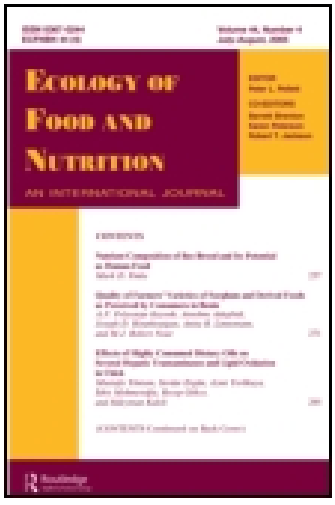

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MACHIGUENGA ENERGY EXPENDITURE

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This article presents the results of a study of energy expended at typical activities and on average days, by adult women and men of a hunter-gatherer-horticulturalist population in south-eastern Peru. Marked differences between the sexes in patterns of energy use are presented. The men tended to work at higher rates of energy expenditure than did the women. On the average day, representative of all activities in an annual cycle, the women expended only about 8.0 MJ (1925 Cals) whereas the men expended about 13.3 (3200 Cals). Seasonal analysis reveals an even greater contrast during the wet months. Relations between the Machiguenga and their upper Amazonian rain forest environment are considered in accounting for the observed patterns of energy expenditure. Factors such as differences in uses of technology, work settings, and population composition are related to the findings.

INTRODUCTION

Human energy studies are now controversial. The significance for human ecology of much extant work in the area is questionable. A few of the contributions, however, have found a place in the history of human ecological studies (for example, see Montgomery, 1977a). Certain recent efforts have aided the systematic description of some human behavior: from these, for example, we now know more about the relationships between heavily-exerting activities and physical fitness (Godin and Shepard, 1974; Shepard and Rode, 1974); between general activities (such as sitting or walking) and daily energy expenditure (Norgan, Ferro-Luzzi and Durnin, 1974); and between behavior and adaptation to energy flow in the environment (Thomas, 1973).

In general, however, the available materials on human energy use are limited in one or more of the following ways. The great majority have been produced with nutritional and physiological rather than ecological concerns in mind. Most have been made in industrialized societies, and their results cannot be easily generalized to agrarian and non-industrialized people. Few have been informed by a population outlook, although this is a key concept for human ecology (Montgomery, 1977b). Frequently, little attention has been given to relating study samples to the populations from which they were drawn. And, few have attended to temporal variations in activities or environments.

Human energy studies need not be limited in any of these ways, as we seek to show.

THE MACHIGUENGA

The Machiguenga are hunter-gatherer-horticulturalist Indians living along tributaries of the upper Amazon near the base of the Andes in south-eastern Peru. We conducted this study with a local population of Machiguenga who live along the valley of the Kompiroshiato River at an altitude of about 700 meters (2300 feet). The Machiguenga usually live in clusters of one to three households dispersed along the river valleys in the tropical forest. Most of their food comes from slash-and-burn gardens that are cleared from primary forest, cultivated for two to three years, and then abandoned for many years or permanently. The major crops are manioc (*Manihot esculenta*), other root crops such as sweet potatoes (*Ipomoea* spp) and arrowroot (*Maranta* spp), maize, and certain legumes. Wild food items such as grubs, game fish, birds, monkeys, palm hearts, and a large variety of fruits supplement the garden produce, but these items are generally in scarce supply. Machiguenga households usually consist of one adult male living with his wife or wives, children, and one or more dependent relatives. The clusters of households are composed of kin who have built homes near to one another, and the population of the clusters varies from four to 30 persons. These

clusters are separated by large expanses of rain forest, and population density is only about 0.3 persons per square kilometer (0.8 persons per square mile).

METHODOLOGY

We conducted research with the local population of Machiguenga at Shimaa. This local population was somewhat larger than the clusters just described because its families settled along the river valley near a school established by a Peruvian-appointed Machiguenga school teacher in 1968. In 1973 there were 13 houses within 45 minutes' walk of the Shimaa school, and 22 Machiguenga children were attending school for a few hours per day, learning literacy in Machiguenga first and then in Spanish. During the 1972–1973 research year the local Shimaa population averaged about 105 persons, fluctuating slightly due to seasonal movements.

