A PORTABLE UNIT FOR ANTHROPOLOGICAL RESEARCH ON HUMAN ENERGY EXPENDITURES*

Edward Montgomery
Department of Anthropology
Washington University
Saint Louis, Missouri

Abstract:
This article describes a lightweight, portable unit which can be used by anthropologists in field studies to obtain data on human caloric expenditures. Human energetics data are in growing demand and the unit here described permits efficient collection and rapid analysis of caloric expenditures in even the most remote research situations. The entire unit consisting of a backpack respirometer and a fuel-cell powered oxygen analyzer with the spares and accessories can be fitted into a small carrying kit at a total weight of under 25 pounds. The use of the unit and the analysis of the data are also discussed.

With the growth of anthropological interest in ecology and nutrition, there has been an increasing concern with human energy utilization. The caloric values of human energetics equations---food, activity, and the products of activity---have become desired data, and yet, lacking adequate reference standards for most of the world's populations, anthropologists have been unable to move ahead quickly with their efforts to build or test models of human energetics. Most efforts have been confined to estimating the caloric values of diets and foods produced. Anthropological use of estimates of caloric outputs are far fewer in number, and nearly all studies to date have relied upon calculations of activity-specific energy expenditures from other populations as reference standards (e.g., Rappaport 1967, Lee 1969, Gross and Underwood 197l). Besides the critical importance of energy expenditure data for understanding human activity in context, such data are urgently needed to better assess human food needs (Durnin, Edholm, Miller, and Waterlow 1973). It is now feasible to measure energy expenditures in field situations, and the remainder of this article describes a portable unity which can be used in anthropological research.

There are three basic steps in calculating energy expenditures, (1) measurement of the quantity of air used in a known period of time, (2) determination of the quantity of oxygen consumed in that volume of air, and (3) conversion of that volume of consumed oxygen to kilocalories. The first two steps require instrumentation (a gas metering device and a gas analysis apparatus) and the third can be accomplished much more efficiently with the aid of a calculator. The portability of the equipment is thus a decisive factor in conducting field studies. Physiologists and nutritionists in their many decades of research on human pulmonary function and energy metabolism have developed increasingly more convenient methods for the measurement of gas volumes, but until recently the available methods for gas analyses could be done only in a laboratory. The laboratory procedures have been well-described by Consolazio, Johnson, and Pecora (1963), and the history of physiological research on human energetics through the mid-1960s has been clearly summarized by Durnin and Passmore (1967).

A Portable Unit for Field Studies

In field research, the volume of air used by a person can be conveniently measured with a Max Planck Respiration Gas Meter. This small, compact, lightweight backpack respirometer was developed by physiologists at the Max Planck Institute for Work Physiology, Dortmund, West Germany. It combines a gas volume meter and a sampling device for continuous sampling of each breath of expired air. The presently available version (Model 59) comes equipped with a rubber mouthpiece, a low resistance two-way respiratory valve, a corrugated rubber connecting tube, a rubber nose clip, a two-liter rubber bladder for collection of the sampled expired air, and a pair of shoulder straps.** This instrument weighs only 8 1/2 pounds and is 4 3/4" x 7 3/4" x 10 5/8" in size. The shoulder straps are adjustable so that it can be comfortably worn without restricting arm or trunk movements. It has been shown that the energy costs of wearing it do not differ significantly from those without it (Consolazio, Johnson, and Percora, 1963, pp. 46-47). The gas meter has an on/off tap for starting and stopping the metering and sampling, and it has a sampling selection tap to permit either 0.3% or 0.6% sampling. With a two-liter rubber bladder, and given that respiration rates for about 6 to 50 liters per minute are likely to be observed depending upon the activity and size of the person being tested, sample at the 0.3% or 0.6% rate can be done for periods of up to 13 to 110 minutes or 6 to 55 minutes, respectively. The exact time periods of respiration measurements can be recorded with a good stopwatch, preferably one capable of 30 minute timings. Breathing through the mouthpiece while wearing a nose clip can be learned quickly, and most individuals rapidly adjust to using the respirometer. The advantages of this unit over the Douglas bag method and the use of meteorological balloons are several. The respirometer is lighter and has been found to be less cumbersome (Durnin and Passmore 1967, pp. 20-21). The rubber sampling bladder can be directly fitted to the oxygen analyzer, thereby eliminating the transfer of expired air samples in glass gas-tight syringes. Also, the respirometer permits the continuous metering of activities of even considerable duration while the rubber sampling bladders are changed or removed as is necessary. In contrast, the fixed volumes of the Douglas bag and weather balloons (maximum capacities, 200 and 120 liters, respectively***) restrict their use to relatively shorter periods of time.

