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Original Research Article

Health and Adult Productivity: The Relation Between Adult Nutrition, Helminths, and Agricultural, Hunting, and Fishing Yields in the Bolivian Amazon

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Objectives: Infectious disease and nutritional stress have both been associated with reductions in adult work productivity and work capacity in the context of wage labor, but less research has investigated their effects among groups relying on more traditional subsistence practices of horticulture and foraging. In this article, we examine the relations among measures of adult nutritional status (BMI, skinfold measurements, and fat-free mass) and infection (presence of soil transmitted helminth infections) and measures of adult work productivity.

Methods: As part of a larger panel study among Tsimane', a foraging–horticulturalist group in the Bolivian Amazon, health surveys, anthropometric information, and the quantity of products (both crops and game) brought into the household were collected for 320 Tsimane' adults over a four-month period in 2003. In addition, a single fecal sample was collected for a sub-sample of 86 adults.

Results: Our analysis shows mixed associations between either BMI or the presence of parasitism and reported adult productivity. Muscularity was not clearly related to adult productivity. In contrast, body fatness (Skinfold z-score) was inversely associated with the average quantity of fish and game brought into the household, especially for men.

Conclusions: These findings suggest that the effects of adult infection and nutritional stress may be less clearly identified outside of the context of wage labor. Further research linking adult physical activity levels and metabolic rates to productivity in diverse contexts is needed. Am. J. Hum. Biol. 25:123–130, 2013.

The relation between nutritional status, infectious disease, and adult activity has implications for understanding foraging patterns (Sugiyama and Chacon, 2000), social behaviors (Low, 1988), and human life-history patterns (Sugiyama, 2004). Although a few exceptions exist (e.g., Sugiyama, 2004), much research examining the effects of nutrition and health insults on measures of adult productivity has focused on wage-labor (Martorell, 1989; Scrimshaw, 2003). In this body of research, the relation between body size, nutritional status, and functional impairment, including decreased physical fitness and work capacity among adult wage laborers, is established (Ulijaszek, 2001). Less research has examined such patterns for groups who maintain traditional foraging or horticulture subsistence practices (Strickland, 2002). This is an important oversight because traditional subsistence patterns are characterized by variation with respect to the intensity and duration of work, daily work patterns, and task allocation across individuals and seasons. In this article, we examine the associations between nutritional status, soil-transmitted helminth infections, and reported labor productivity among a foraging–horticulturalist group in the Bolivian Amazon.

A relatively large body of research has investigated whether under nutrition and disease are related to adult work capacity (a physiological measure of oxygen consumption associated with ability to perform physical activities), which by extension, could result in losses to adult work productivity (an economic measure of income or goods produced). Ample evidence has linked shortness or stunting in adults to reduced work capacity and adult productivity (Bender and Dufour, 2012; Hoddinott et al., 2008; Spurr, 1983). Martorell and Arroyave (1988) also suggest that current nutritional status (height, weight, iron status, and energy intakes) may also be a predictor of adult productivity. Recently, Bender and Dufour (2012) reviewed evidence that current under nutrition has been associated with reduced physical activity levels in diverse contexts. Here, the physiological accommodation of reduced activity levels is argued to extend to reductions in productivity and potential consequences for the household and community. In the research conducted by Spurr and colleagues among Colombian male sugarcane cutters (1975, 1977), adult productivity was related to greater height, weight, and fat-free body mass, but negatively associated with body fat levels. Although this confirms the costs of chronic under nutrition to adult productivity, it also suggests that the relation between current nutritional reserves, such as body fat, may require different explanations including individual motivation, recent physical activity levels, household needs, and ability to adjust work activities (Spurr 1983).

