

Original Research Article

Physical Activity in an Indigenous Ecuadorian Forager-Horticulturalist Population as Measured Using Accelerometry

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Objective: Minimal information on physical activity is available for non-Western populations undergoing the transition to a market economy. This is unfortunate given the importance of these data for understanding health issues such as the global obesity epidemic. We consider the utility of using accelerometry technology to examine activity patterns and energy use regulation among indigenous Shuar, an Ecuadorian forager-horticulturalist population undergoing economic and lifestyle change. We investigate sex differences in Shuar activity patterns and the effects of reproductive status on activity. Finally, we discuss the potential of accelerometry use in human biology research.

Methods: Physical activity levels were measured using Actical accelerometers in 49 indigenous Shuar adults (23 males, 26 females) from a rural Ecuadorian community. Female participants were in various reproductive states including pregnant, lactating, and nonpregnant/nonlactating.

Results: Activity counts (AC), activity energy expenditure (AEE), and physical activity levels (PAL) were significantly higher ($P < 0.05$) in males than females. Significant differences in energy expenditure were found among pregnant or lactating females and males with pregnant or lactating partners ($P < 0.001$). Males with pregnant or lactating partners also had significantly higher activity levels than did other men ($P < 0.01$).

Conclusions: Shuar activity levels are relatively low compared to other non-Western populations. Despite increasing market integration, pregnant and lactating females seem to be adopting a strategy noted in other subsistence populations where male participation in subsistence activities increases to compensate for their partners' elevated reproductive costs. Despite certain limitations, use of accelerometry in human biology research shows promise. *Am. J. Hum. Biol.* 23:488–497, 2011. © 2011 Wiley-Liss, Inc.

In indigenous societies, increased market integration, defined as the commoditization of material, food, and labor (Lu, 2007), has been linked to changes in health outcomes such as obesity, Type 2 diabetes, and hypertension (Baker et al., 1986; Friedlander et al., 1987; Huss-Ashmore et al., 1992; Snodgrass et al., 2007). Changes in energy dynamics, or more specifically, increased energy intake and reductions in energy expenditure, have been implicated in this health shift as populations transition from traditional subsistence economies to 2 increasingly sedentary occupations. Numerous studies have documented dietary transitions (e.g., Monteiro et al., 1995; Popkin, 2006), yet relatively few studies have systematically measured physical activity in populations undergoing economic development and lifestyle change. This is unfortunate given the importance of physical activity data for understanding the health effects of market integration and the increasing global prevalence of overweight and obesity.

The relative lack of available data on activity patterns in subsistence-level populations partially reflects the difficulty of accurately quantifying habitual or “free-living” physical activity under field conditions. Physical activity is typically measured using time allocation, doubly-labeled water (DLW), or heart rate (HR) monitors, but all these methods have distinct advantages and disadvantages (Snodgrass, 2011; Westerterp, 2009). Most popula-

tion-level studies of subsistence groups have used time allocation data, but this technique can underestimate energy costs, especially at high levels of physical activity (Leonard et al., 1997; Spurr et al., 1996). DLW, generally considered the “gold standard” for measuring free-living energy expenditure, estimates activity over a relatively long period of time (typically 7–10 days), is expensive and its high cost has limited its use in non-Western contexts (Coward, 1998). HR monitoring, on the other hand, is far less costly, but requires individual calibration of heart rate/energy expenditure relationships, which is time consuming and adds a significant measurement burden for participants.

Recently, technological advances in accelerometry have given researchers a new tool for estimating total daily energy expenditure (TDEE) and physical activity level

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(PAL) under field conditions although, as with all methods, there are advantages and disadvantages to their use (Chen and Bassett, 2005; Plasqui and Westerterp, 2007; Snodgrass, in press; Swartz et al., 2000). Accelerometers are electronic motion sensors typically worn at the waist that can objectively measure the intensity, frequency, and duration of body movement. The devices are also durable, fairly nonintrusive, reasonably affordable, and allow for the estimation of activity variation on shorter timescales than possible using time allocation studies or DLW. Several models of accelerometers have been extensively validated (Blanton et al., 2005; Chen and Bassett, 2005; Heil, 2006; Hoos et al., 2003; Plasqui and Westerterp, 2007), with data quality from accelerometers generally considered second only to DLW (Westerterp, 2009). While accelerometry has been widely applied in Western research contexts, particularly in clinical studies and among athletes, this technology has rarely been used in non-Western field settings.

An area of research where accelerometry could be particularly useful is in determining the effects of increasing market integration on patterns of energy expenditure and sexual division of labor. Most research to date suggests that a transition from a subsistence-based to market economy typically leads to reductions in female activity levels. For example, among Inuit from Igloodik, Canada, who were experiencing the initial stages of economic development, both males and females demonstrated a reduction in subsistence activities, although males maintained relatively higher activity levels than females (Shepherd and Rode, 1996). In the Yakut (Sakha) of Siberia, a herding population that has experienced rapid economic development over the past decade, overall population activity levels were generally low, but they were considerably lower among females than males (Snodgrass et al., 2006). These sex differences in physical activity patterns are shaped by variation in subsistence participation and by other cultural factors. Even subsistence groups living in broadly comparable environments and with similar subsistence economies can have distinct physical activity levels. For example, the Tukanoan women of Colombia have significantly higher activity levels than Brazilian *Ribeirinha* women (Dufour and Piperata, 2008) despite both populations living in Amazonian neo-tropical forest environments. This difference reflects intercultural variability in household sexual divisions of labor (i.e., male participation in harvesting activities), settlement patterns (i.e., proximity to gardens), and minor dietary differences (i.e., amount of processing of the cassava staple).

