Original Research Article

Energy Expenditure Among Farmers in Developing Countries: What Do We Know?

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ABSTRACT The trend toward overweight and obesity in developing countries is often assumed to be due, in part, to reductions in energy expenditure associated with the transition from agrarian to urban lifestyles. In this article we first review the published studies on energy expenditure in farming populations living in developing countries, populations generally assumed to have high levels of energy expenditure. To facilitate comparison we express energy expenditure as physical activity level (PAL), i.e. the ratio of total daily energy expenditure to basal metabolic rate. Then, with the goal of better understanding variability in energy expenditure between different human groups, we focus on case studies of women farmers in Colombia and Brazil for whom we have good ethnographic data. The published studies reviewed indicate that most farmers have PAL values in the moderate physical activity range, but toward the high end of that range. PAL values of male farmers tend to be higher than female, and show greater seasonal variation. The case studies illustrate that women farmers, living in broadly similar environments, and dependent on the cultivation of the same crop can have quite different patterns of physical activity and hence PAL values. These differences are a function of differences in behavior related to social and cultural variables like the organization of work at the household level and perceptions of how food crops should be processed, as well as micro-level ecological factors. Am. J. Hum. Biol. 20:249–258, 2008.

The global trend toward increased overweight and obesity has led to a renewed interest in physical activity and energy expenditure. The trend toward overweight and obesity is as much of a problem in developing countries as elsewhere and indeed the prevalence of both has risen dramatically in many developing countries over the past 20–30 years (WHO, 1998). We know that overweight and obesity are the consequence of long-term imbalances between food energy intake and energy expenditure in individuals, i.e. when energy intake exceeds expenditure the surplus energy accumulates as tissue (mostly fat) and body weight increases. What we still do not understand very well are the factors responsible for intake exceeding expenditure for so many people in so many different places.

The dominant explanatory model for this increased prevalence of overweight and obesity is that of the nutrition transition which posits that these changes are the result of large scale shifts toward a western-style diet high in fats, sugars, and refined foods, and a lifestyle characterized by low levels of physical activity (Popkin and Gordon-Larsen, 2004). The shifts in diet have been better documented than the changes in physical activity, which remain a major gap in our knowledge (Monteiro et al., 1995; Popkin, 2006). The greater focus on diet is likely due to the fact that the current discussion is based upon the analysis of national data sets, which often include national food supply and disappearance data making shifts in dietary patterns, at least on the large scale, visible. National level data on physical activity are not generally available.

Although such an assumption appears to be widely accepted, the fact that there are little data to support it is often overlooked. Studies of physical activity and energy expenditure in farming populations are limited in number. There are no long-term studies of the changes in energy expenditure that are assumed to accompany migration from a rural agrarian lifestyle to an urban service sector one, and the few studies comparing energy expenditure in rural agrarian communities to urban ones have produced conflicting results. For example, Borgonha et al. (2000) reported significantly lower levels of energy expenditure in male workers living in economically depressed urban areas of India in comparison to male agricultural workers. In contrast, Yamauchi et al. (2001) found similar levels of energy expenditure among male town dwellers and subsistence agriculturalists in Papua New Guinea (PNG), and noted that although the energy cost of the work done by the town dwellers was lower than that of agricultural work, the lower cost was offset by the longer working hours.

The purpose of this article is first to review the available literature on energy expenditure in farming populations living in developing countries with the goal of determining the level(s) of energy expenditure associated with that lifestyle. In other words, how energetically demanding is the farming lifestyle? While often assumed to be high, we expect energy expenditure to be variable both within farming populations seasonally and between the sexes, and between populations, based on staple crops, local ecological conditions, and degree of market integration. For example, populations reliant on highly seasonal crops may experience periods of high energy expenditure during planting and/or harvest, followed by periods of signifi-

Contract grant sponsor: National Science Foundation; Contract grant numbers: BSN 75-20169, BCS 0201936; Contract grant sponsor: Wenner Gren Foundation for Anthropological Research Inc., Brazil; Contract grant number: 6861; Contract grant sponsor: Social Science Research Council, Colombia.

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Received 24 August 2007; Accepted 28 December 2007

DOI 10.1002/ajhb.20764

Published online 17 March 2008 in Wiley InterScience (www.interscience.wiley.com).

TABLE 1. Examples of the time and energy budgets of three individual case study women with PAL values in the light, moderate, and vigorous ranges; time in hours, energy expenditure (EE) in kcal[a]

	Woman 1		Woman 2		Woman 3	
Activity	Hrs	Kcal	Hrs	Kcal	Hrs	Kcal
Garden work	0.4	109	2.2	326	2.8	462
Cassava processing	2.3	370	3.0	425	2.6	495
Housework and childcare						
Standing	4.3	281	1.6	215	2.4	286
Sitting	6.3	397	6.2	527	5.8	397
Lying	1.1	66	0.6	35	0.0	0.0
Walking, unburdened	0.4	66	0.5	69	1.5	236
Walking, burdened	0.2	34	0.7	95	0.6	111
Sleep	9.0	507	9.4	396	8.3	413
Total	24.0	1830	24.0	2088	24.0	2399
PAL (TEE/BMR)[b]		1.54		1.70		2.0
PAL category		*Light*		*Moderate*		*Vigorous*

[a]Energy expenditure values are the sum of energy expenditure in different activities within a general category. For example, garden work includes activities like weeding, harvesting roots, packing baskets, etc., each of which can be assigned an energy cost in kilocalories (kcal) per hour.
[b]BMR, 24-h basal metabolism; TEE, total daily (24 h) energy expenditure (i.e. the sum of energy expenditure in all activities).

cantly lower levels of energy expenditure. Cultural norms regarding the sexual division of labor could lead to differences in energy expenditure between males and females. Lastly, even for groups dependent on the same staple crop, degree of market integration could affect levels of energy expenditure. Therefore, our second goal is to contribute to our understanding of how such factors influence physical activity level (PAL) among farming groups by focusing on the sociocultural context and environmental circumstances associated with the energy expenditures of women in two farming groups for whom we have good ethnographic data.

