NUTRITION, EMPLOYMENT, AND WORKING EFFICIENCY: TOWARD MEASURING HUMAN ACTIVITY IN THE RURAL TROPICS

By

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This paper is a reproduction of Weyland Beeghly's M.S. Thesis. Excluded are only the title page required by the Graduate School and the Biographical Sketch.

Circulating an unedited thesis is justified in this case on two counts:

1. I can't improve on it.

2. It is an original contribution on which we would like to have as many comments as possible before publication.

So let us know what you think. Though the generation of SAMIs employed in the Philippine project did not permit accurate measurement of energy expenditure among truly free-ranging farmers, the Garrow-modified instrument (possibly) and the SATR (certainly) promise to enable us to do so. We would be interested in having suggestions as to further applications of vital rate monitoring. These would seem to be particularly broad in the area of employment, increasingly the problem confronting the Third World.

In this area the limitations of traditional economic analysis--with its emphasis on yield maximization--are becoming more and more apparent. For governments confronted with swelling numbers of unemployed the effect of an investment alternative on employment is no less important than the returns to it. From trials of the sort described in Chapter VI the labor-use elasticities of alternative development strategies would seem possible of derivation.

Readers may be interested in two other recent Staff Papers outlining applications of indirect, indirect calorimetry:

No. 72-11: Peter Matlon, "The Definition and Measurement of Rural Disguised Unemployment in Low-Income Countries: A Review of the Literature and Speculations on the Use of Energy."

No. 72-13: Andrew McGregor, "Agricultural Labor Absorption and Its Possible Quantification in Low-Income Countries: The Fiji Case."

It is a pleasure to recognize the superior job Mr. Beeghly did, and also to thank the friends in Jamaica, Ceylon, the Philippines, and England, and in Agricultural Engineering and Anthropology at Cornell who have over the years worked with us. If what Weyland calls transistorized economics does have a future, it is largely because of them.

Funding for this particular project came, one way or another, from the Ford Foundation, the Agency for International Development, and Cornell's Program on Structural Change. For scratching up this and other scratch (for what was to them a great unknown) I am indebted to Professor B. F. Stanton and Mrs. A. Papas.

Thomas T. Poleman

October 1972

To Lumen

"let your light so shine"

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It is my pleasant task to acknowledge the cooperation and support of three fine institutions: The International Rice Research Institute; The Philippine Food and Nutrition Research Center; and Cornell University.

An unparalleled research environment was provided at IRRI. For this, as well as for their interest and encouragement, I wish to thank Dr. Randolph Barker and Dr. Bart Duff. Three associates--Violy Cordova, Ric Guino, and Bert Orcino worked nearly full-time on the project. For their conscientious effort, advice, and friendship I am sincerely grateful.

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On the hardware side, I wish to thank Mr. Peter Mytton and the people at TEM Engineering Ltd. (Crawley, Sussex) who provided the SAMIs and infrastructure for what was to them a mere pittance. H. S. Wolff, whose genius is reflected in most of the gadgetry, advised from his office in London.

Here at Cornell, appreciation must be expressed to Dr. Kenneth Turk, Director of the International Agricultural Development Program, for providing pleasant housing, a morally-certified cook, and an auto of lesser repute during my stay in the Philippines.

Without the interest and ability of Dr. Timothy Mount the calibration model would never have surfaced. For steering it through the "big machine," I owe a major debt to my close personal friend, Geoffrey Jackson, and his team of dummy variables.

I also wish to acknowledge a substantial debt to the members of my Special Committee. To Dr. Thomas T. Poleman from whose fecund mind transistorized economics emerged. To Dr. Daniel Padberg who frequently bouyed my spirits during these brief two and two-thirds years at Cornell. And to Dr. Olan Forker who was kind enough to substitute for Professor Padberg at my final exam.

In the preparation of this manuscript, Joe Baldwin must be credited for the excellent illustrations. Thanks should also be extended to Lewis Relyea who printed the photographs. For typing the thesis at every stage in its development I wish to thank Lillian Morse.

Finally, to the many SAMI participants, my wife Susan, and our cat Angus--all of whom somehow survived this experience--a particular debt is due and is most gratefully acknowledged.

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CHAPTER I. MEASURING ENERGY EXPENDITURE: WHY BOTHER?

The life of the tropical farmer is both mundane and mysterious. While many consider his days monotonous, few agree on how he spends them. Accounts of long days in steaming fields must compete with descriptions of leisurely afternoons in a handmade hammock. The conflict can be partly laid to cultural differences. There is, after all, no reason to assume that tropical farmers are more homogeneous than those in the temperate zone. But the fact remains that there is little empirical evidence to back either view.

The question is of more than academic interest. Indeed it has a bearing on two of the most basic problems confronting low-income countries: food and employment. For years these countries have relied on FAO's scale of calorie requirements to estimate food shortages and plan future needs (1, pp. 9-46). These standards provide useful caloric adjustments for differences in weight, age, sex, and environment. But they helplessly ignore the impact of alternate levels of physical activity--clearly the most crucial caloric variable.

In recent years, however, unemployment has replaced hunger as the chief concern of politicians and planners. The well-documented farm-to-city migration continues to gain momentum at a time when industry is increasingly capital intensive. If political turmoil is to be averted, new jobs must be found. At the same time, the impact of technology on traditional work patterns should be carefully assessed. It would seem worthwhile to consider how data on human energy output might be used in dealing with these problems.

The Conflicting Evidence on Nutrition in the Tropics

Although seldom applied to the plight of poor nations, the study of human energy is not new. The first measuring devices were developed more than 70 years ago and it was soon established that muscular exertion represents the body's second largest caloric cost. A moderately active person uses 50 percent of his available energy for basal metabolism and 25 percent for physical activity (2, p. 216). But the variation in human endeavor is immense, and has spawned a large number of specialized studies.

Most of the research has been done in industrial environments of the temperate zone with soldiers frequently serving as subjects. Numerous published tables indicate the caloric costs of sitting, standing, and sleeping under various conditions. The energy component for nearly every organized sport has been determined and occupational groups and craftsmen have been studied to the point where we now know that a watch repairman fixing a mainspring uses only a fifth as much energy as a saddened Scottish shepherd burying a dead ewe (Table 1). But the nature of these activities, the technology used, the differing attitudes and physical characteristics of the people, and a host of other factors have made these data inapplicable to most low-income countries.

This void is most easily attacked in the industrial regions of the Third World where activity may vary little during the day and throughout the year. For example, a summary of five Indian studies shows Calcutta

TABLE 1. ENERGY COSTS OF HUMAN ACTIVITIES*

Activity	Average Calories/Minute
Agricultural:	
Feeding mulberry leaves (Japan)	1.4
Milking	
by machine	1.5
by hand	3.5
Cleaning pig sty	4.0
Pushing sheep in dip	5.7
Digging hole for dead sheep	8.0
Service and Industrial:	
Repairing watch	1.6
Typing	
30 words/minute	1.6
40 words/minute	1.7
Stacking beer cases	2.4
Operating a punch press	5.7
Pushing coal tubs	8.0
Athletic:	
Playing poker	1.9
Playing volleyball	3.5
Bowling	4.1
Playing badminton	6.3
Playing tennis	7.1
Scottish country dancing	8.0
Horseback riding	
walking	3.0
trotting	8.0
galloping	10.0

* From Durnin and Passmore, Energy, Work and Leisure, Heinemann Educational Books Ltd., London, 1967.

rickshaw pullers to be among the hardest workers in the world, expending 4880 calories per day--more than three times that required by a college student, and a third more than used by a stone cutter or cotton mill worker (3, p. 117). However, most people in the low-income world are not college students, factory workers or rickshaw pullers. They are peasant farmers, and the task of assessing their energy expenditure is difficult.

One problem is that work periods and levels of exertion are influenced not by a shop foreman, but by the agronomic cycle. The nature of each crop, its state of maturity and overall climatic conditions greatly affect labor requirements. Sampling, therefore, must be much more extensive than for occupations of consistent activity.

Another problem is that peasants do many different kinds of work, some unrelated to farming. For example, Clark's review of African and Indian data show only 17-34 hours per week spent in the field (4, pp. 115-117). But many devote considerable time to carpentry, weaving, processing grain, and other activities which in an industrial society are done by specialists. The most common method of energy measurement[1/] is so taxed when confronted with multiple activities in irregular time periods and informal sequence that Durnin concludes it "is difficult, if not impossible, to assess the energy expenditure of the peasant farmer and so to estimate accurately his food needs." (3, p. 122).

1/ As caloric expenditure and oxygen intake are closely related, traditional measurement relies heavily on the respirometer. The caloric costs of several major activities are determined, and multiplied by appropriate time periods as recorded in an activity diary. This method will be discussed in Chapter II.

For these reasons, among others, less than a handful of studies have dealt with energy output among tropical farmers. In 1949, Fox set out to measure the "...energy expended in cultivating food crops by hand labour during one year in a primitive African Community" (5, p. 1). The Fox study--and one by Phillips a few years later--determined, not surprisingly, that many agricultural operations involve moderate to heavy exertion (5, pp. 86-88; 6, pp. 12-20).

Two other studies have attempted to relate activity and calorie requirements to FAO standards. Burgess and Laidin found that per capita daily consumption of Malay small holders and fishermen was respectively 14 and 22 percent short of requirements computed according to the first FAO report (7). Nicol, however, provides evidence that not all peasants have a level of caloric intake well below FAO standards. Among seven communities in Nigeria, he found mean body weight lowest in two groups of hard-working farmers and herdsmen. Yet their diets supplied up to 120 percent of their estimated requirements. Another group of energetic farmers lost weight over the year presumably because their food intake had been restricted by a poor crop and amounted to only 94 percent of requirements. The men of a third group, who cultivated yams but did not have to travel far to their fields, maintained a higher body weight throughout the survey year on an estimated intake of 94 percent of requirements. Nicol concluded that the intake of calories approximates the computed FAO requirements where men and women are not unduly energetic (8, p. 306).

Unfortunately, hardly any new data has been added to this conflicting picture in 15 years. Thus McArthur suggests there is simply insufficient evidence on activity patterns in the agricultural sector to "...allow us to decide whether...(the FAO calorie scale) gives a per capita requirement figure which is too high, too low, or about right. Hence, we cannot assess accurately...the magnitude of any existing deficiency in order to make allowance for it in estimating future food needs." (9, p. 406).

The Problems in Measuring Unemployment

While the food equation remains blurred, attention has been rapidly shifting to the problems of unemployment and underemployment. The actual extent of idleness is unknown--partly because measurement techniques used in urban areas have been found inadequate for the countryside. Yet an accurate view of current labor use is essential for effective planning.[2/]

Early studies tried to quantify surplus labor through use of standard production functions (12; 13; 14). This basically involves determining the marginal product for succeeding increments of labor. When the marginal product reaches zero, additional workers are considered redundant, even harmful. Although most recent work tends to discount this approach (15; 16), few alternatives have been offered.

2/ I am indebted to McGregor (10) and Matlon (11) for several of the ideas on the next few pages. Matlon, in particular, has speculated on the use of energy in the measurement of disguised unemployment.

An important weakness of the production function methodology is that it measures labor in only one dimension. But labor is more than time. It is as much skill and effort as it is man-days or man-hours. And while skills in traditional agriculture may be rather uniform, the hazards of ignoring the effort component become clear when we consider Parkinson's law, known in the development literature as "work spreading."

It has long been recognized that in slack periods households and laborers in low-income countries spend more time doing a job than is actually required. The marginal product measured under these conditions indicates low labor efficiency. Unfortunately, however, economic tools cannot separate the inefficiency due to lowered work intensity from the low marginal return inherent in the use of traditional non-labor inputs. Thus an adjustable working pace may both camouflage a labor surplus and conceal a seasonal bottleneck.

The same types of problems are encountered in trying to understand the impact of new technologies. There is little doubt, for example, that the new seed-fertilizer technology increases the productivity of labor. Yet partly because of measurement problems, little can be said regarding its total effect on employment. Mechanization, we know, increases the efficiency of labor by reducing the time needed for various tasks. Yet there is evidence that some hand-drawn implements and two-wheel tractors cause such strain that men must change off every hour or two to reduce fatigue (<u>17</u>, p. 24). In such cases, actual labor productivity is less than advertised and labor displacement perhaps less than feared.

What would clearly seem useful in the study of both current and changing labor use would be some indication of effort as well as time. Such information could be of particular value to governments currently colonizing new lands or designing the expansion of an irrigation system (18). For knowing the energy requirements of various crops at each stage of maturity would permit planners to determine the optimal size of holdings and thus avoid both labor surplus and seasonal constraints.

There are at least two other benefits from energy measurement that should be mentioned in passing. First, such studies could be of value in the designing of new equipment and techniques. Most inventors realize that efficiency isn't the only criterion by which farmers evaluate new products. Particularly in areas where most work is done by owner-operators or tenants, there appears to be some concern about stress. Techniques which save a great deal of time may fail to be accepted on a large scale simply because they require unacceptable rates of exertion. Energy trials can help determine the acceptability of new practices from this standpoint, and where necessary, aid in the redesigning of implements.

Finally, as technology changes, basic food requirements will also change. In rural areas, logic suggests that the energy requirement rises with the introduction of irrigation and the adoption of improved practices. It presumably falls if and when mechanization is introduced. Measuring this change is of major interest to those whose job it is to develop national food projections.

* * * * * *

In order to examine some of these questions, a joint research project was undertaken in Laguna Province, the Philippines, from August 1971 to January 1972. In cooperation with the Food and Nutrition Research Center, Manila, an attempt was made to determine caloric expenditure among farm families. The purpose here was not only to determine nutritional needs, but to discover how season and the type of agricultural system might affect energy requirements. The 49 participants, picked from five barrios (villages), included a number of women and children. They represented three major agricultural regimes: lowland irrigated, upland, and shifting cultivation.

A second objective of the study was to determine the efficiency of various techniques for performing the same task. In concert with economists and engineers at the International Rice Research Institute (IRRI), Los Banos, trials were conducted on several systems of plowing, harrowing, planting, weeding, and harvesting. About 20 employees and wage laborers at the Institute participated in this study.

Both phases of the project involved the use of a new system of energy measurement which lacks the clumsiness inhibiting earlier methods. Essentially indirect, indirect calorimetry, it builds on the fact that oxygen consumption and <u>heart rate</u> are predictably correlated for each individual. Thus before considering the research methodology in detail, a look at energy measurement, past and present, would seem useful.

CHAPTER II. THE EVOLUTION OF CALORIMETRY: MAKING THE UNACCEPTABLE ACCEPTABLE

Early Calorimetry and the Atwater Chamber

The measurement of metabolic energy began with the experiments of Lavoisier in the late 18th century. Attempting to quantify animal heat production, he placed guinea pigs in small cubicles surrounded by ice. The degree of melting became his index of metabolic activity. Perhaps of greater consequence, Lavoisier also measured his subjects' respiratory exchanges, and soon discerned a significant relationship between oxygen intake and heat output (3, p. 11).

This relationship is now well understood. Essentially, food enters the body as stored energy. In order to fuel bodily functions it must be liberated by oxygen through a process known as oxidation. Once released, energy facilitates muscular work, chemical systhesis, and ionic balance. Ultimately it is reduced to heat. Thus metabolic activity can be determined at either end: directly, through the output of heat, or indirectly through the intake of oxygen.

Both indirect (respiratory) and direct (heat) calorimetry were used throughout the 19th century. Extensive research on small animals led to the construction of a human respiration chamber which greatly advanced man's knowledge of the energy component in various foods. By the end of the century, Atwater had built a chamber which, for the first time, permitted both indirect and direct measurement of human energy (19, pp. 69-73).

The Atwater calorimeter was a closed but habitable room containing a couch and bicycle ergometer. Food was passed in, and excreta out, through a small hatch. As the walls were heavily insulated, all body heat was taken up by water which circulated in pipes throughout the chamber. Thus the energy output of the subject was determined from the rise in water temperature. In like manner, indirect measurements were simultaneously made through a closed respiratory system.

Experiments with the Atwater chamber yielded two important conclusions. First, that over a short period energy ingested as food exactly equals energy lost as heat--biological support for the first law of thermodynamics. Second, that energy calculated from oxygen consumption closely corresponds with measured heat output. In other words, indirect calorimetry proved to be nearly as accurate as direct measurement. This finding was further supported by the research of Murlin and Lusk. In a long series of experiments on dogs, they found the mean difference between the two types of calorimetry to be only 0.6 percent (20, pp. 15-29).

Although the Atwater calorimeter significantly furthered the study of human energy, it had severe limitations. Operative difficulties were immense, and reliable measurement--either direct or indirect--took days. But perhaps most limiting was the physical nature of the equipment. Coal cannot be mined nor potatoes planted in such devices. The metabolic study of most activities had to await less cumbersome tools.

Approaches to Indirect Calorimetry

The inevitable rejection of sealed chambers focused attention exclusively on indirect calorimetry. Shortly after the turn of the century, respiratory masks were developed. These housed valves by which inspired and expired air could be separated. Since the oxygen and carbon dioxide content of inspired air is known, human utilization of oxygen and production of carbon dioxide can be readily calculated by metering expired air and analyzing the gas content.