One feature of this local population's age-sex structure, which we relate to our findings below, is the unusual adult sex ratio. Several of the families near the Shimaa school had more female than male adult members (that is, persons aged about 15 years or older). The chance coincidence of cases of polygynous marriage, maintenance of widowed relatives, and presence of several unmarried teenage daughters produced an anomalous sex ratio of 34 adult women to 17 adult men in these families. At other Machiguenga settlements and among pre-adults in Shimaa, the sex ratios were more nearly equal.

Measuring Energy Expenditure

In measuring Machiguenga energy expenditure our aim was to select activities that were most representative of the overall patterning of adult life at Shimaa in 1972–73. Only a limited number of observations could be made, given the time available for this phase of the field research. Because of this we concentrated on making measurements of activities that were either of major economic or social importance themselves, or were sufficiently similar to other unmeasureable activities that reliable estimates of expenditure for the unmeasureable activities could be made. Initial results from computerized analyses of the time allocation study (discussed in detail below) were available to us, and with these it was possible to select a sample of activities that accurately reflected Machiguenga behavior patterns.

We measured the energy expended at particular activities by indirect calorimetry (that is, determining calorie expenditure from oxygen consumption) as has been done in other recent field studies (Godin and Shepard, 1974; Norgan, Ferro-Luzzi and Durnin, 1974; Thomas, 1973).† We chose this approach for two reasons. First, we felt that the available data from other studies, most from industralized peoples (Passmore and Durnin, 1955; Durnin and Passmore, 1967) could not be readily extrapolated to typical Machiguenga activities. Hence, we needed original observations. Second, we felt that the low margin of error associated with indirect calorimetry (estimated by Durnin and Brockway (1959 p. 39) to be about five percent) offered greater accuracy overall than heart rate monitoring. This latter technique is particularly imprecise at the low and high ends of the energy expenditure range. With the Weir formula (given in Durnin and Passmore, 1967:18) our oxygen consumption observations could be expressed as energy expenditure values, accurate to one-tenth of a kilocalorie.

Our sample of subjects consisted of 16 adult Machiguenga (eight women and eight men). All became accustomed to using the respirometer before observations were made in actual work settings. Table I shows the mean ages and weights of these Machiguenga, and comparable data for the 35 adults in the time allocation study. Twelve adults (six of each sex) were in both samples; the two samples differ slightly in that the time allocation data include only married adults whereas two unmarried women and two unmarried men were included in the energy expenditure study because of their willingness to cooperate. These four lived in households with married men and women included in the time analyses. For both groups, adjusted ages and weights are given, taking into account the proportional contributions of individuals to the data. To best fit the results to the Machiguenga adult population, mean energy expenditure rates for particular activities have been expressed in relation to these adjusted weights of married adult women and men (that is, 43.3 and 53.4 kilograms, respectively). All subjects appeared

† A Max Planck respirometer (Model 59) and a portable, micro-fuel-cell powered Teledyne oxygen analyzer (Model 331B) were used.

TABLE I

Sample sizes for energy expenditure and time allocation by Machiguenga men and women.

Samples	Men N	Men Age	Men Wt. (kg)	Women N	Women Age	Women Wt. (kg)
Energy expenditure	8			8		
Mean		25	51.8		25	44.5
Std. dev.		10.4	5.1		9.3	7.6
Range		16—49	45.4—63.0		16—41	37.7—60.3
Adjusted		23	49.6		24	42.4
Time allocation	15			20		
Mean		30	53.9		27	44.3
Std. dev.		10.2	5.4		7.6	4.2
Range		17—49	43.5—63.0		16—41	37.9—51.9
Adjusted		30	53.4		27	43.3

to be in good physical health and in excellent physical condition.

We measured the Machiguenga in their customary work settings, and in the context of their regular work schedules. As often as possible repeated observations were made for the same subject and for more than one subject for each activity. We also made notes about activities and contexts when we measured energy expenditure, so that we could compare work performances, work rates, and work conditions. For example, when we measured the planting and harvesting of crops, we recorded the frequencies of component actions in the activity, the relevant conditions of the garden (vegetation, soil, topography), the technological items used in the task (small or large knife, machete, axe), and the quantities of work accomplished (numbers, sizes, weights of crops planted or harvested per unit area and per unit time).† These contexts were taken into account in labeling and categorizing activities for energy and time expenditure analyses.