Since energy is a fundamental limiting resource that must be allocated to different somatic functions, an accelerometry-based energetics approach can provide a useful tool to investigate life history trade-offs such as the energy available for reproduction. An evolutionary life history framework has been useful in understanding the socio-behavioral strategies adopted by subsistence populations for economizing energy expenditure during costly reproductive states such as pregnancy and lactation (Hill and Hurtado, 1996; Stearns, 1992). A small number of studies have addressed the various strategies used by rural women in subsistence-based economies, whose energy conserving options are more restricted than women from urban settings (e.g., Guillermo-Tuazon et al., 1992; Piperata and Dufour, 2007). Among subsistence-based populations in Nepal (Panter-Brick, 1993) and Brazil (Piperata and

Dufour, 2007), women decreased energy expenditure for subsistence activities, presumably as a means of offsetting their elevated energy needs for reproduction, even at the cost of reducing contributions to food production. In some contexts, a decrease in female economic contribution has been shown to prompt a compensatory increase in familial support or, more specifically, male provisioning. For example, Marlowe (2003) observed greater food returns from Hadza hunter-gatherer men with pregnant and lactating wives, a socio-behavioral strategy that extends until the time of weaning.

The present study was designed as a preliminary step towards addressing the data gaps outlined above by using accelerometry to document energetic patterns in the Shuar, an indigenous Ecuadorian forager-horticulturalist population. The goals of this study are to: (1) compare physical activity levels among the Shuar with other populations for which data are available; (2) investigate potential sex differences in physical activity and examine the effects of reproductive status on activity; and (3) discuss the advantages and disadvantages of accelerometer use in human biology research.

METHODS

Ethnographic context

The Shuar are an indigenous forager-horticulturalist population concentrated in the southeastern neo-tropical forest of Ecuador. Approximately 50,000 Shuar primarily reside in the Morona-Santiago and Zamora provinces of Ecuador. Traditionally, Shuar lived in scattered households across the Paute and Upano River Valley between the eastern Andean foothills and the Cordillera de Cutucu mountain range, and in the Yaupi and Morona drainages east of the Cutucu (Harner, 1984; Rubenstein, 2001). Subsistence was based on hunting, fishing, and swidden horticulture. Although these subsistence activities remain common, infrastructural development has led to an increasingly rapid lifestyle change for many Shuar, especially in the Upano Valley. In the past 10 years, dirt roads have been extended to many Shuar villages in this region leading to increased access to market goods and a style of life associated with market integration (e.g., electricity). Despite these changes, Shuar health in more acculturated areas appears to be, in some respects, worse than in less integrated areas, as measured by factors such as body fat, blood lipids, and growth (Blackwell et al., 2009; Lindgarde et al., 2004).

Participants

This study was conducted as part of the Shuar Health and Life History Project (<http://www.bonesandbehavior.org/shuar>) in an Ecuadorian Upano River Valley community located ~40 min by truck from Sucua, the nearest major town center.

Participants included 49 Shuar adult (14–66 years of age; 23 males, 26 females) volunteers, representing ~50% of the adult residents in the study community. Among the female participants, five were pregnant (P), ten were lactating (L), and eleven were nonpregnant/nonlactating (NPNL). Among the male participants, 16 did not have pregnant or lactating wives while the remaining seven males did.

All participants gave individual informed verbal consent, with both parental consent and child consent for subjects under 15 years old. Research was conducted from a Ministerio de Salud health center, and the study design was approved by village leaders, the *Federación Interprovincial de Centro Shuar* (FISCH), and the Office for Protection of Human Subjects at the University of Oregon.

Seasonality

Data were collected over the course of three field seasons: August–September 2008, February 2009, and August–September 2009. Activity data were recorded for each participant for one of the three field seasons. The months of data collection are all considered “dry” months (i.e., periods of moderate rainfall of approximately 300–400 mm) (Sirén, 2007). Furthermore, although neo-tropical in flora and fauna, the Upano River Valley region (located 1000 m above sea level at the base of the Andes) experiences less rainfall and temperature variation across the year than in the Amazonian lowlands east of the Cutucu and, thus, our expectation is that activity will not vary as much seasonally as in some subsistence populations in other regions.

Anthropometry

Participant stature (measured to the nearest mm) and weight (measured to the nearest 0.1 kilogram [kg]) were recorded using a field stadiometer (Seca, Hanover, MD) and digital scale (Tanita BF-558 electronic scale, Tokyo, Japan) respectively, according to established procedures (Lohman et al., 1988). Body mass index (BMI) was calculated by dividing body mass (in kg) by height squared (in meters).

Physical activity

Physical activity was estimated using Actical accelerometers (Respironics, Bend, OR), one of the more widely validated monitoring devices (Plasqui and Westerterp, 2007). Each monitor was initialized before placing it on the participant, which involves entering a start date and time into the Actical 2.1 software platform. During this initialization process, the participant's sex, age, height, and weight were also entered. The Actical begins recording automatically at the designated start time and continues to record activity until the data are downloaded or the device memory reaches its limit (ranging from 11 to 45 days, depending on the user-defined epoch length selected). Each participant wore an Actical at the waist, positioned over their right iliac crest for at least two consecutive days irrespective of weekend or weekday. Participants engaged in their normal activities or those already planned, and kept the monitor on while bathing and sleeping. Following the activity recording period, the data from the Actical were downloaded to a computer.

A shortcoming of the present study is that the number of days the device was worn, the time the device was initialized, and when the device was removed varied between participants. This limitation in the study design reflects the constraints of standardizing the collection of activity data from free-living populations living in remote environments. Participants lived various distances from the health center and although all individuals wore the device for at least two days, a few individuals were not available

to remove the device at a precise time and continued to wear the monitor for several additional days. No participant wore the device for more than four days. The average number of days in which a device was worn was 2.51 days (SD = 0.681). Data were averaged over standardized 24-h periods, so the specific time the device was initialized or removed is unlikely to enter systematic bias in the data.