METHODS AND MEASUREMENT ISSUES

We reviewed the literature for studies that provided data on total daily energy expenditure (TEE) of free-living adult males and females (nonpregnant, nonlactating) in farming communities in developing counties. We excluded studies that only included pregnant and/or lactating (<9 months postpartum) women, and studies with sample sizes of less than eight, except for studies using the doubly labeled water method to measure energy expenditure. We also excluded studies that used physical activity recalls to estimate energy expenditure, and those that used scan sampling techniques to document physical activity and estimate energy expenditure.

To compare mean TEE between and among studies we have expressed TEE as a multiple of basal metabolic rate (BMR). This index is referred to as the PAL (FAO/WHO/UNU, 2004), and should not be confused with physical activity per se, i.e. types of activities engaged in. The benefit of expressing TEE as PAL values is that it corrects for body size and hence allows comparisons between groups of differing body sizes. We classified PAL values as per the FAO/WHO/UNU (2004) recommendations into three categories: *light* (PAL = 1.4–1.69), *moderate* (PAL = 1.70–1.99), and *vigorous* (PAL = 2.0–2.4). An example of the activity budgets that are associated with each category is provided in Table 1. For studies that did not report PAL, we calculated it as PAL = TEE/BMR, using individual data when available, and, when necessary, estimated BMR from standard predictive equations (FAO/WHO/UNU, 2004). Predictive equations are commonly used to estimate BMR and comparative studies have demonstrated such estimates to be within ±10% of that measured using indirect calorimetry (Daly et al., 1985; Johnstone et al., 2006; Piers et al., 1997; Taaffe et al., 1995). We also calculated body mass index (BMI = weight, kg/height, m^2) as necessary.

There are a number of different approaches to measuring TEE, each having its own strengths and weaknesses. Since energy expenditure refers to the loss of heat energy as a by-product of metabolism, it is most precisely measured via direct calorimetry in the laboratory. In field studies of free-living people it is measured indirectly, using one of three methods: doubled labeled water (DLW), heart rate monitoring (HRM), or the factorial method (FACT).

The DLW method uses a dose of water labeled with stable isotopes of hydrogen and oxygen to measure carbon dioxide production, and from that estimates oxygen consumption and hence TEE. The measurement is done over a 12- to14-day period, and accuracy is within 3–5% of that of direct calorimetry (Norgan, 1996). DLW is considered the "gold standard" in assessing TEE of individuals and groups. One limitation is that it provides no indication of the pattern of energy expenditure over time or the types of activities engaged in. Another has been its high cost.

The HRM method uses 1-day (or longer) heart rate records and individually calibrated heart rate–oxygen consumption curves to estimate TEE. It can provide a record of the pattern of energy expenditure throughout the day, as well as the frequency and duration of activities of differing energy costs. Estimates of TEE using HRM are typically within 6% or less of those obtained using direct calorimetry (Ceesay et al., 1989) and DLW (Lof et al., 2003; Racette et al., 1995), and considered acceptable for estimating the TEE of groups (Livingstone, 1997; Norgan, 1996). The HRM method is less accurate for determining the TEE of individuals (Schutz et al., 2001). As with the DLW method, the HRM method does not provide data on the types of activities the subjects engage in.

The factorial method estimates TEE from two sets of data are as follows: (1) an activity diary, which is a record of the type and duration of activities engaged in and (2) the energy cost of specific activities measured by indirect calorimetry (respiratory exchange) (Durnin and Brockway, 1959). TEE is calculated as the sum of the amount of time spent in each activity multiplied by its energy cost. In the studies reviewed here minute-by-minute activity diaries were kept by trained observers for all waking hours of the day, except in a few studies where they were kept for the working hours of the day and the remainder of the activities estimated. The factorial method is the oldest of the three methods and has been widely used in field studies in developing countries. It produces a detailed record of the pattern of energy expenditure during the day, as well as a detailed account of the actual activities engaged in. In laboratory studies, estimates of TEE using the factorial method were within 1% of those obtained from simultaneous indirect calorimetry in a room respirometer (Geissler et al., 1986). In field studies, the method has been shown to produce estimations of TEE for the group that are within 1–5% of those obtained using energy intake-balance as the reference (Acheson et al., 1980;

Kalkwarf et al., 1989), and within 3–8% of those obtained using DLW (Conway et al., 2002; Irwin et al., 2001; Koebnick et al., 2005). The DLW validation studies were all done using literature values for the energy cost of different activities, a modification of the method, which tends to increase error (Kalkwarf et al., 1989). Estimates of TEE using the factorial method are considered acceptable for groups (Livingstone, 1997; Norgan, 1996), but not for individuals (Norgan, 1996). Estimates of TEE based on activity recalls or questionnaires rather than activity diaries are generally not considered acceptable (Conway et al., 2002; Kalkwarf et al., 1989), and thus are not included here. Estimates of TEE based on the scan sampling of activities have not been adequately evaluated and hence are not included here. A limitation of the factorial method is that it is very time intensive.