Daily Energy Expenditure

The most reliable method at present for calculating daily energy expenditure, sometimes referred to as the factorial method, depends upon satisfactory measurements of time allocations (Durnin and Brockway, 1959; Durnin and Passmore, 1967). Two problems of representativeness can affect the reliability of daily time allocation calculations. First, when sampling is done in a limited time span, important long-term variations remain undiscovered. Their omission is perhaps most critical in areas where seasonality is pronounced or where time or energy resources are constraining. Second, time allocation measurements for a few individuals cannot be automatically applied to an entire population, particularly when it is highly diverse occupationally and behaviorally. Even in such an apparently homogenous, small population as the Machiguenga, the wide variation among members in the performance of typical activities is too great to be ignored or handled by casual sampling procedures.

Among the Machiguenga we made behavioral observations on all members of the research population during the daylight hours (6:00 a.m.–7:00 p.m.). Households were visited briefly at random times throughout the annual cycle, and the activities of all persons were recorded. Visit times were chosen in advance with a table of random numbers. Absent persons' activities were elicited by interview, and verified when possible by direct observation. Observations were immediately recorded in long-hand descriptions of each person's activity at the moment of observation. We later transformed these notes into three-letter codes for computer processing. The first letter of the activity code represented a major activity category such as "eating" or "idleness," and the second and third letters of the codes were increasingly specific (for further details, see Johnson, 1975: 302–304). For adults, we grouped the results in ten major activity categories.

These ten activity categories and some of the subsidiary types of activity that they include were:

† All energy measurements were made between 14 June and 12 July, 1973. Usually a team of two observers worked in coordination to record behavioral and energy expenditure data. Anthropologists Rita E. Montgomery and Orna R. Johnson made major contributions as co-observers in this work.

Eating, including all meals and snacks, but excluding wild foods eaten in the forest (which could not be observed);

Food Preparation, including cleaning, cutting, boiling, roasting, etc., of all foods as well as preparing manioc beer;

Child Care, including nursing, holding, bathing, patting, punishing, etc.;

Manufacture, primarily of everyday necessities (axe handles, cane boxes, mats, woven cotton clothing), but also including toys and musical instruments;

Wild Foods, the hunting or gathering of all foods (such as game, fruits, grubs, termites, and fish) except cultigens;

Garden Labor, including all activities related to cultivation performed in the garden sites (such as clearing, burning, planting, weeding, and harvesting);

Idle and Recreation, including sleeping and resting during daylight hours, playing, getting drunk, chatting, playing musical instruments, and sitting doing nothing;

Hygiene, including sweeping house, washing laundry, bathing, and weeding the yard;

Visiting, all activities of individuals observed in households other than their own; and

Other, including such difficult to classify items as getting firewood, fetching water, labor expended in exchange for trade goods, and travel to trading posts.

RESULTS

Measurement of Energy Expenditure

We completed 147 measurements of energy expenditure (89 for men, 58 for women). These are shown in Table II as mean energy per minute expenditure rates for 17 men's and 15 women's activities. Each activity reported in Table II represents a distinct sequence of behavior within a particular environment.

Men typically worked at higher rates of energy expenditure than women. Women usually worked in sitting, squatting, or bent-over standing positions, while men frequently stood erect or moved about in their work activities. Generally the men used larger and heavier items of technology (machetes, steel axes, bows and arrows, digging sticks) whereas women worked with smaller or more stationary tools (such as small knives, spindles, cooking utensils, backstrap looms) or with their hands. Also, the settings in which men were active often were more physically demanding.

TABLE II

Mean energy expenditure of Machiguenga men and women for selected activities.

Men (mean weight 53.4 kg)		Energy expenditure		Women (mean weight 43.3 kg)		Energy expenditure	
Men's activities	N	kJ	Cals	Women's activities	N	kJ	Cals
walking open paths	6	22.1	5.3	planting root crops	2	12.1	2.9
walking level forest paths	6	25.0	6.0	harvesting root crops	7	11.2	2.7
walking up forest paths	9	53.4	8.9	catching fish with hands	4	12.9	3.1
walking down forest paths	3	17.1	4.1	weeding yard	2	10.0	2.4
clearing undergrowth	5	30.5	7.3	sweeping yard	1	11.7	2.8
felling large trees	8	31.7	7.6	deseeding cotton	2	5.8	1.4
planting maize	2	17.9	4.3	beating cotton	4	7.9	1.9
planting manioc	7	21.7	5.2	spinning cotton	6	4.5	1.1
weeding slope	4	25.4	6.1	setting loom	2	8.3	2.0
cutting grass	1	29.2	7.0	weaving	8	7.5	1.8
harvesting maize	5	22.1	5.3	grinding maize	6	11.7	2.8
harvesting manioc	4	18.3	4.4	peeling manioc	3	8.7	2.1
removing palmheart	1	25.9	6.2	splitting manioc	2	8.3	2.0
chopping firewood logs	2	28.0	6.7	straining manioc	6	7.9	1.9
net bag manufacture	9	10.8	2.6	washing laundry	3	10.8	2.6
cane box manufacture	2	9.1	2.2				
bow and arrow manufacture	15	11.2	2.7				
Total	89			Total	58		