Infectious disease, including helminth infections, could negatively affect adult productivity. Guyatt (2000) divides the importance of infection along two potential pathways which parallel nutritional pathways. Firstly, helminth infections affect current physiological state, including low

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body weight or low blood hemoglobin, which could directly contribute to reduced activity levels and labor productivity. Secondly, in regions where infections are endemic, helminths are an important part of disease stress contributing to poor childhood growth and stunting which, in turn, are associated with reduced work capacity and labor productivity in adulthood. Although the pathways are clear, research has found mixed results when considering the association between helminth infections and adult work productivity. A 1970 study in St. Lucia found significant negative associations between parasitic infection, earnings, and other measures of worker productivity among male banana plantation workers, although follow-up research did not find consistent patterns across time (Weisbrod and Helminiak 1977). Among Bangladeshi female tea-pickers, Gilgen et al. (2001) found a negative association between the intensity of a woman's helminth infection and the amount of crops she picked. Additionally, Gilgen et al. (2001) documented that anemia, commonly caused by hookworm species infections, was also associated with both a reduction in the quantity of crops picked and an increase in the number of work days lost.

Overall, this research suggests that both infectious disease and chronic under nutrition may have a negative effect on adult work productivity. In essence, when faced with chronic under nutrition, reductions in physical activity levels become a short-term accommodation that will allow individuals to achieve energy balance with no obvious biological costs (Scrimshaw and Young, 1989). If undernourished individuals work less, reduce their work pace, or cannot sustain high activity levels for long periods, they may then earn less monetary income than their well-nourished or uninfected peers. However, outside of the context of wage-labor or high intensity activities, individuals may have more flexibility to adjust their behavior and associations between current nutrition, body composition, and work productivity may be more complex. In this view, flexibility in work pacing or intensity may allow individuals to buffer the effects of poor health on work productivity.

In this article, we examine the association between nutrition, helminth infection, and agricultural and hunting or fishing yields among an indigenous Amazonian group of hunter–horticulturalists. Specifically, we focus on relations between measures of adult health (BMI, skinfold measurements, fat-free mass (FFM), and the presence of soil transmitted helminth infections) and measures of adult work productivity, both agricultural and hunting/fishing yields reported for multiple 24-h periods. For this case study, we rely on data collected during a four month period from 320 Tsimane' adults (>16 years of age) in 2003.

BACKGROUND AND METHODS

Study group

Research was conducted among Tsimane', an indigenous group of approximately 15,000 people living in the Beni Department of the Bolivian Amazon. Several recent books contain discussions of the ethnographic and historical background of the area and people (Huanca, 2008; Ringhofer, 2010), so here we provide a short description of Tsimane' adult health and household food production.

Tsimane' subsistence patterns center on hunting, fishing, gathering, and horticulture. Crops including rice, maize, manioc, and plantains are produced in swiddens located near households and along the margins of communities. In addition, households keep pigs, chickens, and other domestic animals for food. Both men and women own and maintain fields and consider the crops produced in that field to be their property. Households are, in most instances, reliant on their own crop production or foraging for food. During her research in 2001, Byron (2003) reported that about 71% of foods consumed within a Tsimane' household came from hunting, fishing, and crop products and that 75% of meat consumed in a household was fish or wild game. Hunting is predominately a male activity, although women and children frequently assist with fishing. According to Gurven et al. (2006), Tsimane' men hunt about two times per week and peak hunting return rates were achieved at 45 years of age. With respect to adult activity patterns and time allocation, Reyes-García et al. (2009) note that men spent more time foraging (15.6%) and in market activities (12.6%) than women (foraging = 5.5%; market = 3.3%), but women spent more time cooking (25.2%) than men (7.2%). Finally, daily weather patterns are related to the likelihood that a person would either forage for fish/game or bring crops into the household (Godoy et al., 2009a).