ENERGY EXPENDITURE IN FARMING POPULATIONS

In our review of the literature we identified 26 studies reporting data on the PAL of adult males and females in farming populations living in developing countries that met our criteria for inclusion. These studies are identified and described in Table 2. Six were done using DLW, three with HRM, and 17 with the factorial method. Ten of the studies were done in Africa, five in the Americas, and 11 in Asia and the Pacific. All subjects in all studies lived in rural areas where agriculture was a predominant activity, and most subjects were involved in subsistence agriculture or agropastoralism, as far as we were able to determine. The exceptions were the Guatemalan and Indian (India-2) men and the Bangladeshi women, all of whom were farm laborers. Some studies provided estimates of PAL for a single season, some for multiple seasons, and some for periods of 9–12 months or more. Sample sizes ranged from 6 to 54 individuals, and individuals were measured over periods of 1–9 days in studies using the HRM or factorial methods and about 12 days in studies using DLW. Samples sizes for the four studies based on the HRM method were small, 6–11 subjects, and hence should be interpreted with caution. Mean subject age was in the range of 23–49 years. Mean subject BMI was within the normal range (18.5–24.99 kg/m^2) in all but five studies; it was lower in four (Ethiopia, India-1, India-2, Bangladesh), and higher in one (Ecuador).

The mean PAL values of adult males and females are shown in Figure 1. For studies that reported data for more than one season, the PAL values shown in Figure 1A,B are the unweighted average of all seasons reported, and hence an estimate of the PAL over the course of the year. For these same groups PAL values by season are shown in Figure 1C,D for males and females, respectively.

The PAL values for adult males (unweighted means) ranged from 1.36 to 2.40 with a mean and median of 1.90 (moderate activity level) (Fig. 1A). Three of the groups had PAL values in the light activity range, 10 in the moderate activity range, and five in the vigorous activity range. Of the five groups with PAL values in the vigorous range, two (Philippines, Gambia-4) were studied during their seasons of peak agricultural activity, and hence their PAL values reflect a seasonal high. The others groups with PAL values in the vigorous activity range were the Thai and Iranian farmers, who showed some seasonal variation in PAL values (see Fig. 1C), and salaried diary farm workers in Guatemala whose level of physical activity probably varied little throughout the year. Three of the groups had PAL values in the light activity range. Of those, the data for the BF-3 and Cameroon-M farmers were for a single season and hence it is unclear if the values are representative of the entire year. The other group with PAL values in the light activity range is India-1, where subjects were measured over a 12-month period.

The PAL values of adult females (unweighted means) are shown in Figure 1B. They ranged from 1.47 to 2.35 with a mean of 1.74 and median of 1.71 (moderate activity level). Six of the female groups had PAL values in the light category, nine in the moderate range, and one in the vigorous activity category. The only group with PAL values in the vigorous category is the Bangladeshi women, who were wage laborers on a tea plantation, and stood more than 8 h a day picking leaves (Vinoy et al., 2000). The lowest PAL values were seen among the Ethiopian (1.47) and India-1 (1.53) women. The Ethiopian women engaged in a limited amount of agricultural work (about 50 min a day) and were reported to have a "relatively leisurely and subdued activity profile" which varied little over the course of the yearly cycle (Ferro-Luzzi et al., 1990). India-1 women, on the other hand, were said to be physically active during the peak agricultural work season and less so during the rest of year (Edmundson and Edmundson, 1989), but since the measurements were reported for a 12-month period, seasonal differences are not visible in the data.

Seasonal differences in PAL values were reported in a limited number of studies (Fig. 1C,D). Four of the five studies on males (Thailand, Iran, Burma and BF-2. BF-3) showed marked seasonal differences with PAL values in the vigorous range, or above, for the peak agricultural season, and in the light to moderate activity ranges for others seasons. All four of these groups lived in environments with strong wet-dry seasonality and all relied on seasonally harvested grain crops. Burmese farmers had a PAL of 2.51 in the peak agricultural season, the highest of all PAL values reviewed here, and a value which is greater than the level of physical activity considered sustainable (2.40) over the long term: it was counterbalanced by PAL at the low end of the light activity range (1.46) in the nonagricultural season. BF-2 and Iranian farmers also had PAL values for nonpeak agricultural seasons that were in the light range. In contrast, the Cameroonian-Y, who lived in a relatively nonseasonal environment and cultivated root crops, showed little seasonal variation in PAL values, and all of their values were in the low end of the moderate activity range. Interestingly, the female PAL values showed less sharply accentuated seasonal variation than did the male. Our impression is that the work of females in these kinds of populations does not vary much from day-to-day because it is dominated by housekeeping chores and childcare responsibilities that are relatively constant.

The tendency of males to have higher PAL values than females is evident from a comparison of Figure 1A,B, and from the mean PAL values of 1.90 and 1.74, for males and females, respectively. However, when PAL values for males and females in the same population are compared, it is clear that the general tendency of males to have higher PAL values does not apply to all groups (Fig. 2). In three of the groups there is no apparent tendency of males to have higher PAL values than females. Information on the sexual division of labor, which might explain male–

TABLE 2. *Studies of total daily energy expenditure of farmers in developing countries using doubly labeled water (DLW), heart-rate monitoring (HRM), and factorial methods (Fact)*