This principle formed the basis for the Benedict-Roth spirometer and the Douglas Bag systems, the latter featuring a huge bag in which all expired air is collected, to be later discharged through a flow meter.[1] Both systems were found to be much easier to operate than the 19th century chambers, and could produce metabolic readings in a matter of minutes. Even after 50 years, these devices remain the most reliable means for measuring oxygen consumption over short periods. They are, however, somewhat uncomfortable for the subject. They also lack the mobility essential for field work, and thus are usually found only in hospitals and laboratories.

It wasn't until the late 1920s that an instrument small enough to be taken to the field appeared. The respirometer developed at the Max Planck Institute for Work Physiology in Dortmund was a major breakthrough in the study of human metabolism under somewhat normal conditions. It enabled German physiologists to make a systematic survey of energy expenditure in a number of industries. This was soon used as a basis for the food rationing brought on by World War II.

1/ This material on the standard forms of indirect calorimetry is summarized from Chapter 2, Durnin and Passmore (3).

The Planck respirometer modified by Kofranyi and Michaelis, continues to be the major field instrument for energy studies. Now generally called a KM, it consists of a small dry gas meter (3 kgs.) worn on the back. The subject, doing his usual work, breathes out through an expiratory valve, the expired air, in turn, passing through the meter. A device within the meter directs a fraction of the expired air into a small rubber bag. This air is subsequently analyzed.

Although the KM is of considerable value, it is not without limitations. Connections to the subject make communication difficult and its appearance may cause considerable embarrassment (Photo 1). More critically, the instrument's bulk makes it awkward for the subject to do some activities, and the weight affects energy expenditure during others. All these factors inevitably cause the individual to modify his behavior, resulting in nontypical energy readings.

To overcome some of these problems, Passmore and his associates have used a KM-diary technique in which a continuous activity record is maintained by the subject or an observer during the study period. The oxygen consumption of principle activities is determined with the respirometer at a separate time. The energy expended for each activity is then calculated by multiplying the per minute caloric cost of the activity by the number of minutes spent doing it. Total energy expenditure for the period can be found by summing the expenditure for the various activities.

But this approach also has problems. It necessarily groups all activities into a few categories (e.g., sitting, standing, walking), thus glossing over the variation of daily life. Furthermore, there may be

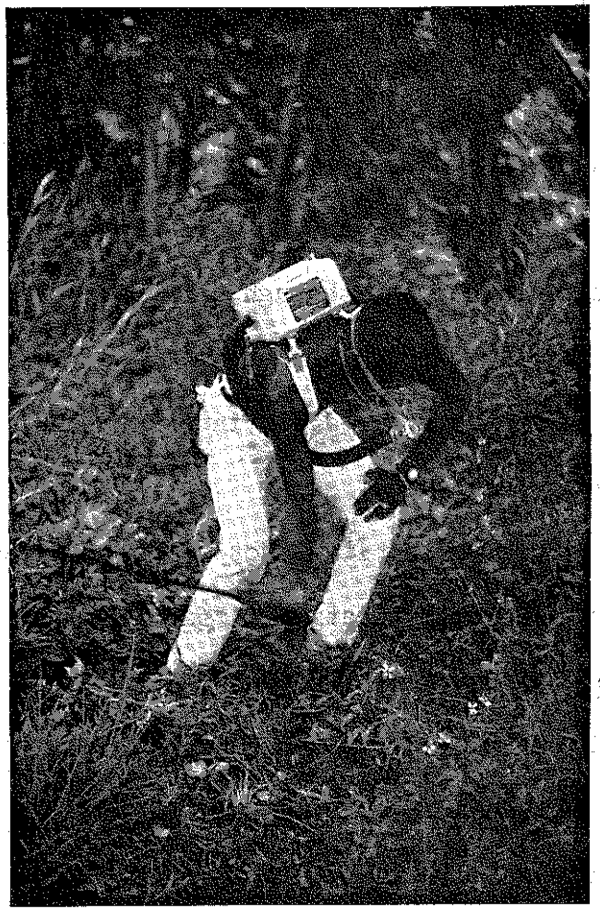


PHOTO 1 (left). TRADITIONAL CALORIMETRY: THE KM RESPIROMETER

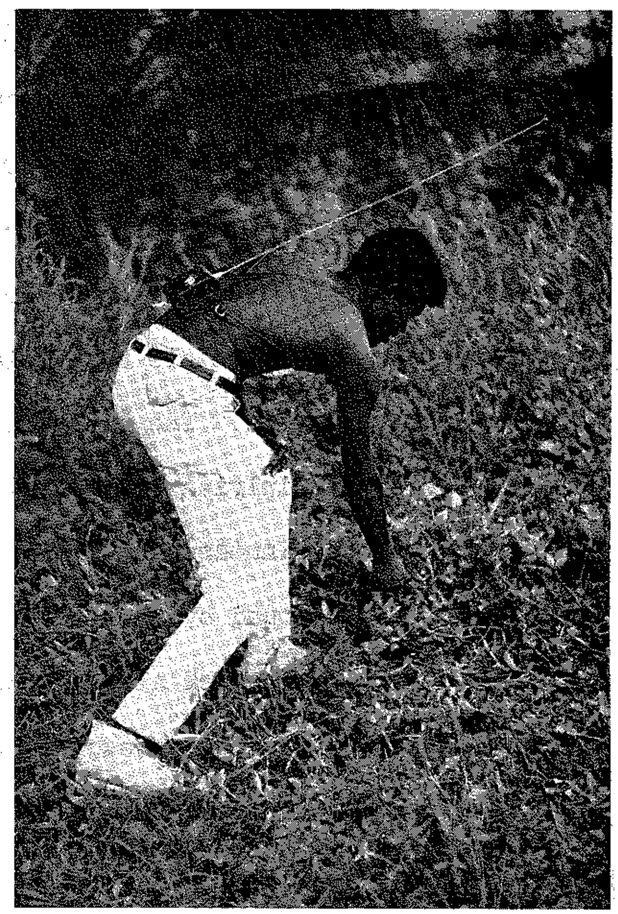


PHOTO 2 (right). MONITORING HEART RATE WITH TELEMETRY circumstances under which a diary observer is unable to keep accurate records, and to depend on the subject is always risky and sometimes impossible. In sum, the device is best suited for applications where the work is homogeneous and where it is possible to obtain meticulously accurate time span recording. Such conditions are uncommon among tropical farmers.

Using Heart Rate to Measure Energy Expenditure

Because of the serious limitations involved in the measurement of oxygen consumption, work physiologists welcomed Lundgren's 1946 discovery that there exists a linear relationship between an individual's cardiac output and his oxygen uptake over most of his range of activities. This phenomenon, described by Wyndham (21), Malhotra (22), and Ekblom (23), is easily understood when we recall that it is the circulatory system which distributes oxygen to all parts of the body. As exertion increases, more oxygen is required. It can be supplied only as the heart works to increase the flow of blood.

Though the variation between the measured consumption of oxygen and that estimated from heart rate has been found to range from only 3 to 10 percent, means for measuring cardiac activity were slow to develop (22, p. 996). All of the early research, and much done even today, relied on a simple pulse count taken within a minute of the halt of activity (22; 24; 25). Such measurement, though less cumbersome than an oxygen analysis, does not get away from the need for a diary if daily activity is to be monitored. There exist at least two other possibilities for error: first, in the well-conditioned individual pulse rate tends to drop very rapidly after activity has ceased, making the understatement of heart rate likely; second, there is a possibility that taking the pulse will increase anxiety in some people, thus raising heart rate above strictly physiological demands.

Within the last decade, however, several portable heart monitoring instruments have been designed. One--an offshoot of the miniturization stimulated by the space program--involves telemetry. The electrical impulses given off by the heart are transmitted by small, battery-powered FM devices to nearby receivers (Photo 2). A big advantage of the system is that it permits the remote reading and recording of a subject's heart rate at all hours. But the technique also presents major problems. If transmissions are to be for more than a few dozen feet, the subject must carry a rather conspicuous antenna on his back, which may have an impact on normal activity patterns. Furthermore, the transmitter contains no mechanism to distinguish electrical impulses related to cardiac activity from those associated with other muscular movement. Finally, a technician must be present at all times to read the signal which, due to line-of-sight transmission, may be interrupted if the subject ventures into an obscure ravine or even enters his hut for lunch.[2/]

The SAMI

The problems generated by bulky or conspicuous equipment appear to have been substantially reduced with the recent invention of the SAMI

2/ The telemetry technique has been compared to earlier forms of indirect calorimetry by Bradfield (26, pp. 696-699); its limitations were revealed by Poleman, *et al.* in a 1968 field trial in Jamaica (27).

(Socially Acceptable Monitoring Instrument) by H. S. Wolff of the British Medical Research Council. Small enough to fit into a shirt pocket, the SAMI can record cardiac activity for up to 48 hours with no discomfort to the subject. Electrodes affixed to the chest pick up the heart's electrical charges and transmit them to the SAMI where, by a process of ion transfer, they are accumulated in electrochemical cells (E-cells). At the end of the sampling period these cells are "decoded" by another instrument, revealing the number of heart beats.

We can perhaps get a better notion of the sequence by following, step-by-step, the procedure used with participants in the Philippine study.

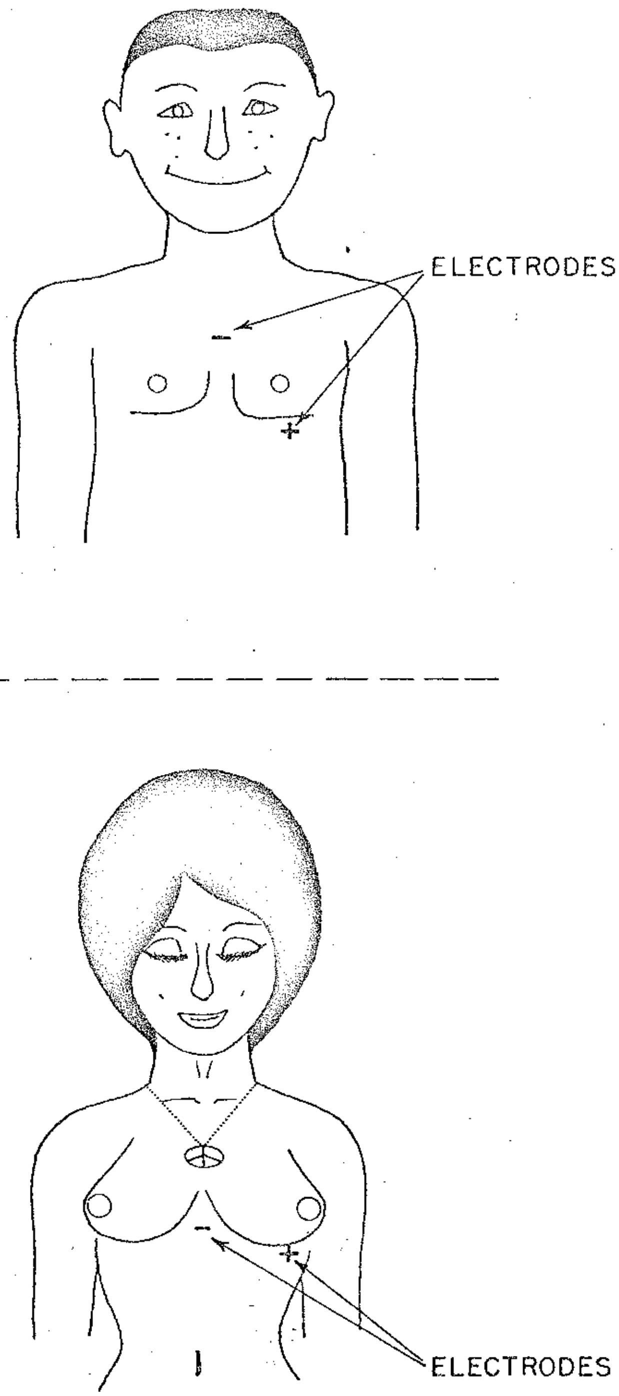
The first task is to approximate good electrode sites, i.e., sites of proper polarity and adequate amplitude. Although there are a number of alternatives, we had the greatest success with the two arrangements shown in Figure 1. One method (A) is to put the positive electrode near the apex of the heart, roughly in line with the nipple and one or two inches below it. The negative terminal is then attached three to four inches above the base of the sternum. A second method (B), less commonly used, is to attach the positive electrode as before, but with the negative wire laterial and slightly higher.

In order to determine the best possible placements, suction electrodes are first attached to several sites and tested by means of an electrode placement test set. Once optimum sites have been selected, they must be properly prepared for the SAMI electrodes. A small abrasive stone should be rubbed against the skin to rough off loose cells and

FIGURE I. COMMONLY USED ELECTRODE SITES

A.

B.



establish better contact. Ether or acetone may then be used to clean each surface. The electrodes are prepared by placing a small conducting sponge in the center of each, and a double adhesive around the perimeter. They are then pressed firmly against the sites (Photo 3).

Next, the placements are again tested with the aid of the electrode placement test set (Photo 4). The first requirement is that the R-wave have an amplitude of at least 1 mV--below that, the SAMI's automatic filtering device will not function. A second requirement is that impedance across the electrodes be less than 10 KΩ. Finally, subjects are asked to do a series of exercises while the technician listens through an ear piece to assure that the SAMI is picking up only impulses from the heart and not muscle artifact.

After the electrodes have been attached to satisfactory sites, the E-cells may be inserted (Photo 5), and the electrode wire joined to the SAMI. The instrument is then ready to be placed in the subject's pocket (Photo 6)[3/]. Monitoring has begun.

While our farmer goes about his tasks, a digression is in order. It should be recalled that heart rate in itself is not a measure of energy expenditure. Before a linkage can be inferred it is necessary to determine the relationship--unique to each individual--between heart rate and oxygen uptake. This process, which we have come to call "calibration," is considered in Chapter III. The linear relationship it yields applies to the bulk of the activity range, but breaks down if

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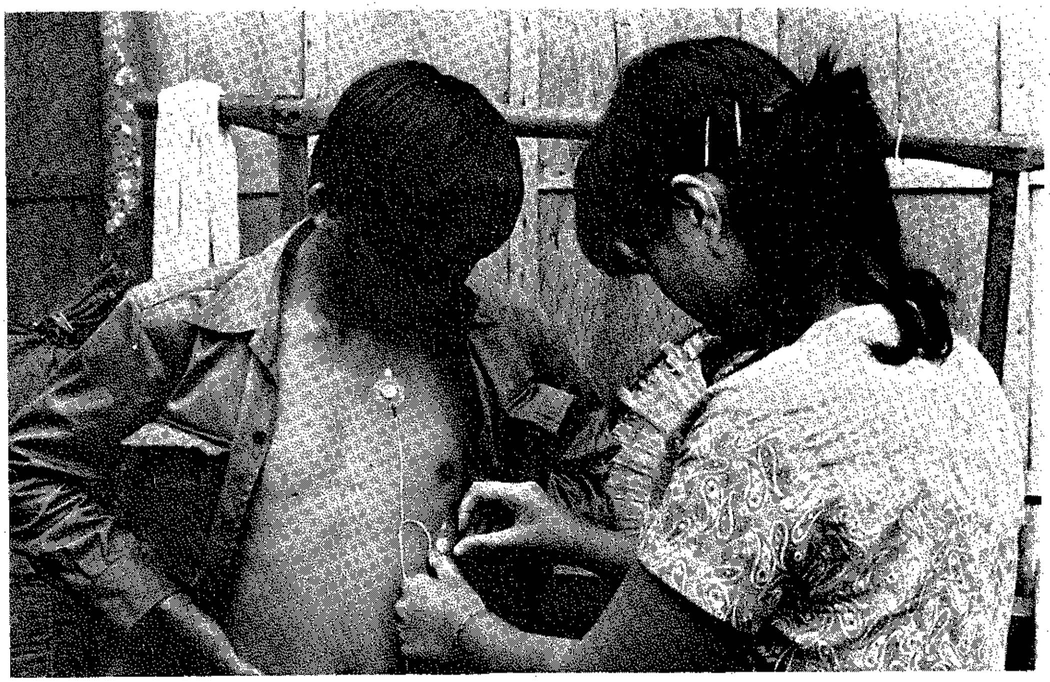
3/ Large adhesive pads (Photo 6) may be used to further protect the electrodes against moisture and detachment.