The accelerometer devices record Activity Counts (AC), which represent the frequency and intensity of acceleration events that occur during user-defined epochs. The epoch length is the period of time the device will accumulate and record ACs, and then reset the counter to zero. Depending on the user preference, Actical epoch lengths may vary between 15 s and 1 min; this option does not affect the actual accumulation of activity counts, only the detail of the data output. The significance of accelerometer epoch lengths will vary depending on the type of research being implemented. For example, shorter epochs are useful for studies examining short, sporadic bouts of activity as with research on children (e.g., Stone et al., 2009). Since the purpose of this study was to examine activity patterns over a period of a few days, the precise length of the epoch is not critical and therefore, the default setting, a 25-s epoch, was used.

Although the Actical software converts ACs into caloric energy expenditure, two additional techniques are employed to estimate energetic parameters from raw accelerometry data: (1) a two-regression model by Heil (2006) to determine activity energy expenditure (AEE) based on ACs (averaged for the recorded days); and (2) total daily energy expenditure (TDEE) calculated as AEE + basal metabolic rate (BMR). BMRs for males and NPFL women were estimated using the Oxford predictive equations according to weight and age (Henry, 2005). BMR among pregnant participants was determined using an appropriate multiplication factor depending on trimester (Prentice et al., 1996). Using FAO/UNU/WHO (2004) guidelines, BMR changes in lactating women were determined as ~675 kcal above their nonlactating metabolic requirements.

Currently, there is no consensus on the best method for adjusting for the effects of body size and composition in energetics, although physical activity level (PAL; TDEE/BMR) is the most commonly used method of comparing activity data in human biology research. However, using PALs as a measure for pregnant women may be complicated by a progressively increasing BMR that occurs throughout the course of pregnancy. Thus, a woman participating in the same activities with similar duration and intensity would show a decline in PAL throughout her pregnant state. For this reason, we also present data for the activity variables AEE and AC in order to examine population-level differences in activity.

Statistical analyses

Pairwise comparisons were conducted using independent samples t-tests, with two-tailed *P*-values and equal variance assumed. Variance components were assessed in R using the *lme* and *VarCorr* procedures from the package *nlme*. Age patterns were fit with thin-plate splines using generalized additive modeling (GAM) by using the *gam* procedure in the R package *mgcv*. ANOVAs were used to assess interactions between sex and the reproductive state of females in a household (i.e., pregnant, lactating,

TABLE 1. Descriptive statistics for anthropometric and activity data^{a,b}

Measure	Males (n = 23)		Females (n = 26)		P	Combined (n = 49)	
	Mean	(SD)	Mean	(SD)		Mean	(SD)
Age (years)	32.7	(12.9)	27.8	(10.7)	ns	30.1	(11.9)
Height (cm)	155.6	(8.6)	146.0	(4.3)	***	149.5	(8.2)
Weight (kg)	58.2	(10.5)	50.0	(8.2)	***	53.7	(9.9)
BMI (kg/m ²) ^c	23.8	(2.8)	23.4	(2.8)	ns	23.6	(2.8)
TDEE (kcal/d)	2,176	(396)	2,033	(374)	ns	2,100	(387)
BMR (kcal/d) ^d	1,403	(170)	1,444	(318)	ns	1,425	(257)
AC ^e	290,064	(128,589)	224,900	(102,905)	*	255,000	(119)
AEE (kcal/d) ^f	762	(290)	573	(227)	*	661	(273)
PAL ^g	1.54	(0.18)	1.42	(0.19)	*	1.48	(0.19)

ns = not significant.

^aTDEE, total daily energy expenditure; BMR, basal metabolic rate; AEE, activity energy expenditure; PAL, physical activity level.

^bDifferences between females and males are statistically significant at * $P < 0.05$; *** $P < 0.001$.

^cWeight divided by height in meters squared (kg/m²).

^dCalculated using the Oxford equations (Henry, 2005).

^eActivity counts (AC) represent the frequency and intensity of acceleration events that occur during a user-defined epoch.

^fAEE from activity counts based on two-regression equation (Heil, 2006).

^gTDEE/BMR.

TABLE 2. GAM models for age, sex, and reproductive status effects on AEE

	Without reproductive status				With reproductive status			
	B	SE	T	P	B	SE	t	P
Intercept	572.60	49.49	11.57	<0.01	653.83	74.68	8.76	<0.01
Sex (Male)	166.62	72.93	2.29	0.03	0.73	96.62	0.01	0.99
PL					-136.84	96.27	-1.42	0.16
Sex (Male) x PL					473.82	145.41	3.26	<0.01
	edf	Ref.df	F	P	edf	Ref.df	F	P
S(Age) Females	1.00	1.00	0.00	0.99	1.00	1.00	0.05	0.83
S(Age) Males	3.44	4.24	1.61	0.19	1.00	1.00	0.21	0.65
Model R ² (adj)	0.18				0.23			

NPNL). Following ANOVAs, post-hoc comparisons were done using two-tailed *t*-tests. Statistical analyses were performed using a combination of SPSS 17.0 (SPSS, Inc.) and R 2.10.1 (www.r-project.org).

RESULTS

Descriptive statistics for age, anthropometric, and activity data are presented in Table 1. Men had significantly higher average AEEs (762 kcal/d vs. 573 kcal/d, $t = 2.56$, $P = 0.01$), PALs (1.54 vs. 1.42, $t = 2.24$, $P = 0.03$), and ACs (290,064 vs. 224,900, $t = 1.97$, $P = 0.05$) than women. However, differences between men and women in TDEE (2,176 kcal/d for men vs. 2,033 kcal/d for women) and estimated BMR were nonsignificant (1,403 kcal/d for men vs. 1,444 kcal/d for women). Controlling for sex, we tested for differences between activity parameters collected during August/September field seasons compared to the field season in February, and between activity levels from weekends (two day averages starting on Friday, Saturday, or Sunday) compared to weekdays. Activity levels from February were lower than activity levels in August/September (marginal means: AEE: 494 vs. 694 kcal/day, $F_{1,45} = 6.32$, $P = 0.02$; PAL: 1.37 vs. 1.46, $F_{1,45} = 5.06$, $P = 0.03$; AC: 199,052 vs. 265,847, $F_{1,45} = 3.23$, $P = 0.08$). Activity levels from weekends were lower than weekdays, but this

difference was not statistically significant (AEE: 525 vs. 662 kcal/day, $F_{1,45} = 2.97$, $P = 0.09$; PAL: 1.38 vs. 1.48, $F_{1,45} = 2.62$, $P = 0.11$; AC: 207,741 vs. 257,159, $F_{1,45} = 1.78$, $P = 0.19$).