Tsimane' adults are short but show little evidence of acute malnutrition and recent analysis of panel data has found that BMI is increasing in the area (Godoy et al., 2009b; Zeng et al., in press). Illness is very common, and Byron (2003) noted that an average of 45% of adults reported that some illness had occurred within a one-week period. Between the years of 2002 and 2007, adults reported that an illness had restricted their activity for an average of 1.2–2.2 days in a two-week recall period, depending on the year. The most frequently reported illnesses for adults include respiratory illness (colds, cough, etc.), muscular-skeletal ailments, and gastrointestinal illness. Infectious disease is common and research has reported hookworm species infection levels among adults range from 55% to over 80% (Tanner, 2005; Tanner et al., 2009; Vasunilashorn et al., 2010). In their demographic analysis of mortality trends among Tsimane', Gurven et al. (2007) found that infectious disease, especially respiratory and gastrointestinal infections, was the most common cause of death over the past 50 years.

Subject recruitment and study design

The data presented in this article were collected in association with the Tsimane' Amazonian Panel Study (TAPS), a project aimed at understanding the effects of markets on health and well-being among Tsimane'. All people in 13 Tsimane' communities were invited to take part in the larger study and four of these communities were selected for a parasitological survey. During May and August 2003, demographic, socio-economic, and health survey information were collected for all participating individuals. Additionally, over a one-week period, anthropometric measurements were collected for all individuals and, in four communities, a single fecal sample for parasitological analysis was collected. A total of 485 adults (16–80 years of age) participated in some aspect of the study. Here we present information from the full sample of 485 adults and two linked sub-samples. The first consists of 86 adults with parasitological data and agricultural and hunting/fishing yield information. The second, larger sub-sample of 320 adults contains information on agricultural and hunting/fishing yields along with anthropometric data.

Permission was first obtained to work in each community and then consent was obtained at both the individual and household level. The study protocol was approved by the Tsimane' Grand Council and the University of Michigan and Northwestern University Institutional Review Board for research involving human subjects.

Individual reports of agricultural and hunting/fishing yields (24-h recall). We use 24-h recall surveys to capture information on the amount of foods that an individual reported bringing into the household. On randomly selected days during May–August, 2003, surveyors selected a random 3-h block to visit households in the community. This period corresponded with a time in which households are not harvesting rice or maize, but are relying more on agricultural stores, crops that are harvested year round including manioc and plantains, and foraging products. If all households could not be visited in 3 h, an additional 3-h block was added the following day. During scan visits, we conducted spot observations of ongoing activities (Sacket and Johnson, 1998) and 24-h retrospective recall of quantities of planted farm crops (hereafter agricultural yields) and wildlife (both fish and game, hereafter hunting/fishing yields) brought into the household. In these recall interviews, adults who were present in the household were asked to list and estimate the weight of all the food products (fish, game, and crops) that they brought into the household in the previous 24 h. If an adult was not present, we asked a household head if they were able to report the missing person's 24-h production. A total of 485 adults were visited an average of 4.8 times (range 1–13). We then use these data to calculate: (a) an average individual hunting/fishing yield per visit, and (b) an average individual agricultural yield per visit. Here, we divided the reported total kilograms of product a person brought into the household over the study period by the number of times we completed a scan for the person.

Helminth and anthropometric data. A single fecal sample is commonly used to assess parasitic infection status in field surveys (Garcia, 2001). Individuals willing to participate were provided with a sample container and instructions to bring a fecal sample to the research house (see Tanner, 2005). Immediately after collection, a portion of each sample was preserved in 10% formalin following manufactures instructions (ParaPack, Meridian Diagnostics). The preserved portion was taken to La Paz for microscopic analysis (SELADIS laboratory—Servicio de Laboratorio de Diagnóstico e Investigación en Salud). Preserved samples were concentrated using the formol-ether acetate concentration procedure following WHO guidelines (WHO, 1991) and two observers examined the samples. Individuals were considered positive for a species of gastrointestinal parasite if the diagnostic stages (eggs or cysts) were observed in the sample during microscopic analysis. An individual was considered to have a polyparasitic infection if more than one species of helminth egg was identified in the fecal sample.