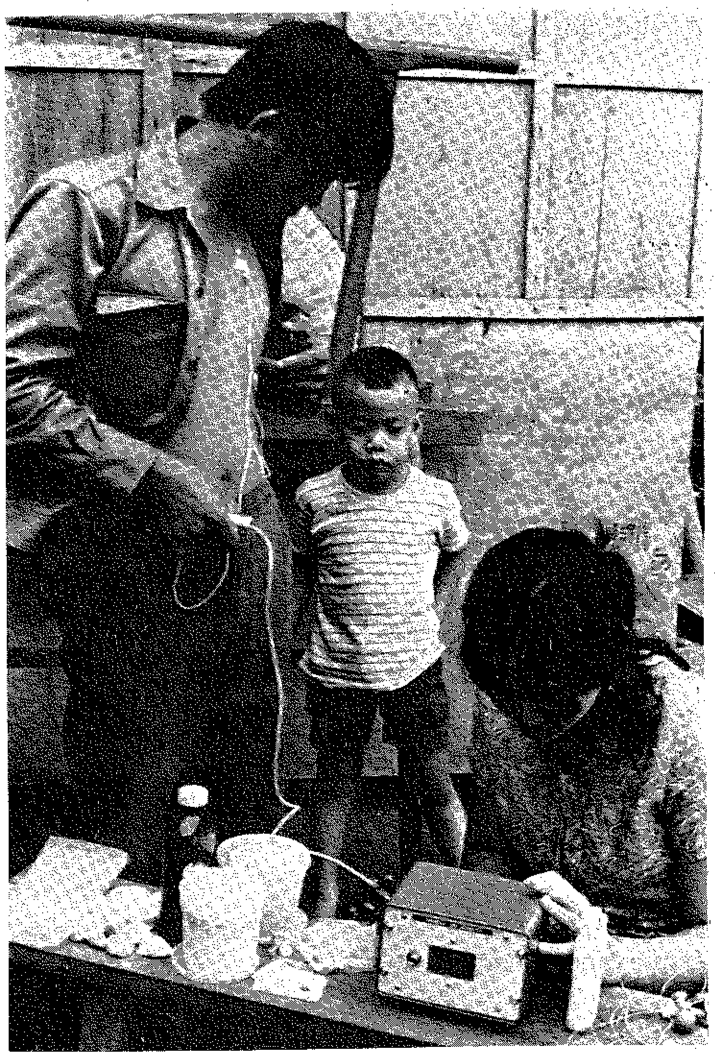


PHOTO 3 (above).
ATTACHING SAMI ELEC-
TRODES TO A FILIPINO
FARMER

PHOTO 4.(left).
TESTING THE PLACEMENT
FOR R-WAVE AMPLITUDE
AND ELECTRODE IMPEDANCE

PHOTO 5. INSERTION OF E-CELLS PRIOR TO MONITORING

PHOTO 6. POCKETING THE SAMI

the subject is resting or under extreme stress. So that this fact can be taken into account, a SAMI with three E-cells and two adjustable thresholds is available, permitting heart rates to be monitored in three ranges.4/

The nature of the heart rate-oxygen relationship (and the region covered by each E-cell) is sketched in Figure 2. Though somewhat simplified, it indicates that oxygen consumption does not move with heart rate in the region of resting metabolic rate (RMR). Similarly, the relationship breaks down in the upper region where at some point an "oxygen debt" may be expected to occur.5/ By adjusting the lower and upper thresholds for each individual, it is theoretically possible to isolate these two regions from the linear one. In the Los Banos study we selected 10 beats above resting heart rate as the likely area in which the linear relationship would begin to develop.6/ The upper threshold, really of little consequence, was uniformly set at 140.7/

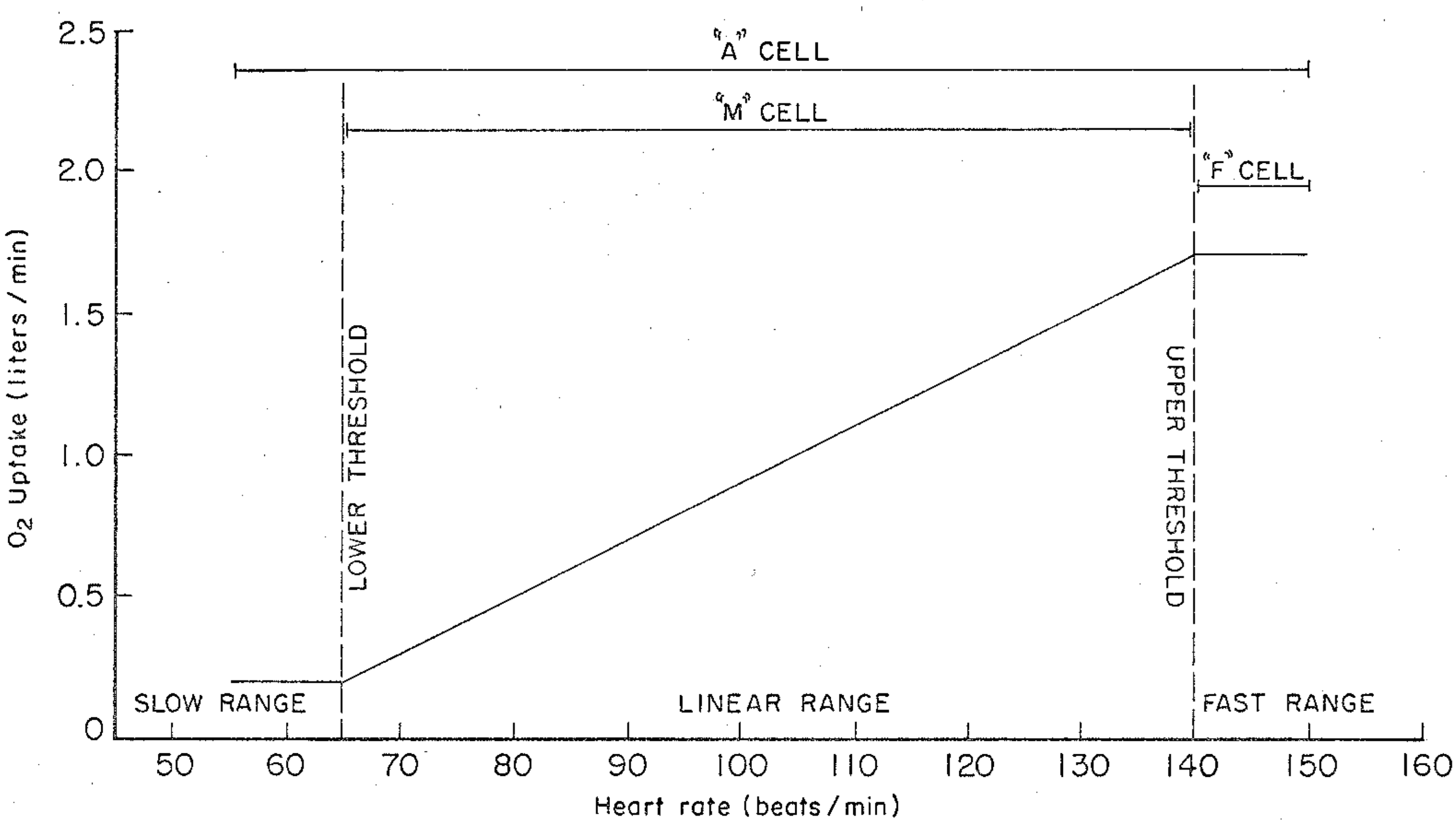
4/ Actually there are a number of instruments in the SAMI family, not all of which have three cells. For example, a one-cell SAMI is available to measure mean heart rate; another will monitor ambient or skin temperature. Other SAMIs include the Garrow modified instrument and a tape recorder--both of which will be discussed in later chapters.

5/ "Oxygen debt" can be defined as a deficit in oxygen intake during exercise that must be repaid during a recovery period (28, p. 50).

6/ Conventional wisdom has the resting heart rate of adult males to be 72 beats. In fact the variation is enormous. In the Philippines the rate of 55 employed in Figure 2 was not uncommon.

7/ There is general agreement among physiologists that the linear relationship begins at about $1\frac{1}{2}$-2 times basal metabolic rate (29). Oxygen debt, on the other hand, seldom sets in with exertion of less than 10-15 Calories/minute (30).

FIGURE 2. SIMPLIFIED HEART RATE - OXYGEN RELATIONSHIP INDICATING REGIONS RECORDED BY EACH E - CELL



We can return now to our barrio farmer who, we will assume, has been wearing the SAMI for 10 hours. The E-cells are removed and the number of heart beats in each cell determined by use of an E-cell replay machine, which counts in multiples of 30.[8/] In this instance we will assume 1650 counts in the "A" cell, 1200 counts in the "M" cell, and 50 counts in the "F" cell. Referring again to Figure 2, it can be seen that the A-cell has accumulated all heart beats during the day; the M-cell has accumulated those presumably in the linear range, and the F-cell has accumulated beats in the fast range. The actual number of heart beats, then, is as follows:

A-cell	1650	X	30	=	49,500 heart beats
M-cell	1200	X	30	=	36,000 heart beats
F-cell	50	X	30	=	1,500 heart beats

Actual caloric expenditure can now be computed.

8/ The nature of the E-cell is described by SAMI inventor, H. S. Wolff, in his book Biomedical Engineering (31, pp. 115-116).

> This E-cell consists of a cylindrical silver can about 1 cm. long and 0.5 cm. in diameter, with a gold-plated electrode at its centre and insulated from it. Wire terminations are made to both the can and the central electrode, and the space between them is filled with an electrolyte containing a soluble silver salt. When a current is made to flow through the cell in such a direction that the gold electrode is the cathode and the silver can the anode, then silver will be plated from the can on to the gold electrode; and, in accordance with Faraday's first law of electrolysis, the quantity of silver transferred will be proportional to the quantity of electricity which passes. Since the SAMI is so designed that each heart beat produces a standard-size pulse of current to be fed into the E-cell, the amount of silver deposited on the gold electrode will thus be proportional to the number of heart beats recorded. If we know the amount that will be transferred for a given number of heart beats and can measure the amount that has in fact been transferred during the known time of recording, it takes only a little simple arithmetic to work out the average heart rate for the whole period.

The first step is to determine the approximate time spent in each of the three ranges (Figure 2). Since none of the SAMI cells measures the slow range, _per se_, the beats must be derived by subtracting F and M from A.

$$49{,}500 - 36{,}000 - 1{,}500 = 12{,}000 \text{ (total heart beats in the slow range)}$$

We can now approximate minutes by suggesting that beats in this range averaged halfway between the subject's resting rate (55) and the lower threshold (65).

$$\frac{12{,}000}{60} = 200 \text{ (minutes in the slow range)}$$

We determine minutes in the upper range by arbitrarily suggesting that these averaged 145 beats per minute.

$$\frac{1{,}500}{145} = 10 \text{ (minutes in the fast range)}$$

Subtracting the minutes in these two ranges from total minutes yields a figure for the linear range.

$$600 - 200 - 10 = 390 \text{ (minutes in the linear range)}$$

With the time in each range approximated, the second step is to determine the number of calories expended. The number of minutes in the flow range should be multiplied by an appropriate resting metabolism.[9]

9/ In this case valid resting data is unavailable, so the slightly lower basal metabolic rate (BMR) has been used. For the average Filipino male this is .92 Cal./min. (_32_, p. 234).

$$200 \times .92 \text{ (Cal./min.)} = 184 \text{ Calories}$$

For the linear range, however, a more complex formula is required. It is first necessary to decide on the average heart rate for this range by dividing "linear" heart beats by minutes.

$$\frac{36,000}{390} = 92.3 \text{ (beats/min.)}$$

We can then find this heart rate on the individual's calibration chart (Figure 3) and read off the liters of oxygen (.74 liters/min.). Since Weir has determined that each liter liberates 4.92 Calories (33), actual energy expended can be computed as follows:

$$.74 \times 4.92 = 3.64 \text{ (Cal./min.)}$$
$$3.64 \times 390 \text{ minutes} = 1420 \text{ Calories}$$

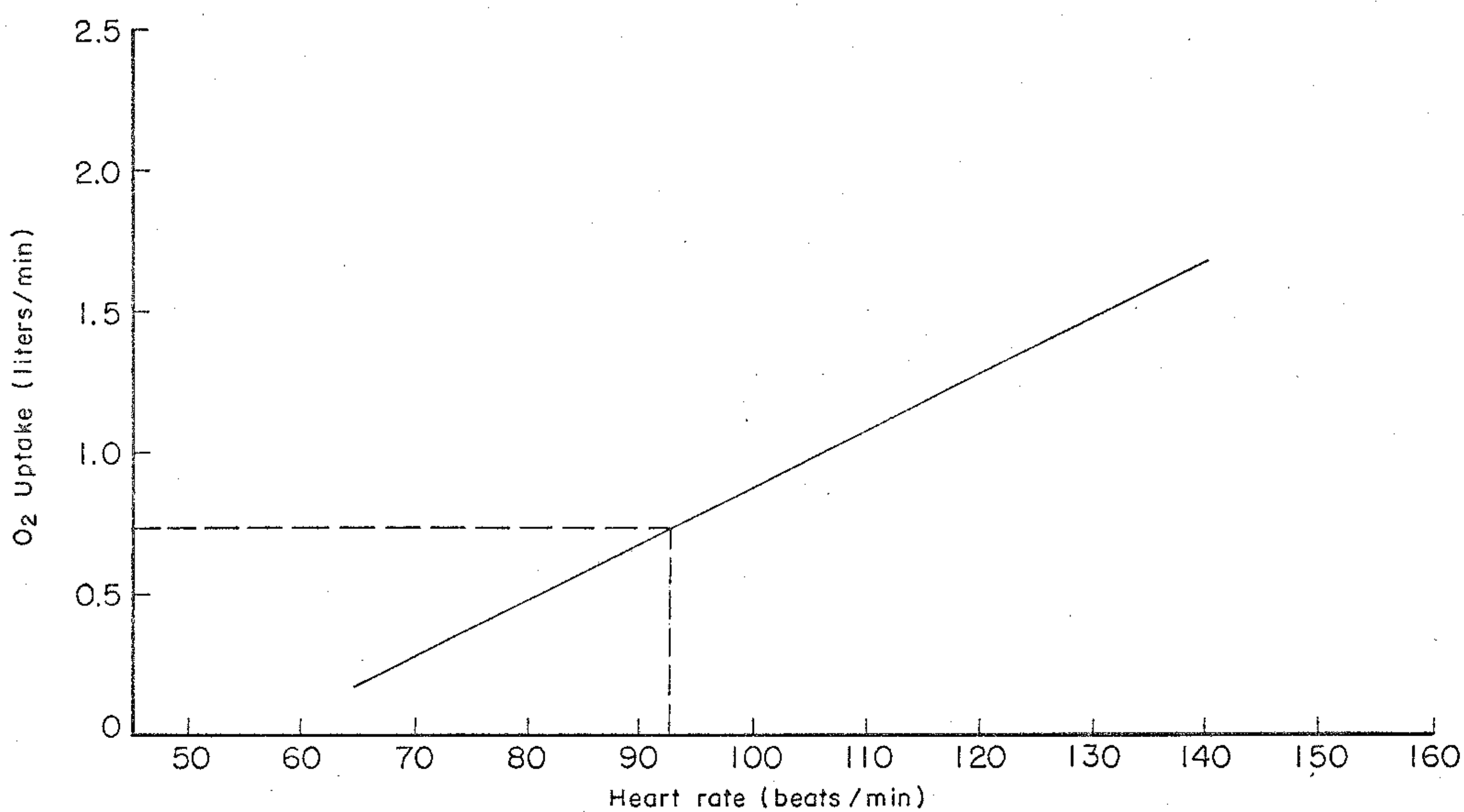
Since it is extremely difficult to know where the fast range begins, beats in the F-cell can usually be treated as part of the linear range and computed in a similar fashion:

$$\text{oxygen intake at 145 beats/min.} = 1.8 \text{ liters/min.}$$
$$1.8 \times 4.92 = 8.86 \text{ (Cal./min.)}$$
$$8.86 \times 10 \text{ minutes} = 89 \text{ Calories}$$

Adding the three ranges together we get a total calorie figure for the day.

$$184 + 1420 + 89 = 1693 \text{ Calories}$$

FIGURE 3. DETERMINING OXYGEN UPTAKE FROM KNOWN HEART RATE - "M" CELL



CHAPTER III. THE HEART RATE-OXYGEN RELATIONSHIP: CAN IT BE PREDICTED?

Calibration--the simultaneous determination of heart rate and oxygen uptake at several levels of activity--is the cornerstone of indirect, indirect calorimetry. As each individual's heart rate-oxygen relationship is unique, all participants in our study were calibrated at least once. Equipment consisted of a KM respirometer and gas analyzer to determine oxygen uptake, an electrode placement test set and strip chart instrument to record heart beats, and a bicycle ergometer to alter the degree of physical stress (Photo 7).

The Calibration Process

The basic procedure is to get oxygen readings at several different levels of stress. In our case five readings were generally made, the first invariably an 8-10 minute test with the subject sitting quietly in an easy chair. The second was taken while the subject pedaled the ergometer just fast enough to raise heart rate by 10-15 beats per minute. The remaining trials were done under progressively greater stress but for shorter time periods, the final trial being three minutes at 120-130 beats per minute. For most subjects calibration was completed within an hour, with brief rests between each level of exertion.