We used a random effects model to examine the variance in PALs between participants, and found that 22% of the variance in PALs was attributable to participant identity (variance participant = 0.013, SD = 0.11, Residual = 0.145, SD = 0.21). Similarly, a participant's day one activity level was significantly correlated with his or her day two activity level ($r = 0.37$, $P = 0.01$). Although correlation coefficients between Days 1 and 2 activity levels are modest, Shuar in the study community engage in mixed subsistence and agricultural production, so day to day variability in activity levels is expected, just as it would be under the traditional foraging economy.

We examined the age and sex patterning of activity levels using GAM, and fit thin plate splines to the age pattern (Table 2; Fig. 1). GAM determines the optimum degrees of freedom for the spline fit through GCV minimization. In the GAM models the overall effect of sex was significant ($t = 2.29$, $P = 0.03$). For females the optimum model included no age effect. For males, the overall effect of age was also nonsignificant, but did include additional degrees of freedom ($F = 1.61$, estimated df = 3.44, $P = 0.19$). Examining a plot of the splines and individual data points (see Fig. 1) reveals that the AEE difference between males and females is driven largely by males in the 25 to 35 year age category and that the only obvious age effect is within this age group. Examining only individuals age 25–35 years shows that males and females differed significantly in AEE ($t = 3.33$, df = 17, $P < 0.01$), PAL ($t = 3.05$, df = 17, $P < 0.01$), and AC ($t = 2.05$, df = 17, $P = 0.05$), whereas sex differences in activity measures were nonsignificant for other ages.

When the effect of pregnancy and lactation on activity levels was examined, a clearer picture of the sex differences in activity profiles emerged. We coded a variable indicating whether the individual (for females) or the individual's partner (for males) was pregnant or lactating (PL) and included this in our GAM (Table 2). Including this variable eliminated the age effect and revealed a significant interaction between having a PL female in the household and sex differences in AEE ($B = 473$ kcal/d, $t = 3.26$, $P < 0.01$). Removing the age terms from the model, we ran two-way ANOVAs on AEE, AC, and PAL with sex and the PL vari-

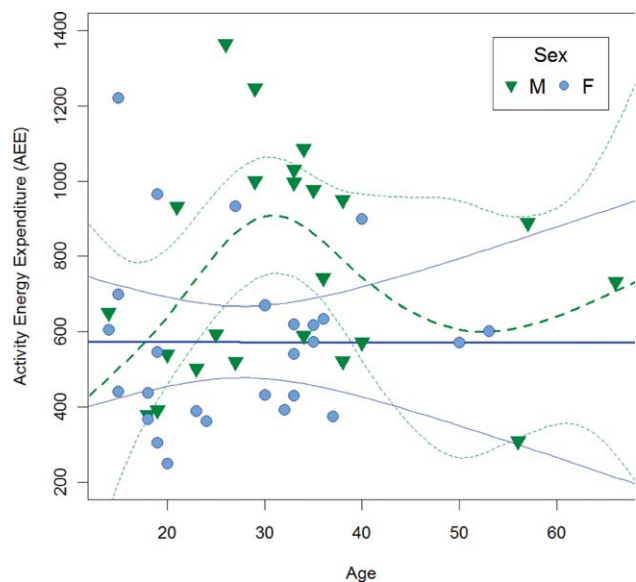


Fig. 1. Activity energy expenditure (kcal/d) by sex and age. Lines are thin plate splines from the generalized additive model in Table 2 that does not control for reproductive status. Solid lines and circles are females, while dashed lines and triangles are males. Lighter colored lines are 95% confidence intervals for the spline value. Note that confidence intervals for males and females overlap except for ages from ~25 to ~35. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

able. The interaction between sex and family reproductive status was highly significant for each activity measure (PAL: $F_{1,45} = 18.8$, $P < 0.01$; AEE: $F_{1,45} = 10.9$, $P < 0.01$; ACs: $F_{1,45} = 6.0$, $P = 0.02$). Including variables for season of collection and whether the data was collected on a weekend did not significantly alter these results (PAL: $F_{1,43} = 15.96$, $P < 0.01$; AEE: $F_{1,43} = 8.45$, $P < 0.01$; ACs: $F_{1,43} = 4.46$, $P = 0.04$). Moreover, neither season nor weekend remained significant in any model.

We next ran post-hoc pairwise comparisons between groups (see Fig. 2). In households without a pregnant or lactating female there were no significant sex differences in activity levels. In families where the female was either pregnant or lactating, males had significantly higher activity levels than females (AEE: $t = 4.79$, $P < 0.01$; PAL: $t = 5.80$, $P < 0.01$; AC: $t = 3.28$, Bonferroni corrected $P < 0.01$). Compared with males without PL partners, males with PL partners had significantly higher AEEs ($t = 2.95$, Bonferroni corrected $P = 0.01$), and PALs ($t = 2.42$, Bonferroni corrected $P = 0.05$), but not higher ACs (Table 3). PL females had lower PALs than non-PL females ($t = 3.86$, $P < 0.01$) but not AEEs or ACs. Table 4 presents descriptive statistics for females based on reproductive status and illustrates that group differences are not the result of activity levels but rather the higher BMRs found in the PL subgroup.