Country–group/study[a]	Reference	Method	Population	BMI		PAL[b]		Sample characteristics[c]
				Males	Females	Males	Females	
Africa								
Cameroon-Y	Pasquet and Koppert, 1993	Fact	Yassa farmers, subsistence (cassava), fishing	22.3 ± 1.8	22.1 ± 3.0	1.72 ± 0.1 1.74 ± 0.1 1.73 ± 0.1	1.71 ± 0.1 1.65 ± 0.1 1.73 ± 0.1	13 males, 3 d each, 15 females, 7 d each; 3 seasons; age males 38.5 ± 13.1 yrs, females 44.7 ± 12.0 yrs
Cameroon-M	Pasquet and Koppert, 1993	Fact	Mvae farmers, subsistence (cocoyams, plantains, taro) hunting	22.3 ± 1.8	22.1 ± 3.0	1.62 ± 0.2 – –	1.70 ± 0.1 1.74 ± 0.1 1.81 ± 0.1	14 males, 3 d each, 15 females, 7 d each; 3 seasons; age males 38.5 ± 13.1 yrs, females 44.7 ± 12.0 yrs
Burkina Faso-1 (BF-1)	Bleiberg et al., 1980	Fact	Farmers, subsistence, and cash crops (millet, sorghum, ground nuts)	–	20.5	– –	1.76 1.45	12 females 2 d each, wet and dry seasons, L status not reported; age 36.6 ± 2.5 years
Burkina Faso-2 (BF-2)	Brun et al., 1981	Fact	Farmers, subsistence, and cash crops (millet, sorghum, ground nuts)	20.2	–	2.18 1.52	– –	16 males, wet season, 23 males, dry season, 2 d each; age 36.6 ± 2.2 yrs
Burkina Faso-3 (BF-3)	Bleiberg et al., 1981	Fact	Farmers, susbsistence, and cash crops (millet, sorghum, ground nuts)	20.0	19.8	1.36	1.54	11 males, 14 females, $L > 6$ months, 6 d each, post-harvest season; age males 45 yrs, females 30.6 yrs
Ethiopia	Ferro-Luzzi et al., 1990	Fact	Farmers, susbsistence, and cash crops (enset, maize, coffee)	–	18.4	–	1.47	22 females, 9 d each, over 12 mo; age n/a
Gambia-1	Singh et al., 1989	DLW	Farmers, subsistence, and cash crops (sorghum, millet, rice, ground nuts)	–	19.7	–	1.98 ± 0.4	10 females, 12 d each, peak agricultural season; age 30 ± 7.0 yrs
Gambia-2	Heini et al., 1991	DLW	Farmers, subsistence, and cash crops (sorghum, millet, rice, ground nuts)	–	20.0 ± 2.0	–	1.90 ± 0.41	7 females, 12 d each; over 9 mo; age 26 ± 3.4 yrs
Gambia-3	Della Bianca et al., 1994	DLW	Farmers, subsistence, and cash crops (sorghum, millet, rice, ground nuts)	20.2	–	1.94	–	54 males, 12 d each, over 12 mo; age 28.6 yrs
Gambia-4	Heini et al., 1996	DLW	Farmers, subsistence, and cash crops (sorghum, millet, rice, ground nuts)	21.2 ± 2.5	–	2.40 ± 0.41	–	8 males, 12 d each; peak agricultural season; age 25.0 ± yrs
America								
Bolivia (highlands)	Kashiwazaki et al., 1995	DLW	Agropastorialists (potatoes, quinoa)	21.0 ± 1.6	–	1.96 ± 0.25	–	6 males, 12 d each; over 3 mo; age 42 ± 14.8 yrs
Brazil	Piperata and Dufour, 2007	Fact	Farmers, subsistence, and cash crops (cassava), fishing	–	21.1 ± 3.2	–	1.55 ± 0.15	18 females, 3 d each, over 12+ mo; age 27 ± 9.3 yrs
Colombia	Dufour, 1984	Fact	Farmers, subsistence (cassava), and fishing	–	22.9 ± 2.7	–	1.83 ± 0.13	16 females (2 L ≤ 6 mo, 3 P), 1–4 d each; over 12+ mo; age 34 ± 5.0
Guatemala	Viteri et al., 1971	Fact	Farm laborers	23.2	–	2.30	–	18 males, 3 d each; season *n*/2; age 29.7 yrs
Ecuador (highlands)	Leonard et al., 1995	HRM	Agropastoralists (potatoes, barley, maize)	24.1 ± 2.5	25.6 ± 4.1	1.95 ± 0.29	1.71 ± .15	11 males, 11 females, 1 d each; 2 mo at peak agricultural season; age males 32 ± 12 yrs, females 40 ± 13 yrs
Asia and Pacific								
Bangladesh	Vinoy et al., 2000	HRM	Farm laborers	–	16.6 ± 0.8	–	2.35 ± 0.2	8 female tea pluckers, d n/a, season n/a; age 28.3 ± 5.6 yrs; *L* at 13 mo; postpartum
Burma	Tin-May-Than and Ba-Aye, 1985	Fact	Farmers (rice) and manual laborers	19.6 –20.2	–	1.92 1.46 2.51	– –	10 males, 3–6 d each, 3 seasons; age 38.4 yrs
India-1	Edmundson and Edmundson, 1989	Fact	Farmers, subsistence (sorghum, rice), laborers and traders	18.6	16.7	1.56	1.53	8 males, 8 females; 4 d each, 12 mo; age male 33.2 ± 4.4, females 28.1 ± 5.0
India-2	Borgonha et al., 2000	DLW	Farm laborers	18.1 ± 0.6	–	1.90 ± 0.19	–	6 males, 12 d each; age 23 ± 2.1 yrs

TABLE 2. (Continued)