N = number of measurements of activity, all subjects combined.

TABLE III

Daily time allocated by married Machiguenga adults to various work activities.[a]

Major activity category and subcategory	Men (N = 15) min/day	Men (N = 15) percent	Women (N = 20) min/day	Women (N = 20) percent
Eating	17	4.9	55	3.8
Food Preparation[b]	12	0.8	141	9.8
Child Care[b]	1	0.1	69	4.8
Manufacture	81	5.6	124	8.6
woodwork	52	3.6	5	0.3
cotton cloth[b]	1	0.1	105	7.3
other	28	1.9	14	1.0
Wild Foods[b]	122	8.5	51	3.5
collecting	22	1.5	19	1.3
fishing	45	3.1	18	1.3
hunting[b]	45	3.1	0	0
other	10	0.7	14	1.0
Garden Labor[b]	144	10.0	51	3.5
clear, burn, plant[b]	29	2.0	0	0
weeding[b]	45	3.1	2	0.1
harvesting	47	3.3	39	2.7
other	23	1.6	9	0.6
Idle and Recreation	141	9.8	149	10.3
Hygiene	20	1.4	35	2.4
Visiting	62	4.3	45	3.1
Other	126	8.8	59	4.1
Daylight hours[c]	780	54.2	779	53.9
Night hours	660	45.8	660	45.8
Totals[c]	1440	100.0	1439	99.7

[a]adapted from Table IV, page 308, Johnson, 1975.
[b]differences between sexes significant at $p < .01$ (t-test).
[c]totals vary slightly from expected due to rounding.

Their gardens frequently were vegetationally dense, log-strewn, and of more difficult access (on steep slopes), and they spent significantly more time walking steep forest trails when hunting.† In combination, these factors rather than differences in body size are important determinants of the contrasts between the men's and women's energy expenditure rates.

Daily Energy Expenditure

About 3500 observations were made on individuals, from which average estimates of time expenditure for individuals could be computed and analyzed according to age, sex, time of day, location of activity, and season. Table III presents these data analyzed according to sex and major categories of activity for all married adults in the local population. These randomly sampled time allocation data for the 1972–1973 research year provide a firm basis for estimating energy expenditure for a representative day. Using the factorial method, the energy expenditure rate (kJ or Cals per minute) for each activity was multiplied by the amount of time spent in that activity. To calculate rates within each of the ten major Machinguenga activity categories, the time spent at each of the detailed activities was first determined. Then the energy expenditure measures from Table II were applied wherever appropriate. For all activities not directly measured except resting and sitting, we based estimates on values for similar activities that had been measured. As an example, Table IV shows how measurements and estimates for component activities were used to calculate an overall rate for one major activity category of men (Manufacture). For resting metabolism and sitting, values were taken from published standards (Tables 3.1 and 3.5 in Durnin and Passmore, 1967:31, 39), and adjusted for body

† The slopes in this foothill region east of the Andes were generally between 20° and 40° and averaged about 30°.

TABLE IV

Components of one major activity category (Manufacture) in Machiguenga men.

Activity subcategories	Time allocation min/day	Energy rate kJ	Energy rate Cals	Basis for energy rate calculation
Woodworking				
1. Assembled small items (wooden comb, bird trap, cane box, etc.)	7.0	9.1	2.2	Measured cane box manufactured
2. Carved items (bow, arrows, wooden spoon, cup, spindle, etc.)	13.1	10.8	2.7	Measured bow and arrow manufactured
3. Heavy wood work (canoe, raft, large beer trough, etc.)	14.1	28.0	6.7	Measured chopping wood
4. Medium heavy wood work (house, chicken house, drum, etc.)	17.4	19.6	4.7	Estimated between nos. 2 and 3 above
Cotton				
1. Work with cotton thread	1.3	7.9	1.9	Estimated between sitting and cane box manufacture
Other				
1. Work with beads, ornaments	2.1	7.9	1.9	Estimated between sitting and cane box manufacture
2. Netting (net bag, fish net)	25.7	10.8	2.6	Measured netting
Total for major activity category	81	15.4	3.7	Mean of components weighed by time

TABLE V

Daily energy expenditure of Machiguenga adults by category of major activity.