Remarkably few problems were encountered, perhaps the most serious being the anxiety shown by teenage girls. Although pictures, comic books,

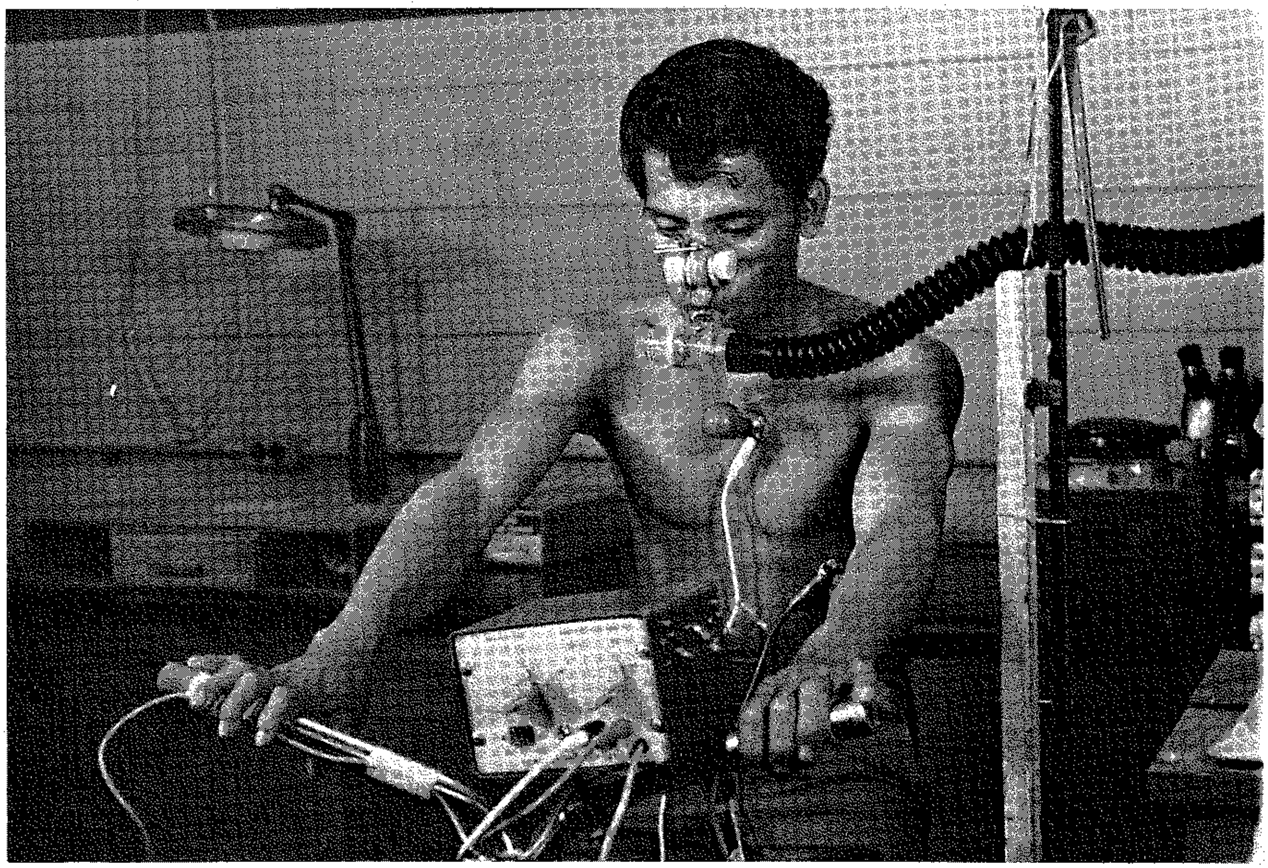


PHOTO 7. THE CALIBRATION OF AN IRRI PARTICIPANT

and music were available to encourage relaxation, an hour or more was often needed to bring the "resting" rate down to a reasonable level. In a few cases, this was never achieved. A lesser problem was that many participants had never pedaled a bicycle and thus lacked a desirable degree of coordination. Such handicaps were overcome by increasing the tension on the wheel rather than calling for additional bursts of speed.

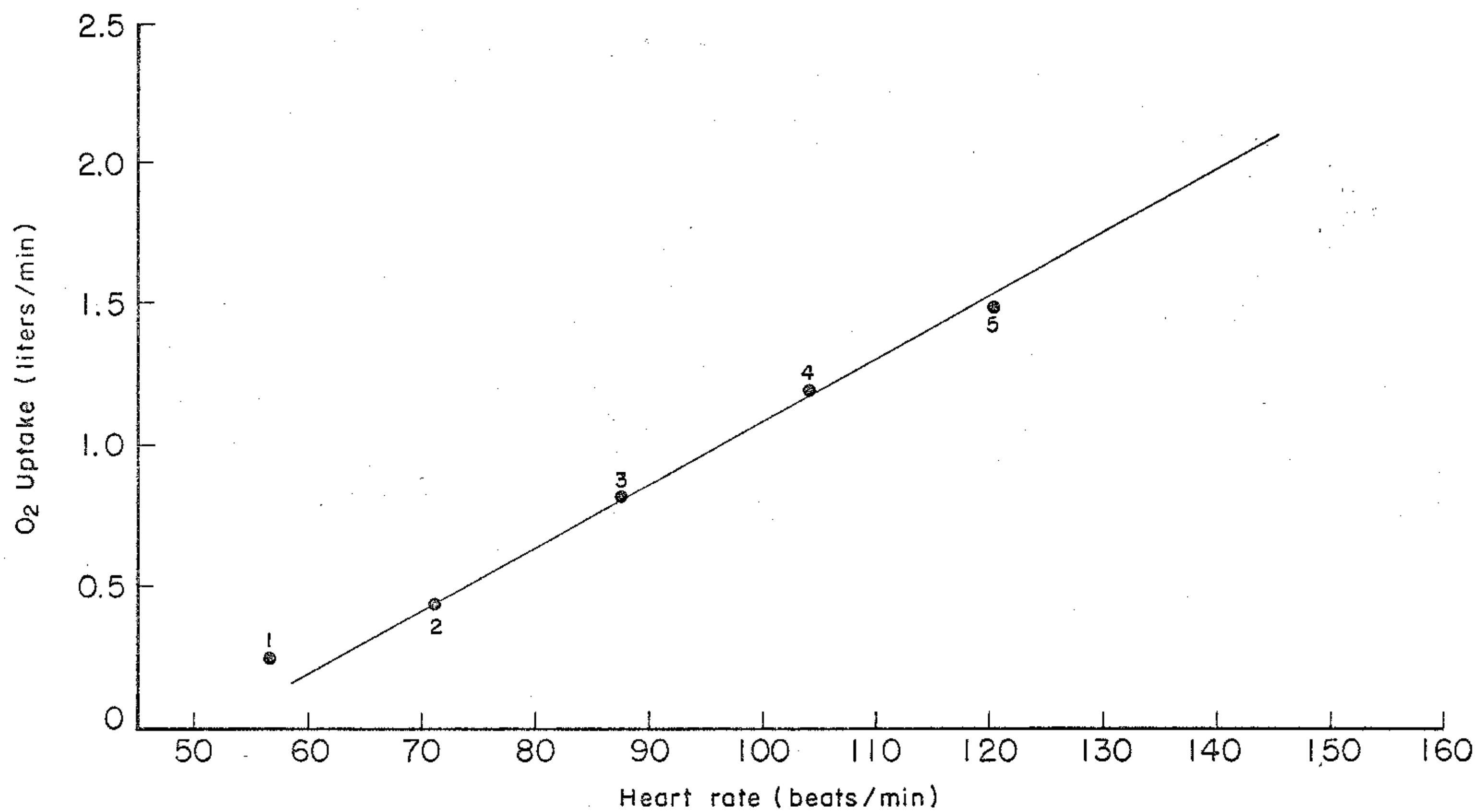
Figure 4 shows the results of one calibration. The five simultaneous readings of heart rate and oxygen are plotted on the graph and an "eye-ball" (rough) estimate of the slope has been drawn. Although observations were more deviant for some individuals, the "fit" was generally good.

A total of 100 people were calibrated during the course of the study. These calibrations were primarily intended to convert individual heart rate data from the barrio and field to caloric equivalents. But they were also viewed in a broader light: to attempt to identify whether physical and occupational characteristics have a significant influence on slope and intercept.

Identifying the Significant Personal Variables

The possible impact of these characteristics on the heart rate-oxygen relationship is of more than intrinsic interest. As Photo 7 indicates, calibration is the least socially acceptable feature of indirect, indirect calorimetry. If the nature of an individual's heart rate-oxygen relationship can (within limits) be predicted through knowing his/her personal features, reliance on this unpopular and time-consuming requirement might be lessened.

FIGURE 4. ACTUAL OBSERVATIONS IN THE CALIBRATION OF A 50-YEAR-OLD UPLAND FARMER



To determine if personal variables are, in fact, significant, we first made the now familiar assumption that the relationship between heart rate and oxygen is linear. Thus the model for a single individual might be written

$$(1) \quad O = a + bH$$

where

O = oxygen (liters/min.), and
H = heart rate (beats/min.)

As it is already known that the two parameters, a (intercept) and b (slope), vary among individuals, we can now make a second assumption that this variation is, in fact, due to differences in personal and occupational characteristics. This suggests the general model

$$(2) \quad O = \Sigma_n a_n X_n + (\Sigma_n b_n X_n) \ (H)$$

where

O and H are defined as in (1), and
X_n = a set of variables for personal and occupational characteristics

Thus, in equation (2) both the intercept ($\Sigma_n a_n X_n$) and slope ($\Sigma_n b_n X_n$) for a particular individual are expressed as a function of his/her personal and occupational characteristics.1/

An estimate of the regression equation (2) revealed an R^2 of .8097, indicating that most (80.97%) of the variation in heart rate-oxygen

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1/ The 30 original variables included age, sex, height, weight, surface area, and ten occupational groups: field laborers, carabao plowmen, IRRI shop workers, tractor plowmen, sedentary workers, and farmers from each of the five barrios. Each variable was evaluated for its impact upon both intercept and slope.

relationships can indeed be explained by individual characteristics. Subsequent regressions eliminated nearly two-thirds of these characteristics as insignificant, leaving the final model with only 11 variables.[2/]

$$(3) \qquad 0 = (a_0 + a_1X_1 + a_2X_2) + (b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8) \quad (H)$$

where

X_1 = sex (a dummy variable with X_1=0 for males, =1 for females)

X_2 = weight (kilograms)

X_3 = height (centimeters)

X_4 = surface area (meters^2)[3/]

X_5-X_8 = occupational dummy variables as follows:

X_5 = 1 for field laborers
= 0 for others

X_6 = 1 for carabao plowmen
= 0 for others

X_7 = 1 for sedentary workers
= 0 for others

X_8 = 1 for barrio folk, tractor plowmen, and IRRI shop workers
= 0 for others

2/ It was immediately found that occupation had little bearing on the intercepts. Dropping this factor yielded an F-statistic of 1.44 (F;9,474) insignificant at the 1% level. However, dropping occupation as a determinant of slope was unacceptable at the 5% level. Additional regressions indicated that slopes for all barrio folk, tractor plowmen, and IRRI shop workers could be grouped. Several other characteristics were subsequently dropped, leaving the final model with only 11 variables. The F-statistic, 1.66 (F; 19,474) is insignificant at the 2.5% level.

3/ Surface area = .007184 X weight$^{0.425}$ X height$^{0.725}$ (34, p. 131).

As the heart rate-oxygen relationship is not, in fact, linear over the entire activity range, it was considered advisable to test the log-log-inverse function (Figure 5).

$$(4) \quad \log O = a + b/\log H + c(1/H)$$

where

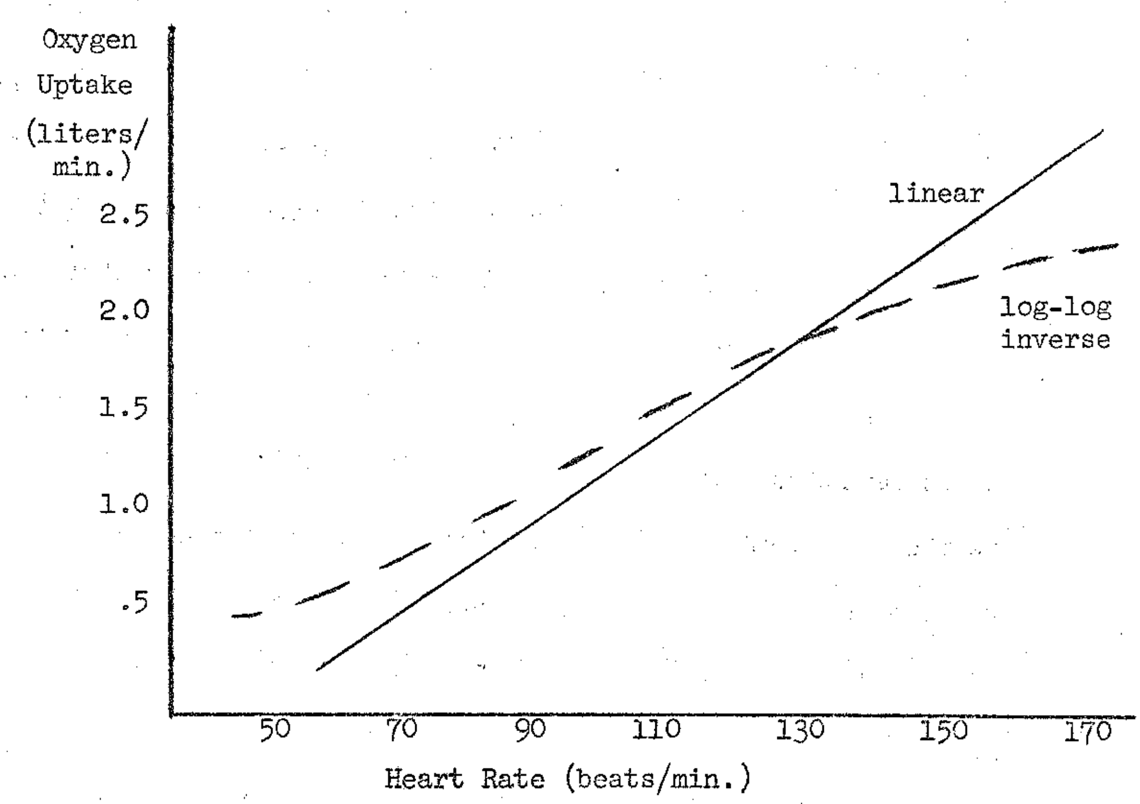
a, b, and c are the regression coefficients

Fitting the personal/occupational characteristics as in (2) yields

$$(5) \quad \log O = \Sigma_n a_n X_n + (\Sigma_n b_n X_n)(\log H) + (\Sigma_n c_n X_n)(1/H)$$

With this function the R^2 was found to be .82, the significant characteristics being the same as in the linear case.

FIGURE 5. COMPARISON OF LINEAR AND LOG-LOG-INVERSE FORMS



Since the linear form explains nearly as much of the variation as the nonlinear form, and as it is considerably easier to work with, it was selected as the final model.

Effect of Individual Characteristics on Calibration Intercept and Slope

The impact of each characteristic on the heart rate-oxygen relationship can be seen in Table 2. Among occupational groups, for instance, the regression coefficients for slope range from .0338 for sedentary workers to .0389 for carabao plowmen. In other words, a carabao plowman takes in an additional .0389 liters of oxygen per minute for each beat increase in heart rate, while a sedentary worker draws only .0338, sex, height and weight being equal. Although such differences appear unimpressive, their cumulative impact is apparent in Figure 6.

Here we see the mean slopes of the four occupational groups with physical factors held constant.[4/] The steep slope of the carabao plowman suggests he is more "efficient" (burns more oxygen with fewer heart beats) than individuals in the other groups. Assuming that average basal metabolic rate for Filipino males is about .2 liter per minute, the slope also suggests that plowmen begin their work from a much slower resting heart rate than other workers. Indeed, it seems quite likely that it is the effect of physical conditioning, not occupation *per se*, which is here demonstrated. Surely chasing a water buffalo through thigh-deep mud develops greater stamina than planting rice or shuffling papers.