Country–group/study[a]	Reference	Method	Population	BMI		PAL[b]		Sample characteristics[c]
				Males	Females	Males	Females	
Iran	Brun et al., 1979	Fact	Farmers, subsistence, and cash crops (wheat, barley, melons, lentils, cotton)	20.8 ± 1.5 20.5 ± 4.5 21.3 ± 0.8	–	2.12 ± 0.10 2.26 ± 0.34 1.62 ± 0.23	– – –	9 males, 1–2 d each spring, age 38.9 ± 11.7; 13 males, 1–2 d each summer; age 38.1 ± 12.0; 9 males, 1–2 d each, winter, age 38.4 ± 14
Nepal	Panter-Brick, 1993	Fact	Agropastoralists (maize, millet, wheat, barley, tubers)	–	20.7 ± 2.1	–	1.77 ± 1.16 1.89 ± 0.22 2.00 ± 0.19 2.01 ± 0.26	19 females, 2 d each in each of 4 seasons; age 37 ± 15.1 yrs
Philippines	Guzman et al., 1974	Fact	Farmers (rice)	20.2 ± 2.4	–	2.15 ± 0.36	–	9 males, 7 d each, peak agricultural season; age 27 yrs
PNG-Kaul	Norgan et al., 1974	Fact	Farmers at Kaul, subsistence (taro, bananas)	21.9	20.7	1.84	1.70	42 males, 40 females (some P or L), 5–6 d each, over 12+ mo; age n/a
PNG-Lufa	Norgan et al., 1974	Fact	Farmers at Lufa, subsistence (sweet potato)	22.7	22.0	1.77	1.85	40 males, 38 females (some P or L); 5–6 d each, over 12+ mo; age n/a
PNG-Kap	Hipsley and Kirk, 1965	Fact	Farmers at Kaporaka, subsistence (yams, sweet potato, bananas)	22.3	–	1.73	–	8 males, 1 d, over 12 mo; age 27 yrs
Thailand	Murayama and Ohtsuka, 1999	HRM	Farmers (rain-fed paddy rice)	20.0	25.2	2.24 ± 0.31 1.99 ± 0.15 2.36 ± 0.33	1.87 ± 0.27 1.66 ± 0.27 1.97 ± 0.31	8 males, 8 females, 1 d each in each of 3 seasons; ages males 46 ± 4.0 yrs, females 46 ± 4.8 yrs

All studies using the Fact method meet the criteria of continuously recorded activity diaries and measurement of energy cost of major activities via indirect calorimetry. All female subjects were non-pregnant, non-lactating, or lactating infants older than 9 months, unless noted otherwise. The Brazil study is an exception as energy expenditure values were taken from the literature. It is included here for purposes of comparison.
[a]Letter(s) after dash indicates ethnic group or specific place, or in the case of numerals, multiple studies in one location. PNG, Papua New Guinea; Kap, Kaporaka.
[b]Multiple entries are for different seasons. PAL values as reported in the literature except for $n = 4$ studies (Gambia-2, Colombia, Philippines, and Iran) where we calculated it from individual values of TEE and BMR, and $n = 9$ studies (BF-1, BF-2, BF-3, Guatemala, Burma, India-1, PNG-Kaul, PNG-Lufa, and PNG-Kap) where we calculated it from mean values of TEE and BMR. To calculate PAL we first had to calculate BMR for some studies. We did it using individual values where possible (Colombia, Gambia-2, and Iran), and group means for studies that did not report individual data (BF-1, BF-2, BF-3, Guatemala, Burma, PNG-Kaul, and PNG-Lufa). In both cases, we calculated BMR from age, height, and weight using the sex–specific equations recommended by the FAO/UNU/WHO (2004). For BF-1 values for TEE was reported in terms of a "standard" 55 kg woman; we corrected the values to the average body weight of the sample which was 51 kg.
[c]P, pregnant; L, lactating; d, days measurement done on each subject; mo, month; n/a, not available. BMI as reported in the literature except for $n = 3$ studies (Gambia-2, Philippines, and Iran) where we calculated it from individual values, and $n = 9$ studies (BF-1, BF-2, BF-3, Burma, India-1, PNG-Kaul, PNG-Lufa, PNG-Kap, and Gambia-1) where we calculated it from mean values for height and weight.