Of the 49 study participants, 13 had partners who were also in the study. These included five monogamous couples and one male with two wives. Of these, four women were pregnant or lactating and three were not (see Fig. 3). Note that the male in Couple 3 is polygynous: he lives primarily with female 3, but is also married to female 4, who lives in a house a short distance away. Both females were lactating at the time of the study. Couple 6 is a young NPPL

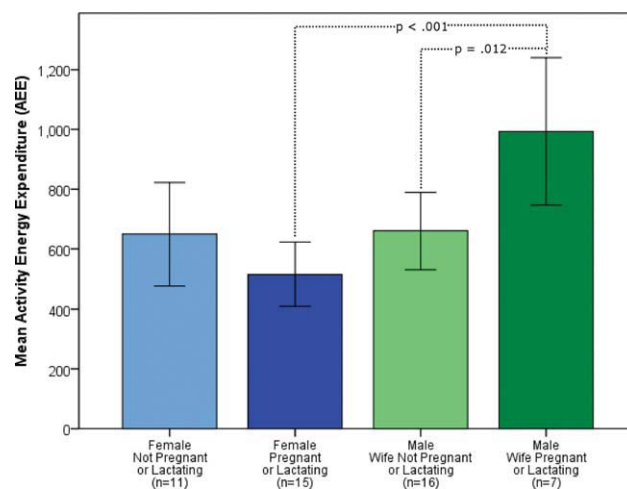


Fig. 2. Mean activity energy expenditure (AEE) by sex and reproductive status. Error bars are 95% confidence intervals for the mean. Two-tailed t -tests were used for pairwise comparisons between males and females in each reproductive category and between reproductive status within each sex. A Bonferroni correction was applied to P -values to account for multiple testing. Nonsignificant P -values are not shown. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 3. Descriptive statistics for males with pregnant or lactating partners (PL) compared with males without PL partners^{a,b}

Measure	Males without PL partners ($n = 16$) Mean (SD)	Males with PL wives ($n = 7$) Mean (SD)	P
Age (years)	33.4 (15.4)	31.0 (4.4)	ns
Height (cm)	154.2 (9.7)	158.8 (4.8)	ns
Weight (kg)	55.1 (10.7)	65.4 (5.0)	*
BMI (kg/m^2) ^c	22.9 (2.6)	26.0 (1.8)	*
TDEE (kcal/d)	2,035 (347)	2,498 (313)	*
BMR (kcal/d) ^d	1,360 (174)	1,505 (112)	*
AC ^e	263,493 (116,902)	350,798 (142,398)	ns
AEE (kcal/d) ^f	661 (242)	993 (267)	*
PAL ^g	1.48 (0.16)	1.66 (0.17)	*

ns = not significant.

^aTDEE, total daily energy expenditure; BMR, basal metabolic rate; AEE, activity energy expenditure; PAL, physical activity level.

^bDifferences between the groups indicated are significant at $P < 0.05$ in an independent samples t -test with equal variance assumed.

^cWeight divided by height in meters squared (kg/m^2).

^dCalculated using the Oxford equations (Henry, 2005).

^eActivity counts (AC) represent the frequency and intensity of acceleration events that occur during a user-defined epoch.

^fAEE from activity counts based on two-regression equation (Heil, 2006).

^gTDEE/BMR.

pair and appears to follow the pattern of PL couples; this characteristic may be explained by their ownership of a small store where they sell a small amount of basic market goods including noodles, rice, eggs, soap, and oil. The NPPL wife often tends the store while caring for her two young children, which may account for why her activity level is relatively low compared to that of her husband. Although the sample size is small, a trend towards higher activity output by males with PL counterparts is evident.

DISCUSSION

This study used accelerometry to investigate physical activity patterns in Upano River Valley Shuar who are

TABLE 4. Descriptive statistics for females during various reproductive states^{a,b}

Measure	Pregnant (n = 5) Mean (SD)	Lactating (n = 10) Mean (SD)	NPNL (n = 11) Mean (SD)	P
Age (years)	24.4 (4.5)	31.6 (7.3)	25.9 (14.3)	ns
Height (cm)	148.2 (4)	146.7 (4.4)	144.3 (4.0)	ns
Weight (kg)	54.1 (7.3)	50.6 (8.4)	47.6 (8.2)	ns
BMI (kg/m ²) ^c	24.6 (2.8)	23.4 (2.7)	22.8 (2.9)	ns
BMR (kcal/d) ^d	1,416 (193)	1,769 (194)	1,161 (99)	***
TDEE (kcal/d)	1,927 (340)	2,331 (234)	1,811 (325)	***
AC ^e	191,847 (121,662)	193,014 (67,560)	268,912 (112,910)	ns
PAL ^f	1.36 (0.15)	1.3 (0.08)	1.55 (0.2)	*
AEE (kcal/d) ^f	511 (238)	519 (180)	650 (257)	ns

ns = not significant.

^aTDEE, total daily energy expenditure; BMR, basal metabolic rate; AEE, activity energy expenditure; PAL, physical activity level.

^bDifferences between females are statistically significant at * $P < 0.05$; *** $P < 0.001$.

^cWeight divided by height in meters squared (kg/m²).

^dCalculated using the Oxford equations (Henry, 2005).

^eActivity counts (AC) represent the frequency and intensity of acceleration events that occur during a user-defined epoch.

^fAEE from activity counts based on two-regression equation (Heil, 2006).

^gTDEE/BMR.