The development of portable battery and fuel-cell powered oxygen analyzers makes it possible to complete oxygen analyses of expired air samples in the field. The Teledyne Oxygen Monitor (Model 331-B)**** enables simple, direct analysis of the concentration of oxygen over the 0-25% range with a sensitivity of 0.125%. This completely portable unit is powered by a micro-fuel-cell with a twelve-month life which is housed in a cylindrical probe assembly connected to the meter. It operates at temperatures between 32 and 125 degrees Fahrenheit, is 3 3/4" x 4 3/4" x 8 1/4" in size, and weighs just under two pounds. The two-liter sampling bladder can be fitted directly to the probe assembly by a short piece of plastic tubing (3/16" I.D., 5/16" O.D.) attached to the inlet nipple of the flow-through adapter cap on the probe. The entry of ambient air into the probe is prevented by placing in water the loose end of another piece of plastic tubing connected to the outlet nipple of the flow-through adapter cap. Oxygen is measured by the micro-fuel-cell which consumes oxygen from the atmosphere surround the cell under the cap in the probe, and the oxygen consumed generates a proportional electric current to drive the micro-ampere meter. A small but sufficient volume of sampled air flowing into the probe will flush out the remaining dead air. A stabilized reading of the oxygen percentage can be made within 30 seconds of introducing the new sample. Four or five same from each bladder should be tested to check the constancy of the readings. The meter can be calibrated against atmospheric air, but in field situations the continued accuracy of the analyzer can be tested against samples of a precisely known concentration (<25%) of bottled oxygen with a nitrogen or carbon dioxide background. For a tested sample, the difference between 20.93% (atmospheric air) and the oxygen concentration of the expired air represents the percentage of oxygen consumed. Once the expired air volume and oxygen consumption are known, the caloric expenditure of an individual can be most conveniently derived using the Weir formula (Durnin and Passmore 1967, p. 18). This formula, which follows, expresses the principle that 4.92 kilocalories of energy are liberated from each liter of oxygen utilized by the body.

$$\text{kcal/min} = \frac{4.92 \text{ X } \begin{pmatrix}\text{corrected vol. of} \\ \text{air consumed/min}\end{pmatrix} \text{ X } \begin{pmatrix}20.93\% \text{ - oxygen\%} \\ \text{in sample}\end{pmatrix}}{100}$$

The corrected volume of air is obtained by converting the metered volume to standard temperature and pressure dry (STPD: zero degrees Centigrade, 760 mm Hg, dry). Charts for this correction are readily available, and a pulmonary function aneroid barometer can be used at altitudes up to 7000 feet for recording the barometric pressure at the time of metering air consumption.***** The temperature during observations can be recorded from the built-in thermometer on the respirometer. In earlier studies of energy expenditure it was considered essential to determine carbon dioxide production as well as oxygen consumption, but it has been calculated that the error involved in eliminating this step is at most ±0.5% (Durnin and Passmore 1967, p. 18). Use of the Weir formula yields an estimate of per minute energy expenditure in kilocalories to two decimal places. Given the specified sensitivity (0.125%) in oxygen analysis with the Teledyne Monitor, energy expenditures based on those readings should be reported to the nearest tenth rather that hundredth kilocalorie. The manufacturer's specifications for the Teledyne unit give the maximal error at ±0.25% oxygen, and this allowance for maximal error should be reported with each calculation.****** The complete calculation can be completed quickly with the use of an electronic calculator, and availability of small, battery powered units now makes possible to rapidly estimate energy expenditures in the field. Table 1 presents an example from an actual field observation which summarizes the steps which have been described in this approach.

Table 1

Person:	"M" (adult woman,
Height: 1	37 cms., wt. 47.2 kgs.)
Location:	"P" 's hillside swidden
Altitude:	approximately 2500 feet
Activity:	Harvesting one manioc plant
Temperature:	37 degrees Centigrade
Barometric Pressure:	712 mm Hg
STPD correction factor:	0.775
Meter reading at start:	48,699.1
Meter reading at finish:	48,868.2
Volume of air used:	169.1 liters
Time at start:	9:31 a.m.
Time at finish:	9:41 a.m.
Exact elapsed time:	9 minutes 56 seconds
Uncorrected vol/min:	17.01 liters/minute
Corrected vol/min:	13.18 liters/minute
% oxygen in sample:	17.2%
% oxygen consumed:	3.73%

$$\frac{4.92 \times 13.18 \times 3.73}{100}$$

2.4 kilocalories/minute allowance for
maximal error in oxygen analysis ±0.2 kcal/min