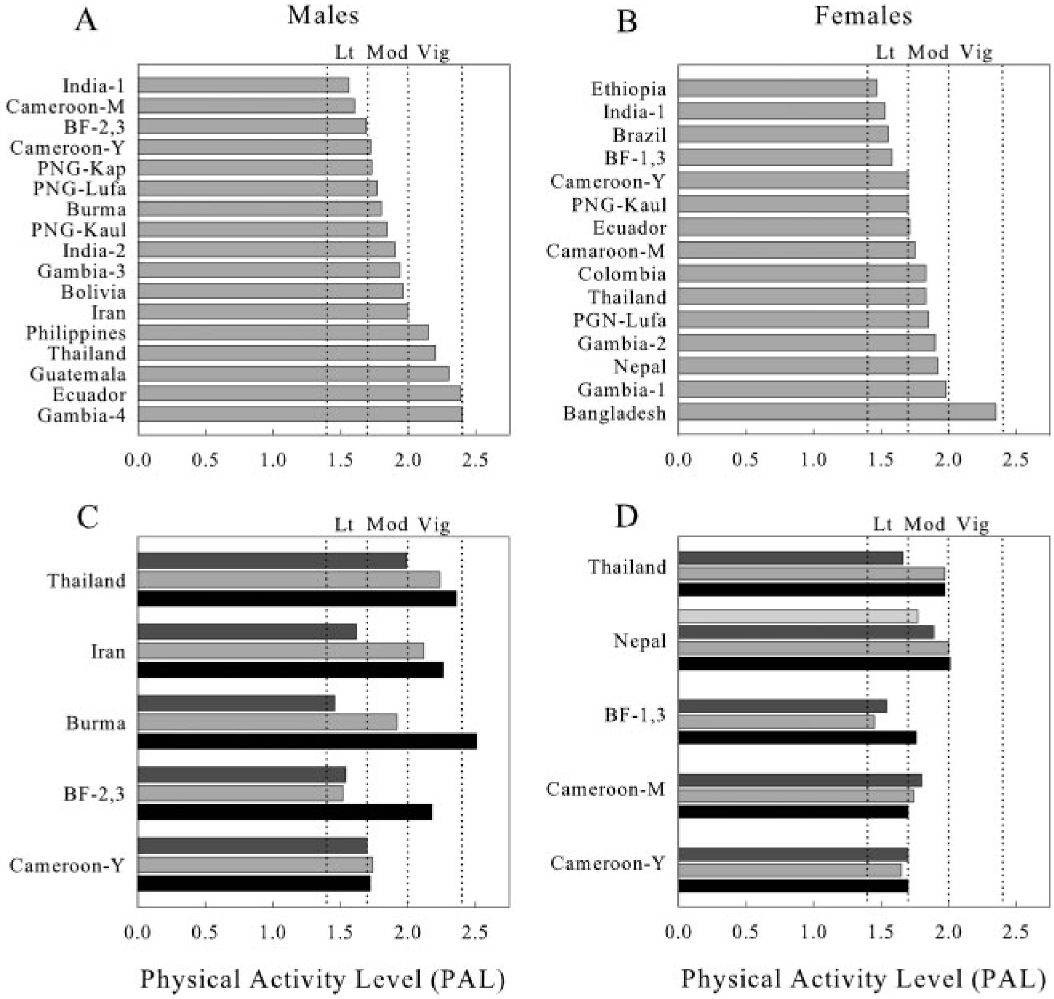

Fig. 1. Mean PAL values for farmers plotted against FAO/WHO/UNU (2004) PAL of light (Lt = 1.40–1.69), moderate (Mod = 1.70–1.99), and vigorous (Vig = 2.0–2.4). Study populations are referred to by country name, and where applicable the name of group within country; multiple references to studies in the same country are indicated by number. References are provided in Table 2. (**A**) Mean PAL values for males, averaged across seasons when study presented data by season. (**B**) Mean PAL values for females, averaged across seasons when study presented data by season. (**C**) Seasonal variation in male PAL values. Bars represent the different seasons reported. (**D**) Seasonal variation in female PAL values. Bars represent the different seasons reported.

female differences and similarities in PAL, is generally lacking in these studies.

PAL values were not associated with BMI as a measure of nutritional status in this data set (see Fig. 3). This is not surprising considering that BMI is a reflection of the balance between both energy intake and expenditure, each of which is influenced by multiple variables. It is likely that energy intake was constrained by food availability, at least seasonally, in some groups, although the studies reviewed here did not generally comment on it. Further, it is noteworthy that four groups (Ethiopian females, India-1 males and females, Gambia-3 males) had average BMIs of less than 18.5 kg/m^2, which is indicative of chronic undernutrition. In such cases the expectation is that PAL is reduced to conserve energy (WHO, 1995). The low BMI values may help explain the low PAL values of the Ethiopian females, and India-1 males and females, but not the PAL values of the Gambia-3 males, which were in the moderate range.

In summary, there are a relatively small number of studies available on the energy expenditure of farmers in developing countries. These studies indicate that the PAL of farmers are predominantly in the moderate range. The fact that the PAL values of only a minority fell into the vigorous activity range, and for some only seasonally, was unexpected and does not match our bias in thinking of developing country farmers as very physically active. Indeed, PAL were surprising low (light activity range) for some groups, and in nonpeak agricultural seasons for other groups.

The highest PAL values (vigorous range) for males and females were associated with farm labor for wages in two of the seven cases (Bangladesh and Guatemala) and with the season of peak agricultural work in two others (Gambia-4 and Philippines) with different farming systems. The degree of emphasis on "cash cropping" which has been used to explain high PAL values (Pasquet and Koppert, 1993), does not clearly separate groups with

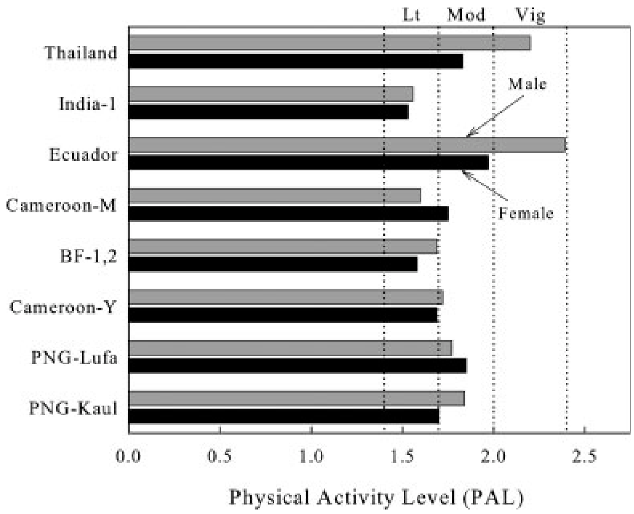

Fig. 2. Mean PAL values for males and females in the same population. Data for Burkina Faso and Thailand are multiseason averages.

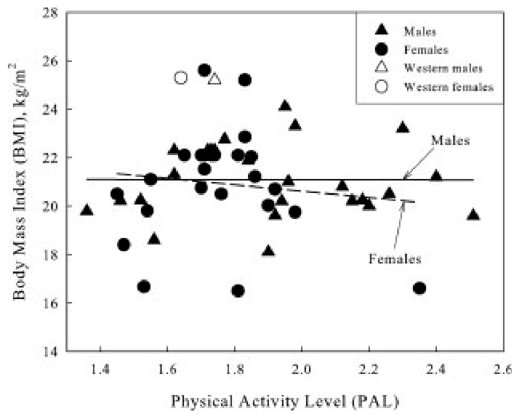

Fig. 3. Regression of PAL (multiseason average) on BMI by sex for all studies of farmers: males, r^2 = 0.01 (P = 0.612); females, r^2 = 0.003 (P = 0.987). Mean values for "Western" populations from Ferro-Luzzi and Martino (1996) are shown for comparison.

higher from those with lower PAL values, perhaps because the relative importance of cash cropping was not clearly specified in any of the studies.