Anthropometric data were collected following standard protocol outlined in Lohman et al. (1988). All adults were measured in light clothing without shoes. Height was measured to the nearest centimeter with a portable stadiometer. Weight was measured to the nearest 0.1 kg with a digital scale (Tanita). Skinfold thickness was measured to the nearest 0.5 mm using Lange calipers. Body composition was assessed with three derived measures. First, body mass index (BMI; weight (kg)/standing height (m)^2) was used to indicate general body composition. In order to examine body fatness, we converted the sum of two skinfolds (tricep and subscapular skinfold measurements) to an age and sex standardized z-score for the sum of two skinfolds (Z Skinfold) according to norms by Frisancho (1990). Finally, to examine FFM we first estimated body fat percentage according to the sum of four skifolds (triceps, biceps, subscapular, and suprailiac) using the sex-and age-specific equations of Durnin and Womersley (1974). FFM was then calculated as total body mass minus fat mass.

Data analysis

We began analysis by examining the bivariate associations between adult agricultural and hunting/fishing yields (outcome variables) and (a) the presence of hookworm infections, (b) the presence of multiple helminth species infections. The agricultural and hunting/fishing reported yield data were skewed toward 0 and non-normally distributed. Because of this, we present results of non-parametric Mann–Whitney rank-sum test results for the bivariate analysis.

Tobit linear regression models were used to estimate the association between agricultural and hunting/fishing yields and three anthropometric measures (BMI, Z Skinfold, and FFM). Tobit linear regression models allow data to be censored at 0, which occurred in these data (Long and Freese, 2006). Sixty-four percent of our observations of hunting/fishing yields (n = 204 of 320 adults) and 60% of our observations for agricultural yields (n = 193 of 320 adults) had values of zero. We focus on BMI because it is a commonly used indicator of adult nutritional status. The interpretation of BMI may be difficult in populations where growth stunting is common (Wilson et al., 2011) so we also consider skinfold measurements and FFM as indicators of available energy reserves and muscularity, respectively. Pregnant women were excluded from analyses.

Men and women differ significantly in the quantity of agricultural products, game, and fish they reported in the surveys. Therefore, we ran regression models independently for men and women. We include control variables for the age of the individual, age^2, height (cm), and the number of times the person was interviewed (count) in each model. The amount of income a person reported earning in wage-labor activities was also investigated as a potential control variable. It did not approach statistical significance and was not included in the final analyses. Statistical analyses were conducted with Stata for Mac, 10.1 (Stata Corporation, College Station, TX).

RESULTS

Adult agricultural/foraging and hunting/fishing yields

The 485 adults in the full sample were visited a total of 2,617 times throughout the four month period between May and August, 2003. Each individual adult was visited an average of 4.8 times (range 1–13). Across the randomly selected 24-h periods, game was reported in 3% (n = 78) of the surveys, fish was reported in 11% (n = 281) of surveys,

TABLE 1. Descriptive statistics for Tsimane' adults

	Men	Women	Total
Sample with parasitological data	(n = 42)	(n = 44)	(n = 86)
Hookworm present	81%	84%	83%
Multiple helminth species present	29%	20%	24%
Sample with anthropometric data	(n = 163)	(n = 157)	(n = 320)
Age (years)	37.0 (13.9)	36.3 (14.9)	36.7 (14.4)
Count of surveys (no.)	4.9 (3.5)	4.6 (3.4)	4.8 (3.4)
Average crops (kg)	2.5 (6.9)***	6.6 (10.4)***	4.5 (9.0)
Average fish/game	0.8 (1.7)***	0.2 (0.7)***	0.5 (1.3)
Height (cm)	162.8 (4.9)***	151.1 (4.7)***	157.0 (7.6)
Weight (kg)	62.4 (7.2)***	54.0 (8.2)***	58.2 (8.8)
BMI (kg/m^2)	23.5 (2.1)	23.6 (3.1)	23.5 (2.6)
Sum of two skinfolds (mm)	19.6 (6.5)***	33.6 (11.2)***	26.5 (11.5)
Sum of two skinfolds z-score	−0.7 (0.5)***	−0.5 (0.6)***	−0.6 (0.6)
Fat mass (kg)[a]	10.7 (3.8)***	16.4 (5.0)***	13.5 (5.3)
Fat-free mass (kg)[a]	51.7 (5.1)***	37.4 (4.2)***	44.7 (8.6)

***$P < 0.01$.
[a]Fat mass and fat free mass calculated using % body fat derived from four skinfolds. Sample size for these two measures is 160 men and 153 women (313 total).Mean and (SD) for continuous variables.