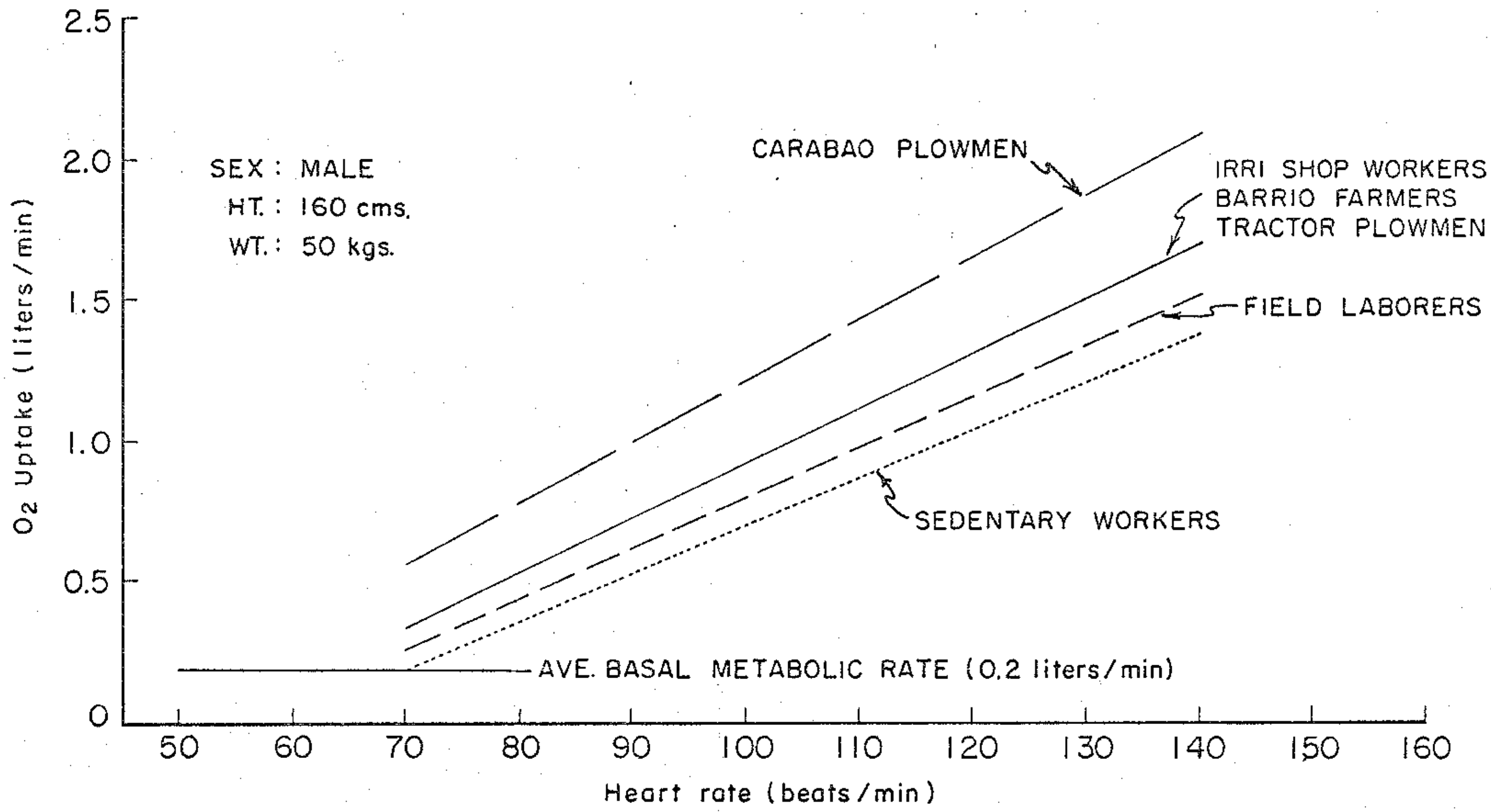
4/ In Figure 6, as in subsequent figures, the constant factors have been arbitrarily specified. However, 160 cms. and 50 kgs. do approximate the mean of our sample.

TABLE 2. COEFFICIENTS AND t-VALUES OF SIGNIFICANT CALIBRATION VARIABLES

Variables	Regression Coefficient	t-Value
Intercept:		
Sex	0.28603	2.4023
Weight	-0.02121	-3.4497
Constant	0.06040	0.1839
Slope:*		
Sex	-0.00579	-5.0510
Weight	-0.00144	-4.0720
Height	-0.00099	-4.6542
Surface Area	0.14240	4.8368
Occupation		
Field Laborer	0.03465	4.1913
Carabao Plowman	0.03887	4.6898
Sedentary Worker	0.03375	4.0689
Barrio Farmer, Tractor Plowman, IRRI Shop Worker	0.03590	4.3462
n = 100		
R^2 = .7970		

* Represents Δ liters of oxygen/one beat Δ heart rate.

FIGURE 6. MEAN SLOPES OF OCCUPATIONAL GROUPS; OTHER THINGS BEING EQUAL



Sex is also a key determinant of the heart rate-oxygen relationship. The negative regression coefficient (Table 2) indicates that women tend to have a flatter slope than men. (Recalling our dummy variable, the coefficient is multiplied by 1 in the case of women, by 0 in the case of men.) The effect is demonstrated graphically in Figure 7, where it is apparent that men take in more oxygen at every level of heart rate than do women of the same size and occupation.

Finally, the impact of physical size can be seen in Figure 8. Although both weight and height have negative coefficients, their impact is offset by the strongly positive coefficient for surface area. The end result, other things being equal, is that large people demand more oxygen at each level of heart rate than do smaller ones.

The Nature of The Confidence Bands

Figures 6, 7 and 8--though demonstrating the affect of physical and occupational variables--show only simple means. Of considerably greater interest is the variance around these means. Is it, in fact, possible to generate slopes for individuals of specific sex, size and occupation with a high degree of accuracy? If so, reliance on the rather uncomfortable calibration procedure might be reduced.

To determine the answer, confidence bands were constructed about the means of several hypothetical individuals. Figure 9, for example, shows the mean slope for a 160 cm.,50 kg. male living in a barrio near Los Banos. In this case, the (.99) confidence band is so narrow that the slope is functional for all practical purposes. At a working heart

FIGURE 7. MEAN SLOPES OF MALES AND FEMALES; OTHER THINGS BEING EQUAL

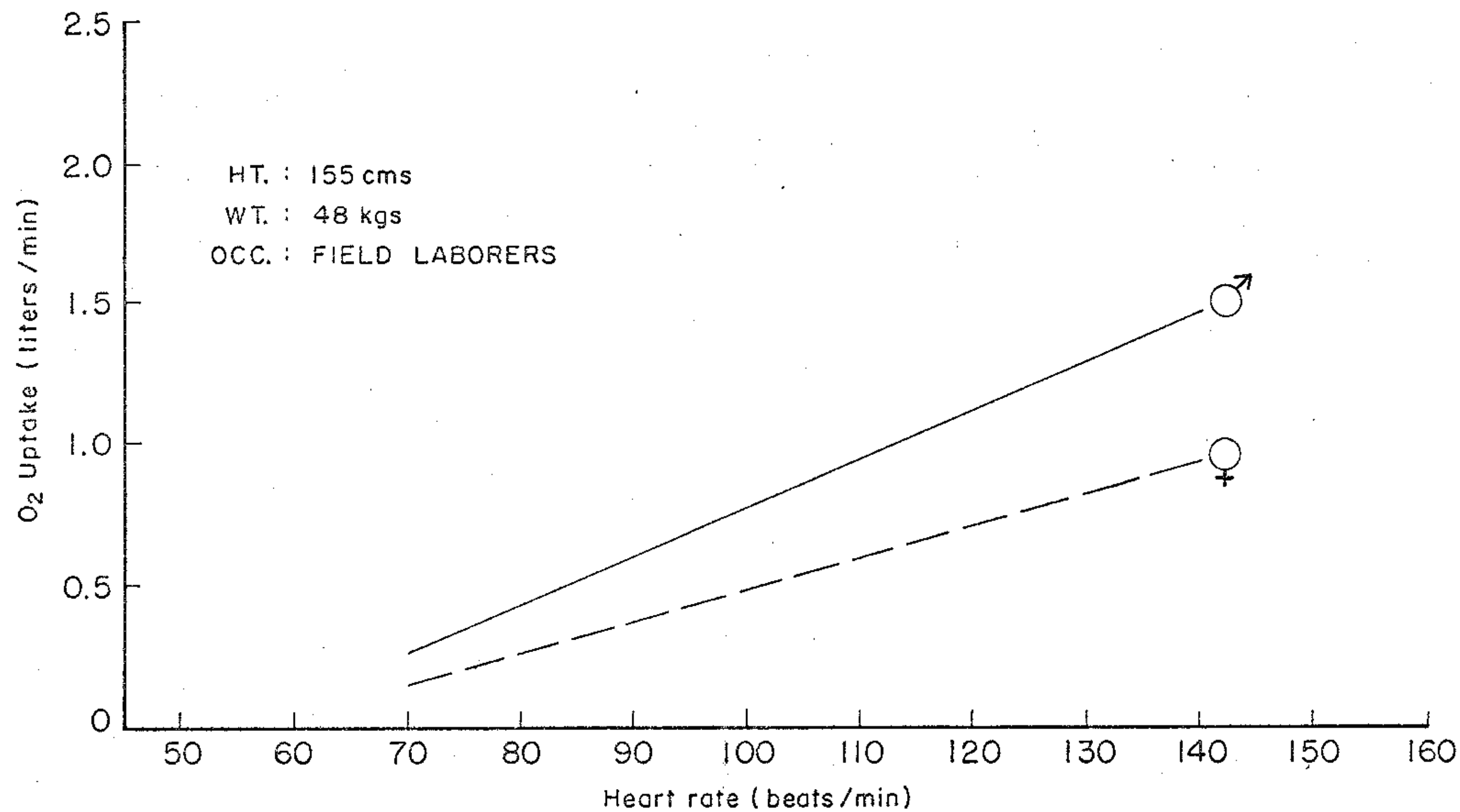


FIGURE 8. MEAN SLOPE ADJUSTED TO PHYSICAL SIZE; OTHER THINGS BEING EQUAL

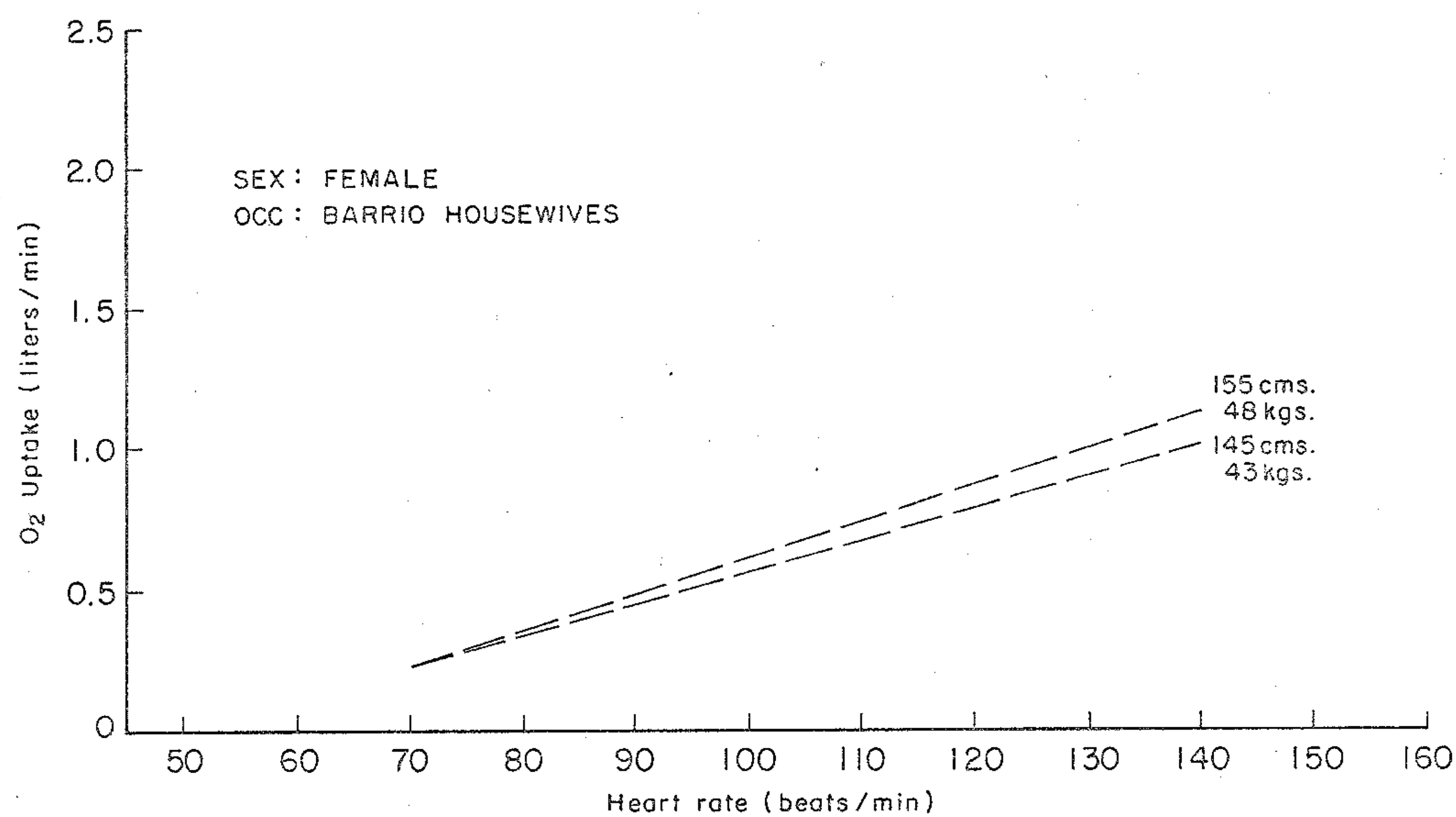
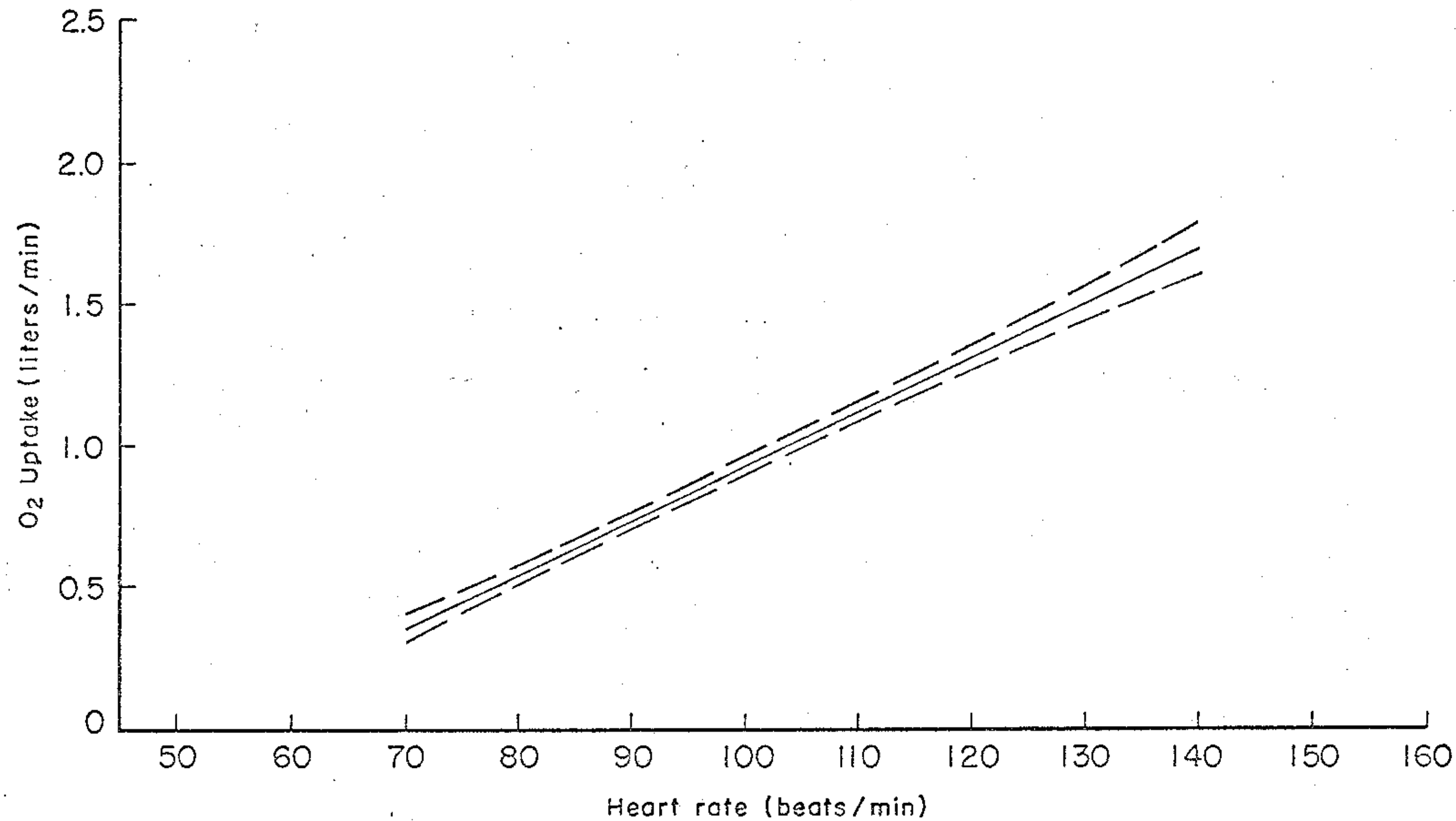