Although the PAL values of farmers were not always as high as anticipated, the majority (83% of males, 63% of females) were at or above the PAL threshold of 1.70 which is associated with lower risk of overweight and obesity (FAO/WHO/UNU, 2004). Average PAL values for farmers were also higher than those reported for "Western" and affluent populations. Ferro-Luzzi and Martino (1996) reported PAL values for "Western" populations in the light to moderate activity range: 1.74 for males and 1.64 for females (see Fig. 3). Similarly, a review by Black et al., (1996) found mean PAL values for affluent populations to be in the light to moderate activity ranges: 1.64–1.85 and 1.68–1.70 for males and females ages 18–49 years of age, respectively. Means for the studies included here are 1.90 and 1.74 for males and females, respectively. Hence, although there is support for the assumption that energy expenditure is high in farmers in developing countries it is not as high as might be expected. It also seems clear that some farmers have activity levels that would be considered light. This variation in PAL values between groups of farmers is no doubt related to the local social, cultural and ecological circumstances of each group because energy expenditure is ultimately a reflection of behavior. The importance of some of these local contextual factors in explaining differences in PAL values are illustrated in the case studies later.

A CLOSER LOOK AT DETERMINANTS OF PHYSICAL ACTIVITY LEVEL

Case studies can help to illuminate some of the factors responsible for between population differences in energy expenditure and hence PAL values. Here we consider two cases: (1) adult women living in the village of Yapu in the Vaupes region of Colombia; (2) adult women living in and around the Caxiuanã Forest Reserve in Brazil (Table 2: Colombia and Brazil, respectively). Both groups were subsistence agriculturists dependent on cassava as a dietary staple and fish as the primary source of protein. Both lived in relatively nonseasonal rainforest environments in very rural settings without the common amenities of electricity and running water.

The women at Yapu self identified as Tukanoan Indians. They lived in a village settlement located about 5 days travel from the nearest town and were self-sufficient in food except for salt (Dufour, 1983). The women living in and around Caxiuanã were of mixed ancestry, primarily Native Amazonian and Portuguese, and self-identified as *Ribeirinhas*. They lived in small settlements along the river, located a long day's travel from the nearest town. Unlike the Tukanoans, *Ribeirinho* families were intimately linked to the larger market economy and exchanged cassava products for other goods including sugar, coffee, cooking oil, salt, and occasionally rice and beans (Piperata, 2005).

The anthropometric characteristics of the women are shown in Table 3. The women in both groups, but especially the Tukanoans, were short in stature, suggesting histories of growth retardation. The women did not differ significantly in BMI or upper arm muscle area (UMA), but they did differ significantly in body fat. They also differed significantly in level of physical activity. The mean PAL value of the Yapu women was in the moderate activity range (1.77) while that of the Caxiuanã women was in the light activity range (1.55). In both groups TEE was estimated by the factorial method using minute-by-minute activity diaries kept by researchers, and BMR was derived from standard equations (FAO/WHO/UNU, 2004; Henry and Rees, 1991). In Yapu energy expenditure in important activities was measured via indirect calorimetry (Dufour, 1984), and some of those same values were used for the analysis of the Caxiuanã data; values for activities not measured were taken from the literature.

The difference in PAL values is striking given that both groups lived in broadly similar humid tropical forest environments and depended on the same crop and wild riverine resources. At one level the differences can be explained in terms of activity budgets and the relative energetic cost of different activities. Briefly, Yapu women

TABLE 3. Characteristics of Yapu and Caxiuanã women (means ± SD)

Characteristic[a]	Yapu $n = 16$	Caxiuanã $n = 18$	Student *t*-test *P* value
Age (yrs)	33 ± 7.7	27 ± 9.3	0.05
Height (cm)	146 ± 4.8	150 ± 3.3	0.005
BMI (kg/m^2)	22.9 ± 2.7	21.1 ± 3.3	0.09
Body fat (%)	27.0 ± 2.0	25.1 ± 6.0	0.02
UMA (cm^2)	41.9 ± 3.0	38 ± 7.4	0.06
PAL	1.77 ± 0.20[b]	1.55 ± 0.15	<0.001

[a]BMI = weight, kg/height, m^2; body fat % estimated from the sum of four skinfolds using the equation of Durnin and Womersley (1974); UMA, upper arm muscle area; PAL, TEE/BMR.
[b]PAL value for Yapu recalculated from original data using Schofield equation for BMR (FAO/WHO/UNU, 2004).

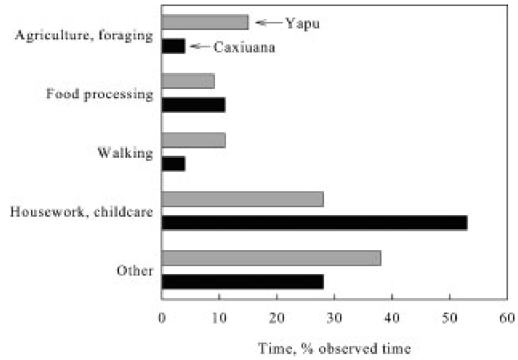

Fig. 4. Time allocation for women in Yapu and Caxiuanã. Values are on a 24-h basis; total observation time of Yapu and Caxiuanã women averaged between 9.2 and 13.7 h per day, respectively.

spent about 15% of their time in subsistence agriculture, and another 9% in food processing (see Fig. 4). Caxiuanã women spent less time on agricultural tasks (4%), and a bit more time on food processing (11%). They also spent more time in activities categorized as housekeeping, cooking, and childcare, while the Yapu women spent more time walking. These differences in time allocation translate into differences in TEE because some activities have a higher energy cost than others. In both groups the higher energy cost activities were agricultural and food processing tasks, some food preparation tasks (in Caxiuanã only), household tasks like the acquisition of water and firewood, and walking, burdened and unburdened, at a moderate to fast pace. The Yapu women spent more time in higher energy cost activities associated with agriculture and food processing, and more time walking than did Caxiuanã women, and these differences explain their higher PAL values.

