60
Diff.	9.75	8.04	1.71
SC			
Mx	9.57	10.07	-0.50
Mn	7.68	8.37	-0.69
Diff.	1.89	1.70	.19
Mx GSR	.98	.67	.31
# GSR	19.60	11.60	8.00

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13. ABSTRACT

The art of physiological telemetry is borderline in three areas: (1) sensors, (2) transmitter, (3) data processing. This study assessed the AMRL 3-channel personal telemetry from all three aspects. Analysis of the records transmitted from men in various graded intensities of physical activity revealed that of the three physiological variables (respiration, EKG, and temperature), respiration was the least valid. Torso circumference changes sensed by rubber tube strain gages proved superior to the impedance method for measuring respiration. Some tentative findings on a stress interview study reveal the telemetry method to have promise. It was shown that the major difficulty preventing widespread use of physiological telemetry in significant field situations is the lack of a practicable high-speed data processing system which can distinguish and utilize the occasionally valid physiological signal emersed in artifact or noise produced by movements and changing environmental influences. The solution to the artifact problem is first to sense and utilize movement and environmental influences to gate out and to correct the physiological data and second to develop automatic editing apparatus and computer programs for recognition and selection of the valid signal patterns.

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