FIGURE 9. (.99) CONFIDENCE BAND FOR A 160cm/50kg BARRIO FARMER



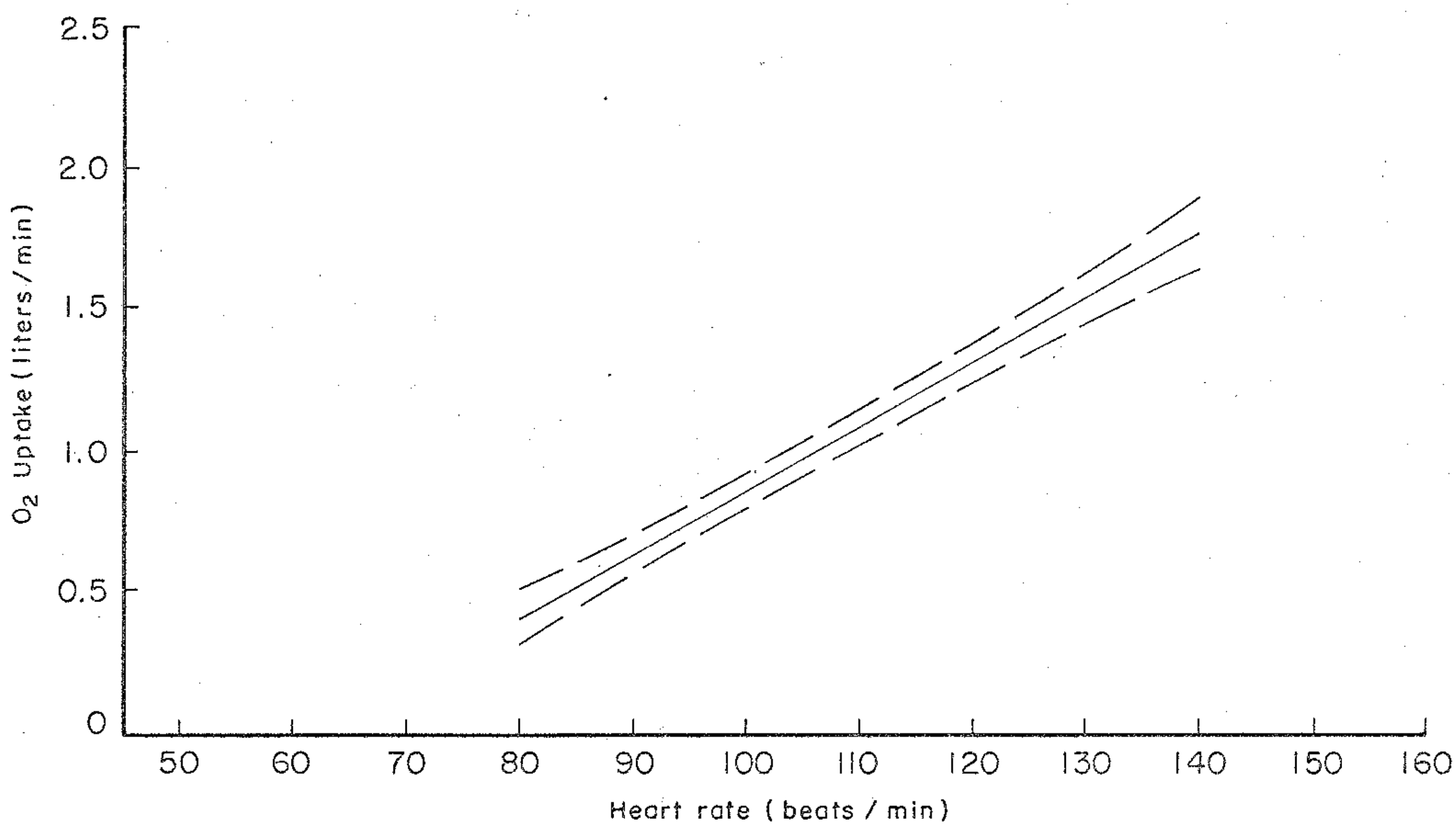
rate of 100 beats per minute the width of the interval represents fewer than 220 Calories per day.5/

The precision with which slopes for barrio males can be predicted is no doubt helped by the large proportion of the sample falling within this category (n=37). Functional bands can also be drawn for male field laborers (n=17), female field laborers (n=13), and barrio women (n=11). Fewer individuals, of perhaps greater variability, were calibrated in several of the other groups. Figure 10 illustrates a mean slope for sedentary males (n=5). Even with a (.95) confidence band, the variability is much greater than for barrio males.

What may be concluded is that calibration data can be employed to statistically generate the heart rate-oxygen relationship for additional subjects. The adequacy of such slopes is, to a great extent, dependent on the size of the base sample and the evenness of physical conditioning. Thus among barrio males, whose occupation generally implies a high level of physical conditioning, a sample of perhaps two score would suffice, while the sample required for sedentary males, whose physical conditioning may vary greatly, might be so large as to dictate individual calibration.

5/ At (.95), 165 Calories.

FIGURE 10. (.95) CONFIDENCE BAND FOR A 175cm/70kg SEDENTARY WORKER



CHAPTER IV. THE LOS BANOS STUDY

The first extensive application of SAMIs in low-income countries was made in and around Los Banos, a municipality in Laguna Province, Southern Luzon. Although originally famed for its medicinal waters, Los Banos is perhaps better known as a rich, rice-growing region. It is also the site of two important educational and research facilities: the International Rice Research Institute, and the University of the Philippines College of Agriculture.

The four-month Los Banos study consisted of two parts. Part 1, what might be called the "macro" phase, involved the measurement of general activity levels in nearby barrios. Most of the equipment and human resources were directed to this effort. The second part, the "micro" phase, centered on measuring the efficiency of various techniques for performing specific agricultural tasks. This work was done entirely at the IRRI test plots.

The Macro Phase

This phase was carried out in association with the Food and Nutrition Research Center (FNRC), National Institute of Science and Technology, Manila. To examine the impact of seasonality and agricultural regime on energy patterns, five barrios within 20 miles of Los Banos were selected for study. Two--Labuin and Masiit--are located on lowland, irrigated tracts. Paddy is double-cropped in both barrios, and virtually no other crops are grown. The two upland barrios have more varied rotations: Putho farmers grow rice during the monsoon, and sow maize or vegetables in the dry season; in Perez, paddy and maize are alternately intercropped with pineapple, which usually requires 20 months to mature. The fifth barrio, Sto. Tomas, offers a modified slash-and-burn regime. The shifting cultivation of vegetables, rice, and roots on the mountainside is supplemented by coconut production and seasonal cane harvesting.

The selection of cooperators in the five barrios was done in a quasi-random fashion. In most instances the barrio captain was contacted and a public meeting held to explain the study to villagers. Among those who volunteered, an effort was made to select only those primarily engaged in farming. Preference was also given to family groups in order to facilitate the application of equipment. All cooperators received a tailored jacket with pockets designed to keep the SAMI dry.[1/] Each was also paid three pesos ($.50) for every day he/she participated.

In all, 49 villagers were selected: 17 from Labuin (split into two groups), and 8 from each of the other four barrios. Thus 25 cooperators were on double-cropped irrigated land, 16 on upland, and 8 practiced

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1/ Though the SAMIs were kept dry, the participants were a different matter. The tailor, in his haste to finish the jackets, neglected to preshrink some of the material. On subsequent visits we found farmers buttoning cuffs near their elbows. The shrinking sizes were, to a degree, offset by an increased price. Though originally quoted at ₱14.50 each, the jackets finally cost nearly ₱20.00 --a cost overrun sufficient to make the Pentagon wince. In the spirit of social acceptability customary to SAMI work the jackets were given appropriate acronyms: SARONGs (Rainment or Native Garment) for the women; SADISTs (Dress in Sticky Terrain) for the male participants.

shifting (kaingin) agriculture. The sample contained 29 men, 7 women, and 13 youths under the age of 17.[2/]

Actual monitoring ran 14 weeks, with each of the six groups sampled once a week on a randomly selected day. SAMIs were generally placed on the subjects at about 7 a.m. and removed near 5 p.m. The average sampling period was nine hours, 50 minutes.

In view of the pilot nature of the investigation, a cross-check in the form of a traditional consumption survey was undertaken. FNRC technicians weighed and analyzed food eaten by the cooperator each day he/she wore the SAMI. Though theoretically unnecessary, an activity diary for each person was also kept.

The calibrating process, being the most unpleasant aspect of SAMI technology, was put off until six weeks after monitoring had begun. It was hoped that by this time the cooperators would have had sufficient experience with the SAMI and enough confidence in field personnel to undergo the process with a minimum of stress.

The Micro Phase

The second major aspect of the study was to get a clearer notion of the energy cost of various farm operations. This phase was conducted jointly with economists and engineers at IRRI, who were particularly interested in understanding labor use under alternative levels of technology.

2/ A general physical checkup, with particular attention to cardiac problems, was required for each volunteer. A surprisingly large number (22 percent) failed this examination, there being heart murmers and other damage attributed to rheumatic fever. Another six percent were dropped due to pregnancy.

The original plan was to evaluate most of the tasks and technologies shown in Table 3. They involve all major farm operations and 20 different technologies. All trials used day laborers and permanent employees of the IRRI shop, and ranged in length from 10 minutes (in the case of winnowing) to more than two hours. Because of the nature of the monitoring equipment efforts were made to make the trials as long as possible.3/ But some operations and technologies made this difficult. Monitoring began at the field's edge, and did not include rest periods exceeding two or three minutes. Oxygen readings were occasionally made with the respirometer as a cross-check on the SAMI results.

The Resource Requirements

During the course of the study, nine people worked in the field on a full-time basis. Four FNRC technicians were in the barrios throughout each day, attaching and detaching the SAMIs, doing the consumption survey, and keeping activity records. At the Institute, one FNRC technician, three IRRI research associates and the author were involved in the efficiency trials and the calibration of all participants.

3/ Long trials are preferred because E-cells, after being cleared, may accumulate a few counts en route to the field. When the period to be monitored is 8-10 hours, as it was in the barrios, the effect of spurious charges on the final result is negligible. However, when the trials are short, distortions may occur.

An effort was made in the Philippines to determine the spuriousness of individual E-cells. Kept in an air-conditioned room and cleared by the replay machine every 24 hours, we found accumulations of one to twenty counts. These accumulations varied from day to day, with some cells being much more consistent than others. Of greater consequence was the effect heat and humidity appeared to have. On several occasions cells were cleared, then not used in the field. Brought back to IRRI 30-60 minutes later, they showed accumulations of up to 30 counts (the equivalent of 900 beats). E-cells, after being inserted in a SAMI, are protected from these charges.

TABLE 3. PROPOSED ENERGY MEASUREMENT TRIALS FOR SPECIFIED TASKS IN RICE PRODUCTION

Task	Operation Alternatives	Data to be Measured
Plowing	1. Tractor 2. Carabao	Cal./hectare
Harrowing	1. Tractor 2. Carabao	Cal./ha.
Planting	1. Manual transplanting (dapog) 2. IRRI row seeder 3. Broadcast seeding	Cal./ha.
Weeding	1. Manual 2. Hand rotary 3. Power rotary 4. Herbicide	Cal./ha.
Harvesting	1. Sickle 2. Hand drop manual harvester	Cal./ha.
Threshing	1. Manual 2. Hampasan (frame) 3. Pedal thresher 4. IRRI table thresher	Cal./ton rice
Winnowing	1. Manual 2. Native winnower 3. IRRI hand winnower	Cal./ton cleaned grain

Major items of equipment included:

15 SAMI HR/3 Monitoring Devices
3 Electrode Placement Test Sets
2 Variable Pulse Generators
2 E-cell Replay Machines
1 Magnetic Tape Recorder
1 Strip Chart Recorder
1 KM Respirometer
1 Electric Gas Analyzer
1 Bicycle Ergometer
4 Food Balances, and
Enough disposable supplies for 3000 applications.

Although sufficient SAMIs were available at the start, not all continued to function.4/ As eight to nine were required in the barrios six days a week, there was often only one or two available for the IRRI field trials.

The heavy schedule of calibrations, barrio visits and IRRI trials also stretched human resources. Little time was available to assess the data as it became known. Nor was leeway available to work out the problems that inevitably accompany the use of a new methodology.

A damaging absence of flexibility is clear by hindsight. Yet what was obvious at the outset was an unparalleled research opportunity. The temptation to exploit this to its fullest in the end proved irresistable.

4/ The principal difficulty was with the potentiometers which were adjusted daily to alter thresholds. Under hot, humid conditions they proved inadequate.

CHAPTER V. THE MACRO PHASE: ESTIMATING RURAL ENERGY EXPENDITURE

To assess the reliability of results obtained with indirect, indirect calorimetry, we must compare our data with other approaches. One check is, of course, the consumption survey--built into the experiment and using the same group of participants. Another possibility is to calculate recommended dietary allowances according to the guidelines of major health or nutrition agencies.

Estimates of Average Caloric Expenditure Among Rural Filipinos

Table 4 compares an estimate derived from SAMI data with consumption survey results and an FAO recommended allowance based on the age, weight, and environment of the 49 cooperators. It is immediately clear that figures provided by the new methodology exceed those of the other two sources, for males significantly so. Several reasons for this discrepancy might be offered.

Giving our methodology the benefit of the doubt, it could be suggested that rural Filipinos are, in fact, move active than the FAO reference man/woman who stands much of the day but does little strenuous work. Judging from participant's diaries this is quite likely. But FAO figures are consciously inflated (35, p. 7) and therefore may accommodate some if not all of this factor. Add in the consumption survey[1] which largely supports FAO estimates and there seems little choice but to conclude that some of the results derived from SAMI data must be considered suspect.

TABLE 4. ALTERNATIVE ESTIMATES OF AVERAGE DAILY CALORIC EXPENDITURE AMONG RURAL FILIPINOS

	Consumption Survey	F A O[2]	SAMI[3]
Male	2252	2645	3759
Female	1895	2073	2169

Overstated Energy Expenditure: The Problem with Resting Heart Rates

Where lies the scope for error in our methodology? One possibility is that the raw data have been improperly evaluated; another is that the crucial heart rate-oxygen-calorie relationship in at least some cases broke down.

1/ Consumption surveys are also not without criticism. They are most often cited for understating actual consumption--neglecting the between meals intake of coconuts, fruit, and other instant snacks.

2/ The FAO recommended allowance assumes "a moderately active" population (1, p. 10).

3/ As SAMIs were used only from 7 a.m. to 5 p.m., this is obviously a constructed mean. First, the average 10-hour SAMI reading for men was determined to be 2866 Calories. Then the average resting rate of the Filipino male (.92 Cal./min.) was multiplied times 8 hours of sleep to add another 443 Calories. An average of daytime and sleeping activity yielded 893 Calories for the remaining 6 hours. In like manner, the female mean was computed starting from a 10-hour SAMI base of 1240.

It will be recalled that the SAMI is capable of storing heart beats in three frequency ranges. This is of value because it permits those beats which occur during rest and at extremely high levels of activity--both of which fall outside the linear heart rate-oxygen relationship--to be isolated and appraised separately. But in retrospect the problems in getting reliable resting heart rates from our cooperators went far toward invalidating the separation.

The basic approach was to take the resting pulse of a participant at least twice each day the SAMI was worn. After three weeks (six pulse readings) the lowest was assumed to be the actual resting rate. SAMIs were then individually adjusted so that only beats faster than 10 above resting, but less than 140 per minute, were recorded in the "M" (linear) cell. Beats above 140, of which there are few, went into the fast cell. If, in subsequent weeks, a lower resting rate was found for an individual, his SAMI was appropriately adjusted.

The importance of getting a reliable resting rate can be seen if we consider an example: assume that a farmer has an actual resting rate of 50 beats per minute and that he spends eight hours of the day resting (it's the slack season) and 2 hours working at an average of 100 beats per minute. His SAMI would show 24,000 beats in the slow range (480 min. X 50 beats per min.) and 12,000 beats in the medium range (120 min. X 100 beats per min.). His actual caloric expenditure would be as follows:

<u>Slow range</u>

480 min.	X	.92 Cal./min. (mean basal rate)	=	441.6 Calories

<u>Medium (linear) range</u>

120 min.	X	4.53 Cal./min. (mean cost to Filipino farmer at 100 beats/min.)	=	543.6 Calories
		TOTAL (10 hours)		985.2 Calories

Now assume that the lowest pulse reading we have for this farmer is 60 beats per minute--10 beats above his actual resting rate. Accepting this rate, we set the SAMI threshold at 70. Assuming the same activity pattern (8 hours of rest and 2 hours of sleep) we again accumulate 24,000 beats in the slow range and 12,000 beats in the medium one. The 12,000 beats were again put in at the rate of 100 per minute, <u>but this, the SAMI data does not reveal</u>. We, in fact, must find a way to determine the average rate in the linear range as a prerequisite to computing actual calories. This would seem possible by estimating the number of minutes in the slow range, subtracting from total minutes, and then dividing beats in the linear range by the remaining time (as was explained in Chapter II). Where true resting rate has been found this works fine. But with assumed heart rate 10 beats per minute over actual resting rate, the results are unfortunate:

$$\frac{24{,}000 \text{ beats}}{65 \text{ beats/min.}} = 369 \text{ minutes in the slow range, or 111 less than actual}$$

(halfway between 60 and 70)

This has profound implications for the linear range. For if 369 of the total 600 minutes were spent in the slow range, the other 231 minutes had to have been spent there.

$$\frac{12,000}{231} = 52 \text{ beats/min.; mean rate in the linear range}$$

This is obviously wrong since only beats at a greater frequency than 70 per minute were suppose to enter this cell. What has happened is that a misjudgment of resting heart rate has confused the time dimension and reduced the average of the linear cell to nonsense. Unfortunately, far too much of the data we collected possessed this problem, casting doubt even where there appeared to be reasonable results.