Major activity category	Men Rate kJ	Men Rate Cals	Men Energy expenditure kJ	Men Energy expenditure Cals	Men % of total	Women Rate kJ	Women Rate Cals	Women Energy expenditure kJ	Women Energy expenditure Cals	Women % of total
Eating	7.9	1.9	564	135	4.2	5.4	1.3	296	71	3.7
Food Preparation	7.9	1.9	91	22	0.7	7.9	1.9	1120	268	13.9
Child Care	9.1	2.2	8	2	0	5.8	1.4	401	96	5.0
Manufacture	15.4	3.7	1254	300	9.4	7.1	1.7	881	211	11.0
Wild Foods	22.1	5.3	2696	645	20.1	18.3	4.4	948	227	11.8
Garden Labor	20.9	5.0	3017	722	22.5	10.8	2.6	560	134	7.0
Idle and Recreation	5.4	1.3	769	184	5.7	4.1	1.0	622	149	7.7
Hygiene	10.0	2.4	196	47	1.5	10.4	2.5	353	88	4.6
Visiting	5.4	1.3	388	81	2.5	4.1	1.0	188	45	2.3
Other	13.3	3.2	1688	404	12.6	7.5	1.8	447	107	5.6
Daylight average	13.3	3.2				7.5	1.8			
Daylight hours			10625	2542	79.2			5835	1396	72.6
Night hours	4.1	1.0	2758	660	20.6	3.3	0.8	2207	528	27.4
24 hour totals[a]			13384	3202	99.8			8042	1924	100.0

[a]Totals vary slightly from expected due to rounding.

TABLE VI

Comparison of the daily energy expenditure of men and women in Machiguenga and other selected groups.

Group	Men MJ	Men Cals	Women MJ	Women Cals	Ratio of expenditure men : women
University students[a]	12.2	2930	9.5	2290	1.28 : 1
Elderly Swiss peasants[a]	14.0	3530	12.0	2890	1.22 : 1
Kaul, New Guinea, natives[b]	9.8	2347	7.6	1830	1.28 : 1
Lufa, New Guinea, natives[b]	10.7	2570	9.3	2245	1.14 : 1
Igloolik Eskimo hunters and married women[c]	15.3	3670	10.0	2400	1.53 : 1
Igloolik Eskimo sedentary men and married women[c]	10.4	2500	10.0	2400	1.04 : 1
Machiguenga (annual average)[d]	13.3	3202	8.0	1924	1.66 : 1
Machiguenga (dry season)[d]	12.4	2987	8.0	1922	1.55 : 1
Machiguenga (wet season)[d]	14.3	3432	8.0	1928	1.78 : 1

[a]Durnin and Passmore, 1967: 115–116.
[b]Norgan, Ferro-Luzzi, and Durnin, 1974:328.
[c]Godin and Shepard, 1974:210.
[d]Present study.

weight differences.† Using the energy expenditure rates for each of the major activity categories, daily energy expenditures were then calculated.

Table V presents our findings for Machiguenga women and men for the major activity categories and for full days. These daily totals represent an average day, which included the entire repertoire of Machiguenga daylight-hours activities as performed by all married adults in the local population throughout the full research year.

Machiguenga women and men expended markedly different amounts of energy in a day. The magnitude of this difference is illustrated in Table VI which includes data reported in other studies. The high degree of contrast for the Machiguenga is partially explained by the men performing the more energy expensive activities. Of equal importance is the fact that Machiguenga men spend significantly more time at activities in the two most energy expensive categories, (Wild Foods and Garden Labor) while Machiguenga women spend significantly more time at two energy inexpensive categories, namely Food Preparation and Child Care (see Tables III and V). Also, the large proportion of adult women in this population is possibly implicated in this pattern of energy and time expenditure, because demand for women's labor is relatively lower.

† Our anthropometric data affirm the comparability of Machiguenga adults with "thin" men and "average" women in Durnin and Passmore's tables.