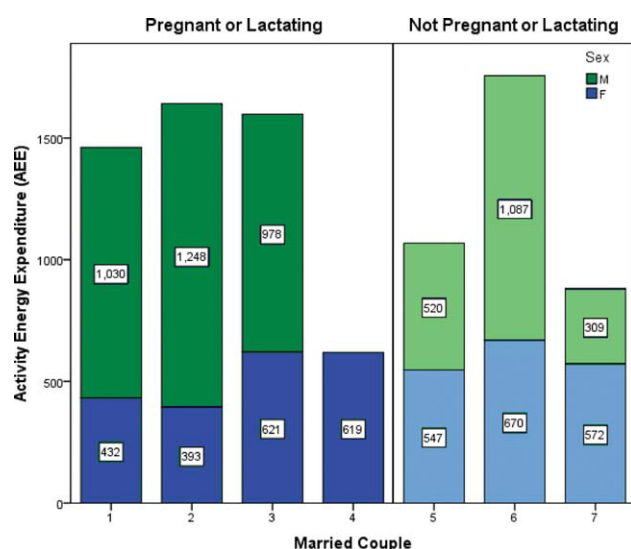


Fig. 3. Activity energy expenditure (AEE) in kcal/d for married couples for which both partners participated in this study. [Color figure can be viewed in the online issue, which is available at www.wileyonlinelibrary.com.]

currently undergoing rapid economic development and lifestyle change. Despite the shift towards increasing market integration, Shuar from the region continue to be dependent on subsistence activities, particularly horticultural production. Most people in the study community actively engage in subsistence activities, spending most mornings and afternoons at their *chacras* (gardens) cultivating the land and harvesting cassava (yuca), plantains, papa china (a local tuber), maize, legumes, and other staple foods.

Physical activity levels for Shuar males are ~ 1.54 , while Shuar females exhibit significantly lower PALs of 1.42. On the basis of FAO/WHO/UNU (2004) standards, average PALs among the Shuar are within the light (PAL ~ 1.4) to moderate (PAL ~ 1.75) range. Other measures of physical activity, including AC and AEE, were also significantly lower among females than males.

It is difficult to compare activity profiles between the Shuar and other subsistence populations since other energetics studies have used a variety of different techniques

to assess physical activity (e.g., DLW, HR monitors, and time allocation). Few studies to date have used accelerometry to estimate energy expenditure in remote field settings. Further, because various types of accelerometers generate different output (e.g., uni-axial versus tri-axial accelerometers), comparing activity levels between studies using different types of accelerometers can also be problematic. Converting activity counts into common energetic parameters using published regression equations is one means of overcoming the obstacle of comparing between accelerometer types. However, comparisons between populations using different activity techniques will always introduce error so results must be interpreted with caution. Nevertheless, these problems of interstudy comparison are not limited to this study. Until researchers employ a standardized means of recording activity data, or systematize analytic procedures for cross-methodological comparisons, such approaches remain essential in order to address important issues in human biology, including those related to global health.

Shuar activity values are low when compared with other subsistence populations (Table 5). Using the DLW method, Snodgrass et al. (2006) found that among the indigenous Yakut of Siberia, individuals who participated in fewer subsistence activities had significantly lower activity levels and consumed a greater percentage of market foods than individuals with more traditional lifestyles. The Shuar participant community is in the process of transitioning towards a market economy, so low activity levels might be similarly related to decreased participation in subsistence behaviors and increased market good consumption. However, among Gambian (Lawrence and Whitehead, 1988) and Andean Aymara (Kashiwazaki et al., 1995) rates of energy expenditure were attributed not to short bursts of intensive activity, but to extended periods of activities with moderate energy cost. In fact, in a comparison of activity levels across populations in developing countries, Dufour and Piperata (2008) show that subsistence activities may not necessarily involve high energy expenditure, and therefore they caution researchers from making generalizations about the energy needs of subsistence-based lifestyles. Lower than expected activity values among the Shuar may therefore be explained by a focus on habitual tasks of long duration requiring relatively low energy output (e.g., gathering legumes, clearing weeds from *chacras*, or processing yuca for the production

TABLE 5. Activity profile comparison between the Shuar and published data sets^a

Population	Source	Method ^b	Sex	n	Age (years)	Weight (kg)	TDEE (kcal/d)	AEE (kcal/d)	BMR (kcal/d)	PAL	Activity level ^c
Shuar	This study	ACC	M	23	32.7 (12.9)	58.2 (10.5)	2,175.6 (395.5)	761.8 (289.5)	1403.3 (169.6)	1.54	L
			F	26	27.8 (10.7)	50.0 (8.2)	2,033.2 (374.4)	572.7 (227.3)	1443.7 (317.8)	1.42	L
Coastal Ecuadoreans	Leonard et al., 1995	HRM	M	5	49 (19)	61.3 (9.2)	2,414.7 (353.5)	885.7	1529	1.58	L-M
			F	5	34 (16)	55.7 (11.5)	1,992.0 (138.5)	767	1225	1.63	L-M
Highland Ecuadoreans	Leonard et al., 1995	HRM	M	11	32 (12)	61.3 (9.2)	3,807.2 (759.5)	2207.2	1600	2.39	H
			F	11	40 (13)	55.7 (11.5)	2,457.7 (707.0)	1205.7	1252	1.97	H
Ache (Paraguay)	Hill et al., 1984; Leonard and Robertson, 1992	TIME	M	n/a	n/a	59.6	3,327	1796	1531	2.17	H
			F	n/a	n/a	51.8	2,626	1232	1394	1.88	H
Yakut (Siberia)	Snodgrass et al., 2006	DLW	M	14	33.3 (9.8)	72.2 (14.5)	3,100.9 (1,939.0)	1254.3 (168.7)	1848.7 (69.1)	1.68	L-M
			F	14	31.4 (9.6)	65.2 (19.5)	2,297.7 (124.7)	765.5 (84.8)	1533.9 (65.0)	1.5	L
Burkina Faso	Bleiberg et al., 1981	TIME	M	11	45 (3.32)	56.5 (1.75)	2,261 (67.4)	n/a	n/a	1.36	L
			F	14	30.6 (2.63)	49.9 (0.92)	2,144 (49.1)	n/a	n/a	1.54	L
!Kung (Botswana)	Lee, 1979; Leonard and Robertson, 1992	TIME	M	n/a	n/a	46	2,319	936	1383	1.68	L-M
			F	n/a	n/a	41	1,712	613	1099	1.56	L
Huli (PNG)	Yamauchi et al., 2001	HRM	M	15	n/a	63.6 (7.3)	3,138 (506.4)	1434	1704	1.84	M-H
			F	12	n/a	53.3 (7.6)	2,639 (621)	1248	1391	1.88	H

^aMeans (SD).^bACC, accelerometry; HRM, heart rate monitors; TIME, time allocation; DLW, doubly labeled water.^cActivity level is determined using the FAO/WHO/UNU (2004) classification system of light (L), moderate (M), and heavy (H) activity levels.

of *chicha* [a locally-made fermented beverage]). Alternately, the low values could be due to the fact that Shuar activity was measured only during dry season months. Although we documented variation in activity levels across the dry season, it seems unlikely that wet season activity levels would be higher, given that Shuar devote less time to hunting, fishing, and garden clearing activities during this rainier period. Future data collection is necessary to test this proposition.