Estimating Resting Rates

It is becoming common knowledge among doctors, physiologists, and other specialists that there is no such thing as the resting heart rate for a particular individual. Resting rate fluctuates from day to day and within the day depending on the length and nature of the previous night's sleep, psychic stress, fatigue, and a host of other variables. Generally, resting rate tends to be lowest toward the end of sleep, gradually increasing through the day. But despite this variation, there is a rather narrow band of readings for each individual which can properly be considered the true resting rate.

Determining this rate is not easy, particularly among tropical farmers. Such people are active very early in the day, and it must be considered an imposition to ask them to sit quietly for an extended period so the heart rate can fall to a resting level. There is, in fact, considerable evidence that even such physical quiescence will not satisfactorily reduce heart rate. The excitement generated by visitors to the barrio, the demands of small children and animals, and the general anxiety caused by actually taking the pulse all conspire to give abnormal readings.4/

As we will see in Chapter VII, the SAMI has recently been modified to lessen dependence on an accurate resting rate. The "M" cell can now be used as a "timer" for one of the other cells. In this way we can know (rather than derive) the actual minutes spent in the slow range and the linear range as well as the number of heart beats in each.

In our macro study, however, inadequate resting readings did cause a violation of the limits set on the linear cell, i.e., it is simply illogical for a cell receiving frequencies of 70-140 beats per minute to average 52 beats per minute. To salvage the component data, therefore, a makeshift system was devised to free the linear cell from a time constraint imposed by the slow range.

The estimated linear cell rate was conceived as a function of the proportion of beats in each of the three cells.

$$M = f\left(\underset{F'}{\frac{F}{F+M+S}},\ \underset{M'}{\frac{M}{F+M+S}},\ \underset{S'}{\frac{S}{F+M+S}}\right)$$

4/ Some effort was made to get true resting rates by having participants wear the SAMI overnight. However, in roughly half the cases nighttime readings were a bit higher than resting rates obtained during the day. This avenue probably warrants greater exploration under more controlled circumstances.

These fractions were given coefficients such that a large proportion of beats in the fast cell would argue for a higher mean in M than if the bulk of the beats were in the slow cell. For example:

$$M = f\ (.25 + 5/6\ F',\ 1/2\ M',\ .6 - 3/5\ S')$$

The three estimates of M were then evaluated on a weighted basis in order to determine the most appropriate figure.

While this formula did not violate the limits of the linear cell, it did yield some lethargic, if not impossibly low, heart rates in the slow range. A number of different coefficients were in turn tried, but none seemed adequate for the entire range of data. In the end we had no choice but to scrap the component concept and use a simple mean--total heart beats divided by total minutes giving an average heart rate for the entire day. It was in this fashion that the figures in Table 4 were computed.

The necessity of reverting to the grossest statistical measure does not heighten confidence in the final result. It lumps cardiac activity outside the linear range with linear frequencies and in this manner estimates mean oxygen intake for the entire day. Component data would have been preferable--and a frequency distribution of heart rates would have been even more desirable.5/ But it is unfair to pin the problems of our estimate totally upon the inadequacies of the lowly mean. It is to the real culprit that we now turn.

5/ Instruments for measuring this dimension are on the way (Chapter VII).

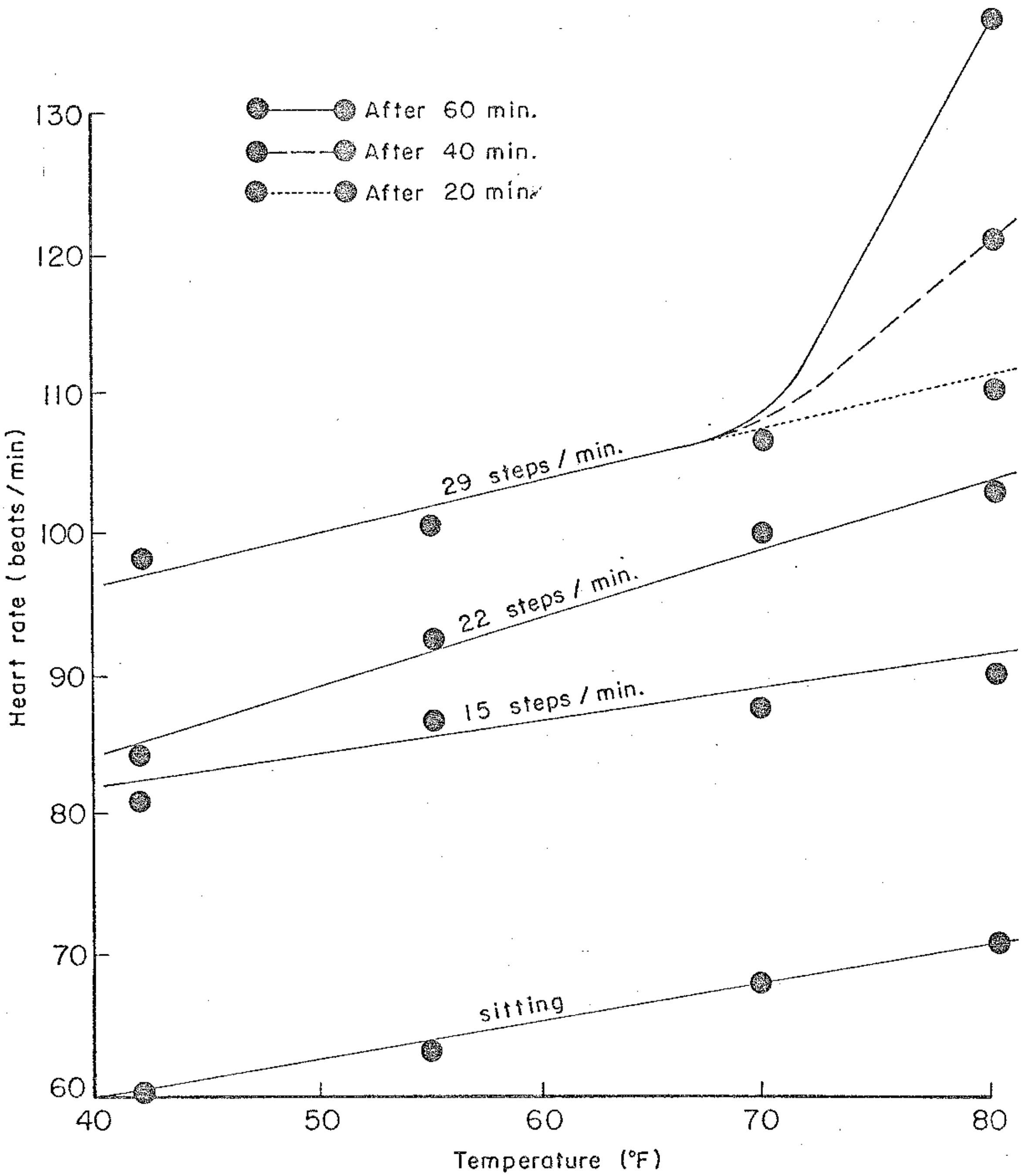
Overstated Energy Expenditure: The Problem with Heat and Durational Stress

A clue to its nature can be found when we compare apparent overstatement for men with that for women. Assuming for a moment that actual energy expenditure lies half way between the FAO recommendation and the consumption survey results, we find our estimate for males more than 50 percent higher, while the estimate for females is off by only 9 percent. This would suggest that there was some condition imposed on men which was generally not encountered by women.

In retrospect, it is clear that this condition was an environmental one. Whereas calibration was performed in an air-conditioned, dehumidified room with liberal rest periods, the tropical farmer's day-to-day existence depends upon his willingness to work under a hot sun, often for fairly long stretches of time. Most women, on the other hand, help in the fields only during peak periods, and spend much of their time indoors where the impact of the tropical sun is greatly reduced. In addition, their work is generally more intermittent.

All this has an effect on the heart rate-oxygen relationship. Research in the area is limited, but indicates that the heat load imposed by a warm environment and extended exertion will increase heart rate faster than oxygen consumption, altering the relationship established under less trying conditions (24, p. 277). The effect can be seen in Figure 11, taken from a study by LeBlanc among military personnel. Here we observe that heart rate rises slowly with increasing temperature. That the calibration slopes themselves shift was demonstrated by Winterhalder and Poleman among U. S. Army reservists in May 1972 (36). Far

FIGURE 11. EFFECT OF AMBIENT TEMPERATURE AND PROLONGED EXERTION ON HEART RATE (Subjects exercising at different rates on a six-inch platform)*



*From LeBlanc, "Use of Heart Rate as an Index of Work Output," <u>Journal of Applied Physiology</u>, Vol. XXVI, No. 3, 1969 (p. 277).

more damaging, however, is the effect of prolonged exertion. At moderately high levels of exercise the heart rate increases sharply after 20 minutes,[6] becoming more and more estranged from the calibrated relationship.

What seems to have happened then is that heat, perhaps humidity, and durational stress combined to give heart rates which resulted in an inflated picture of energy expenditure--particularly for men. Although some error no doubt can be traced to the use of a statistical mean to estimate heart rate, it is most probably to our inability to take into account changing environmental factors that most blame must be attached.

Comparison of Energy Investment Under Three Agricultural Regimes

In spite of problems encountered in accurately quantifying energy expenditure, some distinctions can be made concerning the level of activity under different agricultural regimes. It will be recalled that some of the participants worked lowland, irrigated rice fields while others farmed upland acreages or engaged in slash-and-burn operations. If we can assume the same degree of statistical and environmental error in all heart rate readings, we can use the implied calories as indexes of effort. Employed in this fashion we obtain the readings in Table 5.

Labor investment is greatest on the lowland, irrigated tracts, and least in the upland barrios. A general review of activity diaries bears

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6/ This would seem to be due to internal heat build-up and the onset of fatigue.

this out. Comparing the means through a standard F test we get a statistic of 5.06--significant at the 95 percent level. These distinctions cannot, of course, be considered conclusive as the study encompassed only a quarter of the year. It is perhaps instructive, however, to look at the averages over the 14-week period (Figure 12).

TABLE 5. MEAN ENERGY INVESTMENT UNDER THREE AGRICULTURAL REGIMES

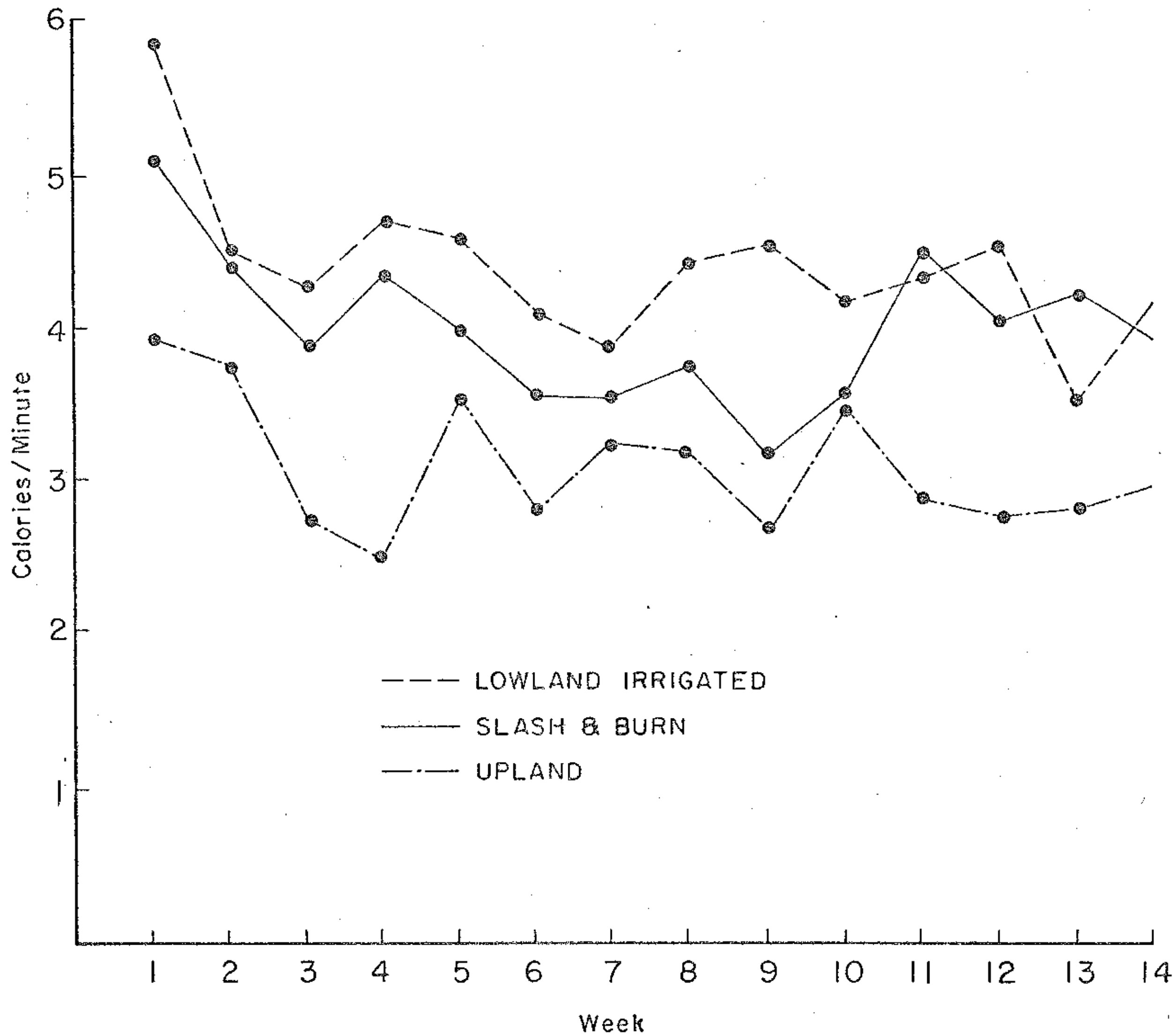
	Lowland Irrigated	Upland	Slash and Burn
Mean Cal./min.	4.50	3.16	4.03
Mean Cal./10-hour day	2,700	1,896	2,418

It is apparent that farmers in the lowland, irrigated areas had a higher energy expenditure throughout almost the entire period. It is likewise apparent that the energy investment of upland farmers was consistently low. The data in Figure 12 are plotted simply in the sequence they were recorded. An effort to correlate the weekly energy means to an agronomic cycle was made, but yielded little: in nearly all barrios there was considerable overlap among agricultural tasks; and activity on a given day was significantly influenced by weather patterns.

The Social Acceptability of the SAMI

Whether unsophisticated peasants would accept the procedure was initially unknown but of obvious importance to the study. Prior to the Philippine experiment, SAMIs had been used mainly in the Western world, chiefly on university students and cardiac patients. And although the

FIGURE 12. ENERGY INVESTMENT UNDER THREE AGRICULTURAL REGIMES: WEEKLY MEANS *



* The inexperience of the technicians and uneasiness of some participants would suggest that the data for the first week might be best ignored.

instrument is much less cumbersome than earlier equipment, it does require a short series of placement tests, minor abrading of the skin, and a calibration away from the barrio.

The SAMIs were well received by nearly all participants. Only one farmer canceled his participation before the end of the study. Murmers of discontent were heard from only two others. Most, in fact, seemed to enjoy the experience. SAMIs and SAMI jackets were conspicuous enough, however, that most cooperators shed them before going to nearby towns--not to mention weddings, funerals, and other major events.

CHAPTER VI. THE MICRO PHASE: MEASURING THE EFFICIENCY OF ALTERNATIVE TECHNOLOGIES

The trials conducted on IRRI plots were designed to determine the labor requirements of major tasks in paddy rice production under several different technologies. Due to breakdowns of the monitoring equipment, it was not possible to examine all the technologies listed in Table 3 (Chapter IV), nor to conduct as many repetitions as desired. Nonetheless, some trials were run on each of the major farm operations.

Unlike the macro phase, only one cell ("A") was used in the IRRI study. This was because trials began at field's edge and stopped when the cooperators ceased working. Thus we could assume virtually all activity to be in the linear range and use a simple average to estimate oxygen.

Tables 6 through 9 summarize the results. Though subject to the same environmental distortions discussed in Chapter V, the effect may not be consistent since the length of the trials varied--most lasting about two hours, but a few for as little as 10 minutes.

Energy Costs of Land Preparation

The two basic tasks of land preparation are plowing and harrowing. Table 6a indicates that the stress involved in plowing seems to be similar for both carabao and tractor plowmen. However, the greater speed of the hand tractor sharply reduces total effort per hectare.