Energy expended/min:	2.4±0.2 kcal/min
Energy expended in task:	24.1±1.6 kilocalories

Discussion

Energy expenditure estimates can be obtained by a single investigator using this approach. The method is, however, somewhat demanding, and the careful recording of time, meter readings, temperature, barometric pressure, changing rubber air sample bladders, and so forth leaves the the single anthropological research little time for concomitant observations such as time and motion tabulations or measurements of quantities of a harvested crop. Expired air samples should be analyzed within 60 minutes of collection, though the results of delayed analyses can be corrected for the diffusion of oxygen inward through the wall of the rubber bladder. Certain parts of the respirometer (mouthpiece, respiratory valve, rubber connecting tube, and sample bladder) need to be kept clean at all times, and the proper functioning of the meter itself needs to be checked regularly. A small repair kit should be kept on hand, especially in field situations where mechanical help is not readily available. Regular work with this unit requires having several mouthpieces, rubber bladders, extra nose clips, and at least one spare respiratory valve.******* It is probably also advisable to have a spare micro-fuel-cell for the oxygen analyzer. Apart from the mechanics of competently utilizing this unit, there are the additional tasks of explaining its purpose to possibly cooperative individuals and allowing them to become adjusted to using the respirometer. It is important to permit a person to become thoroughly accustomed to breathing through the respirometer, and this can perhaps most easily be accomplished with one or more measurements of ten to fifteen minutes' duration while the person is just sitting. As mentioned earlier, most persons adjust to respirometer rather quickly. It is important to obtain accurate heights, weights, and ages for all persons whose energy expenditures are measured, for this allows for later comparisons relative to weights and body surface areas.

In sum, this portable unit for anthropological research on energy expenditures enables the relatively simple and straightforward collection of a category of data with multiple uses. A number of questions relevant to human behavior and evolution including those pertaining to work outputs, work efficiencies, physical fitness, degrees of skill, and the relative energy costs and benefits of technologies and changes in technologies (possibly even some symbolic and communicational systems) will become better understood as energy expenditure data become increasingly available.

END NOTES

* A Faculty Research Grant from Washington Washington University enable the assembling of this unit; Dr. Robert M. Senior facilitated the pre-field evaluations in the Pulmonary Laboratory, Jewish Hospital, St. Louis; extensive tests in a field situation in south-eastern Peru were made possible by Allen W. Johnson and Orna Johnson of Columbia University. I am grateful to these individuals and institutions and to N.S.F. which funded the collaborative work with the Johnsons.

** U.S. distributor: Instrumentation Associates, Inc., 1 Graphic Place, Moonachie, New Jersey 07074.

*** As available from Warren E. Collins, Inc., 220 Wood Road, Braintree, Massachusetts 02184.

**** Teledyne Analytical Instruments, 333 West Mission Drive, San Gabriel, California 91776.

***** Correction Chart P-453; Barometer (7000')
P-410; both from Warren E. Collins, Inc.

****** A laboratory comparison of oxygen analyses for 20 expired air samples using the Teledyne unit and the Scholander apparatus (sensitivity ±0.02%) revealed that the values obtained by the Teledyne unit tended to be very close to those obtained by the more lengthy Scholander method (r = .997). These results suggest that observations of oxygen concentration values which approach the specified maximal error are likely to occur quite infrequently.

******* Original spares can be obtained from Instrumentation Associates; several similar items are available from Warren E. Collins; Hans Rudolph, Inc., 7200 Wyandotte Street, Kansas City, Missouri 64114 also supplies respiratory valves.

BIBLIOGRAPHY

Consolazio, C. Frank, Robert E. Johnson, and Louis J. Pecora
1963 Physiological Measurements of Metabolic Functions in Man, New York: McGraw-Hill Book Company.

Durnin, John V. G. A., and Reginald Passmore
1967 Energy, Work and Leisure, London: Heinemann Educational Books, Ltd.

Durnin, John V. G. A., O. G. Edholm, D. S. Miller, and J. C. Waterlow
1973 "How Much Food Does Man Require?," Nature 242: 418.

Gross, Daniel R., and Barbara A. Underwood
1971 "Technological Change and Caloric Costs: Sisal Agriculture in Northeastern Brazil," American Anthropologist 73: 725-740.

Lee, Richard B.
1969 !Kung Bushman Subsistence: An Input-Output Analysis," in Environment and Cultural Behavior, (ed.) A. P. Vayda, Garden City, New York: Natural History Press.

Rappaport, Roy A.
1967 Pigs for the Ancestors. New Haven: Yale University Press.