Sex differences in activity patterns

Energetics provides a powerful tool with which to study life history trade-offs under different ecological conditions (Snodgrass, in press). Life history theory examines the age- and context-dependent resource allocations that organisms make between competing demands such as growth, reproduction, and somatic maintenance (Charnov and Schaffer, 1973; Gadgil and Bossert, 1970; Hill and Hurtado, 1996; Hill and Kaplan, 1999; Lessels, 1991; Stearns, 1976). For successful reproduction, women in subsistence-level societies must allocate sufficient resources to energy intensive pregnancy and lactation for extended periods of time, while simultaneously maintaining essential metabolic function and the physical activity levels necessary to acquire food, care for offspring, and engage in other critical daily activities (Bogin, 1999; Ellison, 1994; Hrady, 1999). Biological and behavioral strategies regulating the balance of energy allocation to costly reproductive effort (e.g., pregnancy and lactation) and the energetic costs of food acquisition, somatic maintenance, and parental investment are therefore expected to have evolved. Strategies may involve increasing dietary intake or minimizing energy expenditure, such as through adjusting metabolic efficiency, drawing on fat stores, or reducing activity costs (Piperata, 2009; Piperata and Dufour, 2007; Ulijaszek, 1995). Adoption of any of these energetic strategies may be dependent upon the degree of social support available to the woman, including from husbands or older nonreproductive aged offspring who contribute substantially to the high costs of child-rearing.

This investment from other community members would support heightened energy demands during critical reproductive periods by way of provisioning for young infants and mothers themselves (Hill and Hurtado, 2009; Hrady, 2005; Marlowe, 2003; Meehan, 2009; Reiche et al., 2009). From this perspective, female reproduction and energy dynamics may be better understood within the dynamics of a larger cooperative reproductive effort, which would take into account familial energetics or, at the very least, those of mating partners.

This study was a preliminary investigation of the utility of accelerometry to study potential sex differences in energy expenditure and considered activity patterns based on reproductive status. Males had significantly higher PALs than females, but as over half of the women in the study were either pregnant or lactating, using PALs are problematic when comparing between sexes. When AC and AEE were used as the energy parameters, significant sex differences were maintained.

Male AEE was more variable than female AEE, with female activity values generally clustering under 600 kcal/d. Male activity peaked between the ages of 25–35 years. Almost all pregnant and lactating females fell into this age category; they also produced the lowest total energetic output in the study population. There were no significant differences in energetic output, as measured by AEE and AC, between females who were pregnant or lactating and those who were not. PALs did vary significantly between PL and NPNL females, a difference attributable to the higher BMR costs of energetically costly reproductive states. Interestingly, while BMR requirements are higher in PL women, their work output is fairly constant, comparable with that of NPNL female participants. A more critical observation is the significantly higher activity levels among males with PL partners compared with other males. Although the sample size is small, the data suggest that while the higher basal metabolic costs for PL females do not cause a decline in their energy expenditure, it appears to incite a compensatory increase in the activity output of male partners.

In some subsistence populations, women reduce energy expenditure during pregnancy and lactation, which appears to at least partially offset elevated energy needs (Panter-Brick, 1993; Piperata and Dufour, 2007). A decrease in female economic contribution can present costs to household production and, therefore, may prompt a compensatory increase in male provisioning as noted among the Ache and Hiwi foragers (Hurtado et al., 1992) and the Hadza hunter-gatherers (Marlowe, 2003). Our data suggest that the increased energetic needs of pregnant or lactating females initiates behavioral changes, not by a reduction in activity output by females themselves, but rather through an increase in the activity levels of other family members, more specifically, their male partners. The necessity to contribute to work output may demand women to maintain their baseline activity patterns while men are increasing their own economic contribution as a means of offsetting their partner's up-regulated metabolic costs.

Although the sample size in this preliminary study is small, the low PALs, AEEs, and ACs among pregnant and lactating women coupled with significantly higher activity levels among men with pregnant or lactating partners suggest a cooperative effort to cope with high maternal energy demands. Despite the rapid shift towards increasing market integration among Shuar in the Upano Valley, the results of the present study are consistent with data from other subsistence-based populations in which male and children's subsistence activities appear to be critical for supplementing women's energetic needs during pregnancy and lactation (e.g., Ivey, 2000; Marlowe, 2003; Reiches et al., 2009). Although these data logically fit well with a cooperative breeding model of human reproduction (Hill and Hurtado, 2009; Hrdy, 2000), it should be emphasized that our results are based on a small sample, and further research is needed to confirm them. Nevertheless, the results do indicate the potential utility of accelerometry for investigating such issues.

Field methods of measuring physical activity

Measurement of physical activity outside of a laboratory setting is notoriously difficult and no method is without problems (Snodgrass, in press). A variety of methods are available for estimating physical activity levels and TDEE, the most accurate of which is the doubly labeled water (DLW) technique. DLW yields a measure of TDEE over the course of one to two weeks, based on the elimination rates of two labeled stable isotopes from the body. This technique is generally accepted as the most accurate measure of energy expenditure among free-living humans, and has been used extensively in clinical studies in industrial nations (Black et al., 1996; FNB/IOM, 2002; Speakman, 1997). DLW provides an excellent basis for analysis of average TDEE across longer timescales and is particularly useful for characterizing and comparing general activity levels between men and women, or between populations. Unfortunately, the high cost of DLW has limited its use in populations in the developing world (Coward, 1998). When data are available from non-Western groups, sample sizes are generally small (less than 50 individuals), which makes comparisons between populations problematic. Further, DLW does not provide information on daily or hourly fluctuations in energy use, or the energy costs associated with specific activities.