Seasonal Differences in Energy Expenditure

Our findings also reflect seasonal patterns. There are two clearly contrasting seasons in this region of the upper Amazon: a dry season that prevails during the months of April through September, and a wet season that extends from October through February; March is a transition month between the two. Our rainfall data from Shimaa for 1972–1973 support this characterization. During that year the average monthly rainfall in the dry season was 11.4 cm (4.5 inches; range: 9.1–14.2 cm; standard deviation: 2 cm); in the wet season the mean monthly rainfall was 34 cm (13.4 inches; range: 22–63 cm; standard deviation: 17 cm). The annual total was 268 cm (107 inches).

During the wet season, both women and men spent more energy and time in Manufacture, Wild Foods, and Garden Labor than they did in the dry season. Correspondingly, both sexes spent less energy and time during the wet season in activities in Idle and Recreation and Hygiene. The sexes differed in the wet season in that women spent more energy and time in Eating and Visiting, whereas men expended less energy and time on these two categories. Table VII shows the seasonal patterns of energy expenditure and time allocation for married adult Machiguenga in the Shimaa population. The same category-specific energy expenditure rates have been used as in Table V. The average daily energy expenditure for men was increased by almost 15 percent in the wet season from that for the dry season, whereas the women's

TABLE VII

Daily time allocation and energy expenditure for adults by season.

Major activity category	Dry season						Wet season					
	Men			Women			Men			Women		
	Time	Energy		Time	Energy		Time	Energy		Time	Energy	
	mins	kJ	Cals	mins	kJ	Cals	mins	kJ	Cals	mins	kJ	Cals
Eating	74	589	141	44	238	57	67	530	127	66	355	85
Food Preparation	11	87	21	142	1128	270	12	91	22	140	1107	265
Child Care	2	20	5	72	418	100	0	0	0	66	384	92
Manufacture	69	1061	254	114	810	194	94	1446	346	136	965	231
Wild Foods	115	2558	612	49	902	216	129	2867	686	55	1003	240
Garden Labor	110	2299	550	41	447	107	182	3799	909	62	668	160
Idle and Recreation	184	999	239	158	660	158	94	509	122	140	585	140
Hygiene	22	217	52	51	539	129	17	171	41	20	204	49
Visiting	85	463	111	41	171	41	38	209	50	48	188	48
Other	107	1429	342	68	509	122	147	1960	469	50	376	90
Daylight hours[a]	779	9726	2327	780	5826	1394	780	1586	2772	783	6019	1440
Night hours	660	2758	660	660	2207	528	660	2758	660	660	2207	528
Totals[a]	1439	14285	2987	1440	8033	1922	1440	14345	3432	1224	8059	1928

[a]Totals and averages of seasons vary slightly from expected due to rounding.

daily expenditure was virtually unchanged from one season to the other.

Annual Energy Budgets

Annual energy budgets can also be calculated for the average married woman and man who are represented in Table V. In one year of 365 days the woman would expend 2935 MJ (702,260 Cals) and the man would expend 4885 MJ (1,168,730 Cals). Since these average adults represent all married members of the population, the annual energy budget for the 15 married men would be 73,279 MJ (17,530,950 Cals); for the 20 married women it would be 58,708 MJ (14,045,200 Cals).

Discussion

Some of the problems with many of the existing energy use studies have already been noted; it has also been pointed out that such limitations are not inherent. On the contrary, we find that our understanding of energy expenditure is furthered by investigating the relations between the local population of Machiguenga and their upper Amazonian rain forest environment. The Machiguenga are an active people, busy much of the time during daylight hours. Both sexes are equally active in major tasks and in spending large parts of their waking days at them. Through calorimetry we find that Machiguenga men are clearly more energetic than the women. The daily energy expenditure contrast is more marked than that usually seen in other studies, and our seasonal observations reveal that it is heightened during the wet season. The local sexual division of activities, the usually larger and heavier tools that the men use, and the garden and tropical forest settings where the men more frequently work all contribute to the generally higher rates of energy expenditure and, for the longer time spent by men on certain important activities. Also, the greater number of adult women in the local population may be implicated in the observed patterns of energy expenditure. Random sampling of activities through an annual cycle strengthens these observations. In sum, environment, population composition, technology, and allocation of tasks and time are specifically related to our energy expenditure findings.

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