At another level, the interesting question is why the activity budgets of the Yapu and Caxiuanã women were so different? Answering this question requires a consideration of the factors influencing physical activity as a behavior. Some of the more important factors were the organization of work in the household, the kinds of cassava-based foods preferred, and the settlement pattern. Local ecology also had an effect.

Yapu households were organized such that women were responsible for all the harvesting and processing of agricultural crops (except coca). They had help from their daughters but not their husbands or sons. In contrast, in Caxiuanã husbands and wives collaborated on the agricultural work. Both men and women expressed the cultural ideal that women focus on household tasks, which included cassava processing, and when possible, avoid the strenuous labor of agricultural work. Women also expressed reluctance to bring infants and young children to the cassava gardens where they could be injured (insects and snakes) and would distract adults from the work they needed to accomplish. The integration of males into the harvesting and processing of cassava probably reflects the fact that the principal cassava product, *farinha*, was sold to earn income.

Although both groups were dependent on cassava as a dietary staple they processed the roots somewhat differently. In Yapu, cassava was consumed principally in the form of bread, the production of which involved the grating of raw roots and the separation of the starch—two time and energy intensive tasks. In Caxiuanã, on the other hand, cassava was consumed in the form of *farinha*, a product that required less grating of raw roots and no starch separation. Unlike the Yapu women, those in Caxiuanã had access to mechanical graters, which were typically powered by men. Finally, for the Caxiuanã women, making *farinha* involved a wide range of tasks, many of which required low levels of energy expenditure. Hence, children could assist their mothers, further reducing women's energy expenditure.

The impressive difference in walking time between the Yapu and Caxiuanã women was a function of the differences in time spent in agricultural work since most of the walking in both groups was in travel to and from the cassava gardens. However, local ecology and settlement pattern also played a role. Yapu women had cassava gardens located further from the village than might be expected because agricultural land near the village was limited by patches of savanna vegetation, unsuitable for agriculture. Further, because they lived in a relatively large village (about 18 families) they had to share agricultural land near the settlement with a number of other families. The combination of these two factors meant that, on average, gardens were located about 35 min walking time from the village. In contrast, the Caxiuanã women lived in an area of the Amazon where a greater proportion of the land near settlements was suitable for agriculture. Further, most lived in one or two family settlements strung out along the rivers, and hence had greater access to suitable agricultural land near their homes, typically within about 15 min walking time. Cassava gardens located further from the home were often accessed by canoe and both men and women shared the paddling. After harvesting, roots were placed in the canoe and transported back to the processing huts minimizing overall walking distances and specifically distances walked with a heavy burden.

In summary, two groups of women living in broadly similar environments and dependent on the cultivation of the same crop can have quite different patterns of physical activity and hence PAL values. These differences in physical activity are not a function of biological variables like body size, but rather expressions of differences in behavior related to social and cultural variables like the organization of work at the household level and perceptions of how food crops should be processed, as well as microlevel ecological factors.

CONCLUSION

What do we know about the energy expenditure levels of farmers in developing countries? The literature review revealed that studies of the energy expenditure of farmers are limited both in terms of the number of studies and the geographical regions represented and show some bias toward peak agricultural seasons. The available data suggest that the PAL of farmers range from light to vigorous, and most have PAL values in the moderate range. Adult males tend to have higher PAL values than females, and show stronger seasonal variation. The considerable differences in PAL values between groups of farmers provide little support for the idea that farming as a lifestyle necessarily involves high levels of energy expenditure, especially in the case of women. These data should caution us from making broad generalizations regarding the lifestyle changes driving the nutrition transition. Variation both among and between populations and especially between the sexes are important to note and may help explain differences in the rate and degree of overweight/obesity observed in different regions as well as between males and females.

As the case studies illustrate, between-group differences in PAL can be understood in terms of sociocultural and ecological factors. This is because PAL values are reflections of behavior, which itself is attuned to the sociocultural and ecological context of people's lives. Unfortunately, most studies of PAL among rural farmers lack these contextual data. Hence, to understand how lifestyle changes associated with rural to urban migration translate into increased rates of overweight and obesity will require more ethnographically informed data on the activity patterns of both rural and poor urban populations. The need for local level dietary data, the other side of the energy balance equation, is also pressing because it is easy to imagine scenarios where significant changes in diet as well as energy expenditure would accompany the change to a nonagrarian lifestyle.

ACKNOWLEDGMENTS

The ideas in this paper were first presented in the symposium "Physical Activity, Physical Fitness and Human Biology" at the 2007 Annual Meeting of the Human Biology Association. We would like to thank the people of Yapu and Caxiuanã for their cooperation. We would also like to thank Drs. Walter Neves and Rui Murrieta at the University of São Paulo and Drs. Peter Mann de Toledo and Ima Guimarães Vieira at the Museu Paraense Emílio Goeldi for the support and infrastructure that made the research in Caxiuanã feasible. In addition we would like to thank two anonymous reviewers for their helpful comments.

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