The time allocation technique is the most commonly used method for estimating activity levels in subsistence populations and can provide a record of daily or hourly changes in activity. This method estimates physical activity by either observing or using interview techniques to estimate the amount of time an individual spends in different activities, and combining this with published information on energy costs of each activity (e.g., FAO/WHO/UNU, 2004; James and Schofield, 1990; Ulijaszek, 1995). Summing the results for one day thereby provides an estimate of TDEE. However, published values for the energy costs of different activities are typically based on only a few individuals and no data exist for many common activities researchers observe in field settings. In addition to being time and labor-intensive, the time allocation technique often substantially underestimates energetic parameters, since it does not record many involuntary activities (e.g., fidgeting). This method is most inaccurate at moderate to high activity levels, often underestimating TDEE by at least 15% (Kashiwazaki et al., 2009; Leonard et al., 1997; Spurr et al., 1996).

Heart rate (HR) monitoring can also be used to estimate physical activity, based on the known relationship of HR to energy expenditure. The HR monitor records HR at a designated interval (e.g., every minute) while participants wear the monitors during waking hours over the course of several days. At the end of the measurement period, HR data is downloaded from the instrument and energy expenditure is calculated. Despite proven accuracy of the measurement compared to DLW (e.g., Kashiwazaki, 1999), there are also limitations to this technique. For example, in order to obtain accurate results, one key issue involves the need for individual calibration of HR with energy expenditure. This process requires the relationship of HR to energy expenditure to be established for each individual both at rest and during graded submaximal exercise (Leonard, 2003).

Technological advances in accelerometry promise to help overcome some of the challenges of affordably quantifying physical activity under field conditions. Accelerometers can objectively measure the movement of the body by detecting and recording acceleration in one or multiple planes (Chen and Bassett, 2005; Gerdhem et al., 2008; Heil, 2006). The devices are durable, noninvasive, relatively inexpensive, and can provide detailed information on physical activity patterns, including the duration and intensity of activity. Several accelerometer devices, including the Actical, have been validated and show a high correlation with oxygen consumption and DLW (Heil, 2006; Hoos et al., 2003; Plasqui and Westerterp, 2007). However, it is important to note that most accelerometer validation studies to date have been conducted in laboratory-based samples of participants from industrialized nations.

The Actical is one of the more extensively validated commercially available accelerometer devices (Plasqui and Westerterp, 2007). Acticals are small, rugged data loggers, equipped with a highly sensitive multidirectional accelerometer. The ability to sense motion in more than a single plane is an advantage for measuring complex human movements (Heil, 2006). The Actical accelerometer generates a variable voltage based on amplitude and frequency of motion and produces an electrical current that varies in magnitude. An increase in the intensity of motion will result in an increase in voltage; this information is integrated over a user-selected epoch and recorded

in onboard memory in the form of "Activity Counts." An activity count (AC) is an arbitrary dimensionless unit that varies between different brands of accelerometer devices, so direct comparisons of raw activity counts from assorted devices are not inherently meaningful. However, ACs can be used to calculate AEE or TDEE using the device software or through accelerometer-specific published regression equations allowing for cross-methodological comparisons yet, as noted earlier, with limitations.

As with other means of activity recording there are restrictions to using accelerometry to determine activity levels and energy expenditure. These limitations vary with the type of device used and how it is utilized. For example, placement at the hip captures gross body movement but may be less sensitive to upper body movements or the energetic costs associated with load-carrying, which may result in underestimations of physical activity output (Swartz et al., 2000). Nevertheless, several studies have documented the validity of hip-placed activity monitors for estimating whole-body energy expenditure when compared to alternative sites such as the wrist and ankle (Freedson et al., 1998; Hendelman et al., 2000; Swartz et al., 2000). Another limitation is that accelerometers do not provide the context of activity, although this may be obtained by simultaneously incorporating other techniques (e.g., daily recall or direct observation). Further, as mentioned earlier, an issue with accelerometer devices that can be extended to all types of activity monitors is that comparison of activity across populations using different models of accelerometers will entail greater measurement error than will studies that use the same device, thus small but statistically significant differences must be interpreted cautiously. However, if one is interested in documenting relative activity differences within a population using identical devices and methods, these are minor limitations.

The current study represents a preliminary step towards greater use of accelerometry in nonclinical, non-Westernized contexts. The results presented here are consistent with predictions based on a life history theory approach to understanding energetics, thus illustrating the potential usefulness of accelerometer devices in addressing such questions. Clearly, at this preliminary stage, comparisons of activity patterns with other populations must be interpreted with caution. However, given the importance of recognizing how shifts in energy expenditure can inform emerging global health issues, and the scant nature of these data from subsistence-level populations, researchers must overcome the urge to wait until a perfect dataset is available prior to reporting their findings.

CONCLUSIONS

This study investigates energetic patterns in an Ecuadorian Shuar community undergoing rapid economic development and lifestyle change. It provides preliminary evidence that activity levels in this transitioning Shuar community are modest, especially when compared with other subsistence populations. This study also investigated life history trade-offs related to female reproductive status. With regard to the Shuar participant community, it suggests that female reproduction and energy dynamics may be better understood within the dynamics of a larger cooperative reproductive effort, including that of mating part-

ners. Despite a shift towards market integration, Shuar pregnant and lactating females may adopt a cooperative strategy noted in other subsistence-based populations where male participation in subsistence activities is higher in order to compensate for their partners' elevated reproductive costs. Finally, this study demonstrates the promise of accelerometry use under field conditions and argues that despite some limitations, this technique offers useful information regarding population-level activity patterns.

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