TABLE 6a. ENERGY COSTS OF LAND PREPARATION ALTERNATIVES: PLOWING

Coop-erator	Carabao Cal./Min.	Carabao Man-Min. per Ha.[1/]	Carabao Cal./Ha.	Hand Tractor Cal./Min.	Hand Tractor Man-Min. per Ha.	Hand Tractor Cal./Ha.
1	3.74	2,784	10,412	3.99	812	3,240
2	5.17	2,784	14,393			
Ave.	4.46	2,784	12,405	3.99	812	3,240

With so few trials it would be pointless to attempt statistical analysis. Human variability is so great, even from the standpoint of basal metabolism, that two men can be doing the same work under the same conditions at very different energy costs. In order to get a meaningful average in situations such as this, a larger sample is needed.

In the case of harrowing (Table 6b), there is some indication that the per minute energy cost is greater for the tractor operator. Here as in plowing, however, the speed of the tractor results in much lower total energy cost. This margin would be doubled by the common belief that one tractor harrowing is worth two by a carabao.

1/ In this, as in several subsequent tables, the man-minute/hectare figure may be identical for two or more individuals. This is because in some trials more than one individual was involved. Though the calorie expenditure can be separated through the use of two SAMIs, it is far more difficult to ascertain the area covered by each man. Thus calories/hectare is determined by multiplying the same total man-minutes by individual energy costs.

TABLE 6b. ENERGY COSTS OF LAND PREPARATION ALTERNATIVES: HARROWING

Cooperator	Carabao Cal./Min.	Carabao Man-Min. per Ha.	Carabao Cal./Ha.	Hand Tractor Cal./Min.	Hand Tractor Man-Min. per Ha.	Hand Tractor Cal./Ha.
1	4.77	840	4,007	4.77	225	1,073
2	3.40	840	2,856	6.89	210	1,447
3	4.03	1,127	4,542	3.94	302	1,190
4	3.49	1,127	3,933			
Ave.	3.92	984	3,835	5.20	246	1,237

Energy Costs of Seeding

In contrast to land preparation, the stress of seeding appears to differ markedly depending on the technology used (Table 7). The two transplanting trials involved seven and four laborers respectively, the findings for whom are averaged for each group. The data indicate that transplanting is only half as taxing as hand broadcasting. While at first glance this might seem unlikely, it should be recognized that whereas transplanters mainly stand and stoop, broadcasters must walk through rather deep mud at a moderate pace.

Much more taxing than either transplanting or broadcasting is the mechanical seeder, an experimental hand-drawn aluminum implement which plants eight rows at a time. Indeed the mechanical seeder seemed to require more effort (10.5 Cal./min.) than any other task and technology tested. The draft is so great that there is some discussion about modifying the implement.

Column three indicates that both mechanical seeding and broadcasting are far less demanding than transplanting from the standpoint of calories per hectare. These technologies, however, are not strictly comparable. The jobs of land preparation and water control need much more attention when land is directly seeded. On the other hand, transplanting necessitates a nursery, the cost of which is not included in the table.

TABLE 7. ENERGY COSTS OF SEEDING ALTERNATIVES

	Cal./Min.	Man-Min./Ha.	Cal./Ha.
Transplanting			
(Ave., 7 laborers)	3.00	6,792	20,376
(Ave., 4 laborers)	3.31	5,538	18,331
Average	3.16	6,165	19,354
Broadcasting			
(1 laborer)	6.74	187	1,260
Mechanical			
(1 laborer)	10.58	220	2,328
(1 laborer)	10.53	285	3,001
Average	10.56	253	2,665

Energy Costs of Weeding

Table 8 summarizes the caloric cost of weeding using four alternative methods. There seems to be little difference in the effort required by the various technologies. Great differences are, however, apparent in the total cost per hectare. This again is a reflection of the time needed to complete the task.[2/]

TABLE 8. ENERGY COSTS OF WEEDING ALTERNATIVES

	Cooperator	Cal./Min.	Man-Min./Ha.	Cal./Ha.
Hand				
	1	6.84	4,610	31,531
	2	5.31	4,747	25,205
	Ave.	6.08	4,679	28,368
Rotary				
	1	6.99	1,826	12,755
	2	5.71	1,750	9,993
	Ave.	6.35	1,788	11,374
Power				
	1	7.63	609	4,647
	2	7.87	812	6,390
	Ave.	7.75	711	5,519
Herbicide				
	1	6.84	86	588
	2	6.00	114	684
	3	8.71	69	601
	4	5.85	91	534
	Ave.	6.85	90	602

Energy Costs of Harvesting

Harvest consists largely of four tasks: the cutting of the standing grain; hauling it from the field and piling it in a place suitable for threshing; the actual threshing; and winnowing. Measurement of all these

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2/ As in other operations, the effectiveness of these methods may vary. Although it is possible to weigh the weeds left at harvest, it is indeed difficult to scale the impact of the treatment to the energy cost of applying it.

tasks was hampered by the unevenness in yields due to an attack of tungro virus on the IRRI plots during the sampling period. For example, the straw output of a diseased field is likely not as severely reduced as grain yield. Thus on a calorie-per-ton basis, the energy cost of threshing a devastated field is much greater than for a bumper crop.

The results of the cutting, hauling, and piling tasks are summarized in Table 9a. Cutting was all done by use of a sickle, and of course manually hauled and piled. Man-minutes per hectare varied sharply according to the crop's stand, and these are reflected in the total calorie figures. Four trials with the respirometer yielded an average 5.56 Calories per minute as against the 4.69 Calories derived from SAMI data.

TABLE 9a. ENERGY COSTS OF HARVESTING: CUTTING, HAULING, AND PILING

	Cooperator	Cal./Min.	Man-Min./Ha.	Cal./Ha.
Cutting (sickle)				
	1	5.28	2,680	14,150
	2	3.78	5,132	19,399
	3	4.10	6,356	26,060
	4	4.89	4,192	20,499
	5	5.38	2,868	15,430
	Ave.	4.69	4,245	19,108
Hauling-Piling				
	1	5.07	592	3,001
	2	5.32	3,242	17,247
	3	5.36	2,207	11,830
	4	4.87	2,898	14,113
	Ave.3/	5.18	2,782	14,397

3/ This excludes the first observation, made on a severely damaged field in which most of the grainless straw was left standing.

Table 9b indicates the results of the threshing trials. Two systems of threshing were considered: 1) the traditional method of beating bundles of the cut plant against a wooden frame (hampasan); and 2) the use of an implement developed at IRRI which employs a jaded wheel powered by a motor. The data show the IRRI table thresher to be only slightly less strenuous than the traditional system. This is intuitively puzzling, and leads to the notion that perhaps the use of this equipment--a bit strange to our cooperators--may have raised heart rate above physiological requirements.

Respirometer trials were conducted on the frame thresher with an average reading of 5.48, again slightly higher than the SAMI results. The grain weight in all trials was adjusted to 14 percent moisture. But because of the variability in yields, the calorie per hectare figures are virtually meaningless.

TABLE 9b. ENERGY COSTS OF HARVESTING: THRESHING ALTERNATIVES

	Cal./Min.	Man-Min./Ton	Cal./Ton
Table thresher			
(Ave., 4 laborers)	3.73	884	3,297
(Ave., 3 laborers)	4.36	2,666	11,624
Average	4.05	1,775	7,461
Frame threshing "Hampasan"			
(Ave., 3 laborers)	5.20	980	5,096
(Ave., 4 laborers)	5.28	2,698	14,245
(Ave., 4 laborers)	3.96	1,983	7,853
Average	4.81	1,887	9,065

Several trials were conducted on two different systems of winnowing, but no meaningful results were obtained.

Applications of Energy Cost Data

Although problems of disease and smallness of sample preclude use of our data for labor budgetry exercises, the applicability of the methodology seems clear. Governments committed to reducing unemployment must in the future evaluate investment alternatives in terms of employment generation as well as yield maximization. From extensive trials of this nature, tables linking labor utilization with a wide range of technologies--and combinations of technologies--could be constructed; and from such tables it would seem possible to work toward the creation of optimum labor-land ratios at different levels of technical input. One could, in short, determine the labor-use elasticities associated with alternative development strategies.

CHAPTER VII. HELP IS ON THE WAY

We have learned a lot about the tropical farmer since World War II. We know his life expectancy, income, and level of education. We know what crop varieties he sows, the amount of fertilizer he applies, and the harvest he reaps. His soil has been classified, his social order stratified, and his creditors vilified. Yet we know painfully little about the pace of his day to day existence.

Both nutritionists and economists need such information, and in their own ways have set about getting it. Nutritionists, out to refine caloric standards, have wrestled with the stop watch-diary-KM techniques. Its drawbacks, however, have only sustained the popularity of the consumption survey.

Economists, on the other hand, want to understand labor use. Questionnaires have been devised to expose the work calendar; production theory has been deployed to ferret out "disguised" unemployment. But these techniques often seem culture-bound. They have, at any rate, been unable to substantially enhance our knowledge of activity levels in the rural tropics.

This is not to suggest that questionnaires, traditional theory, activity diaries and food balances should be abandoned. What does seem apparent, however, is the ample scope for new techniques. The use of physiological tools and relationships would appear to be a reasonable approach to the problem, and it was in this spirit that the Los Banos study was conceived.

The Philippine experience identified the major strengths and weaknesses of the methodology:

1. The SAMI seems to be socially acceptable.

While this may appear to be of small consequence, it is not. No energy monitoring system can be effective if it is uncomfortable and/or embarrassing to wear. And earlier devices--from the mask over the face to the antenna up the back--were just that.

The SAMI, however, encourages normal behavior--a prerequisite to accurate energy study. Within minutes after being placed in the pocket it is generally forgotten. It does not hinder the performance of any task, it is concealed from the public view, and it allows us to record activity in circumstances unaccessible to the technician.

2. The heart rate-oxygen relationship appears to be linked to physical and occupational variables.

It has been known for some time that the heart rate-oxygen relationship is unique to each individual. Analysis of the slopes of 100 calibrated Filipinos indicates that the nature of this relationship can be largely explained by a few physical and occupational variables. When occupation is such as to imply a uniform level of physical conditioning, height, weight, sex, and occupation yield a slope the confidence bands about which are surprisingly narrow.

The significance of this is that once regression coefficients are established for a particular group of tropical farmers, accurate heart rate-oxygen slopes can be generated for their neighbors without putting them through the calibration process. This would permit a much broader sampling of the population as well as eliminate the least comfortable aspect of the methodology.

3. Indirect, indirect calorimetry, as tested in the Philippines, is an inadequate indicator of physical activity.

There is no question that the methodology overstated the energy expenditure of the Filipino male. The more reasonable results from Filipino women and data from several independent studies suggest that the major reason was a shift in the heart rate-oxygen relationship which the monitoring devices were unable to take into account. As external temperatures rise there is a quickening of the heart rate without a corresponding increase in oxygen uptake. This effect is aggravated if work continues for long, uninterrupted periods.

Contributing to the misstatement of energy expenditure was our inability to get reliable resting rates from which average heart rates in the linear cell could be computed. Even where resting rate is known, however, there is an unavoidable margin for error when the simple mean must be used as an estimator of oxygen for all time spent in the linear range.

Both these problems were compounded in short trials by a basic mechanical problem. The small electrochemical cells which the SAMI system uses to count electrical impulses given off by the heart can also accumulate charges while laying in a drawer or carried in hand. Although the number of charges accumulated in this fashion are of little consequence in a 10-hour trial, they may be extremely misleading in a 10 or 20 minute test.

Fortunately all these problems are amenable to solution. A modification to the SAMI known as the "Garrow Specification" greatly lessens dependence on a reliable resting rate. Illustrated in Figure 13, it has the "A" cell collect all beats as before, but alters the responsibility of the "F" and "M" cells. "F" collects all beats above the lower threshold (adjustable from 70 to 120 beats), while "M", acting as a timer, monitors the total minutes in this range. Thus the average rates in the linear and sub-linear cells can be computed with precision. In the process the upper threshold is eliminated, but as we have seen, this is hardly a significant loss.

An instrument with even greater promise is the SATR,[1/] a miniature cassette recorder which samples heart rate at one-minute intervals. Deployed in prototype stage among farmers in Ceylon in Summer 1972, the SATR not only eliminates E-cells with their bothersome spurious charges, but yields a frequency distribution of heart rate which will serve more accurately than averages as an indicator of oxygen uptake.

With mechanical and statistical problems largely solved, there remains the distortion of physiological relationships caused by heat and durational stress. In its present prototype the SATR will accept up to three inputs and can be modified to receive up to six. Sensors exist to record ambient and skin temperature, and work is in hand on one to reflect posture. Monitored simultaneously with heart rate, these

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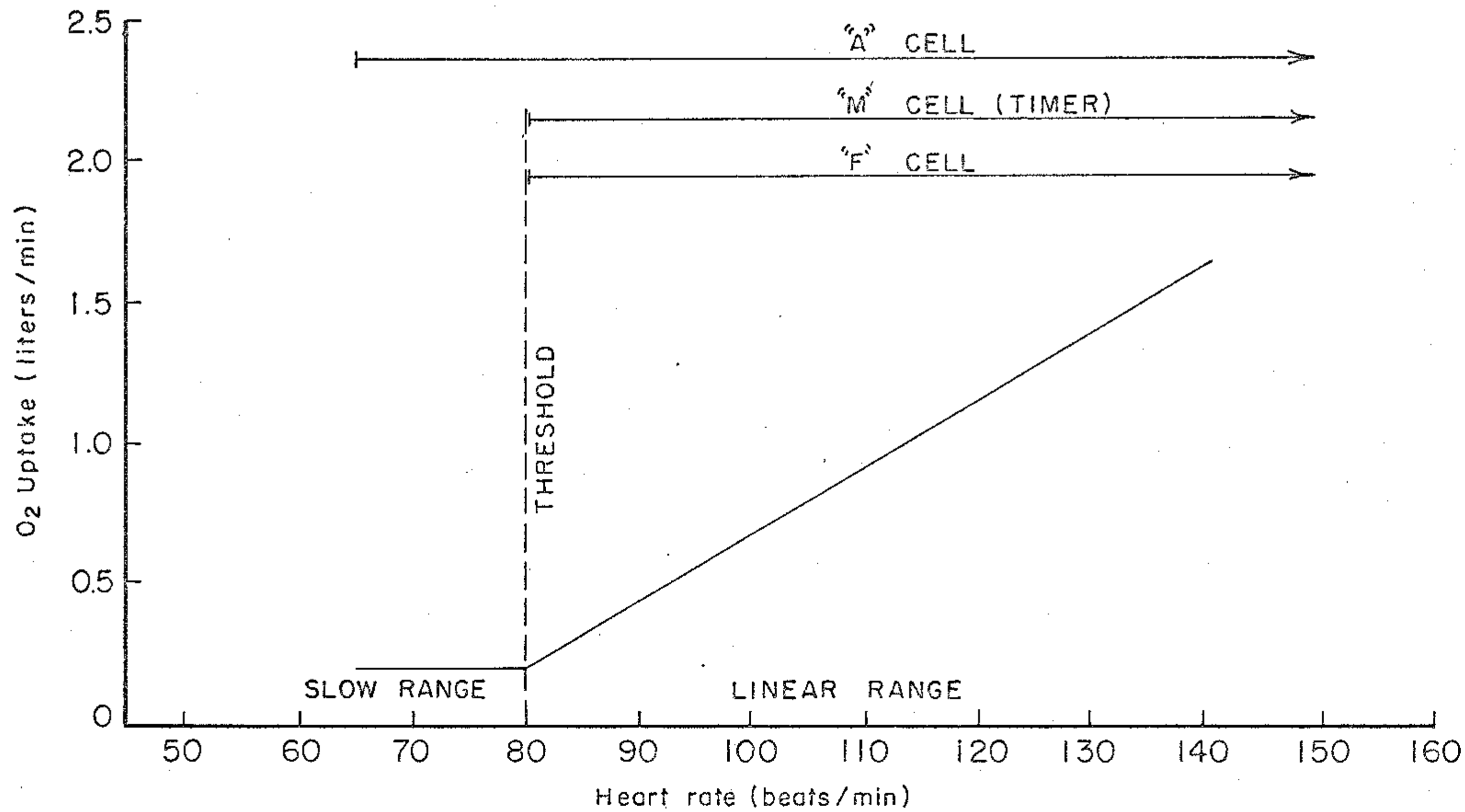
1/ Socially Acceptable Tape Recorder, again the brainchild of H. S. Wolff.

FIGURE 13. SIMPLIFIED HEART RATE - OXYGEN RELATIONSHIP INDICATING REGIONS RECORDED BY EACH E-CELL: GARROW MODIFIED SAMI



may well enable the investigator to distinguish between work-related heart beats and those stemming from environmental factors. If they do not, it may prove necessary to discard the Calorie as the unit of activity. The SATR opens up the possibility of substituting percent increase over resting rate or some other measure of stress.

What seems clear at this point is that a knowledge of physical activity in the low-income world will be of increasing importance. The development of techniques which are able to measure it cannot be overemphasized.

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