TABLE 2. Differences in average amount of crops and game Tsimane' adults reported bringing into household by helminth infection status

	Hookworm		Multiple helminth species	
	Uninfected	Infected	Single species	2+ species
Total	(n = 15)	(n = 71)	(n = 54)	(n = 21)
Crops (kg)	6.8 ± 2.68	4.4 ± 1.13	5.1 ± 1.34	4.7 ± 2.35
Game (kg)	0.2 ± 0.10	0.3 ± 0.08	0.2 ± 0.07	0.5 ± 0.20
Men	(n = 8)	(n = 34)	(n = 23)	(n = 12)
Crop (kg)	1.8 ± 1.08	0.9 ± 0.88	1.2 ± 0.60	0.5 ± 0.30
Game (kg)	0.4 ± 0.17	0.5 ± 0.15	0.3 ± 0.15	0.8 ± 0.33
Women	(n = 7)	(n = 37)	(n = 31)	(n = 9)
Crop (kg)	12.5 ± 4.93	7.7 ± 2.00	8.0 ± 2.15	10.3 ± 5.00
Game (kg)	0.02 ± 0.02	0.1 ± 0.05	0.1 ± 0.05	0.1 ± 0.09

Values are mean ± standard error

and agricultural crops in 14% (n = 360) of surveys. When the data for all individuals were combined for the four month period, 33% of individuals reported bringing fish or game into their household at least once over the 4 months (n = 160 of 485) and 37% (n = 177) reported bringing crops including rice, maize, manioc, plantains, and sugarcane. It is important to remember that the recall periods are randomly selected days throughout the study period, therefore the values should be interpreted as daily averages over the four month study period.

In the sample, the most commonly reported foods were plantains, which represented 67% of the total kilograms of food that were brought into the household. Other important reported foods included manioc (16% of total), game (7%), and fish (5%). Less commonly reported foods brought into the household during the study period include rice (1% of total), maize (1%), and sugar cane (2%). While both rice and maize are important food staples in the area, they were not harvested during the study period and are both relatively rare in the data. Finally, the reported yield variables for agricultural crops and hunting/fishing had a Pearson correlation coefficient of −0.05 (P = 0.52) among women and 0.12 (P = 0.06) among men, suggesting that the activities are independent of each other for women and weakly but positively associated for men.

Important differences are present between the types of foods that women and men brought into their households. The per person daily average reported yield for fish was 0.2 kg (sd = 0.5 kg), game was 0.3 kg (sd = 1.1), and agricultural crops was 4.1 kg (sd = 8.6kg). However, men reported a higher daily average yield of both fish (0.2 kg/person/day) and game (0.4 kg/person/day) than women (0.1 kg fish and 0.1 kg game/person/day). In contrast, women reported a higher daily average yield of agricultural products (6.2 kg/person/day) than men (2.0 kg/person/day). Women reported bringing 68% of total food into the household (total of 7,773 kg by women vs. 2,684 kg by men. In sum, during the study period women reported bringing more agricultural products (mainly manioc and plantains) into the household. Men reported bringing more wild game and fish.

Adult health and agricultural or hunting/fishing yields

Infection with soil-transmitted helminths. To determine whether parasitic infection among adults was related to the quantity of food brought into the household, we focus on a smaller sample of 86 adults (46% males) that participated in both the 24-h yield recall and parasitological survey. The sub-sample was similar to the larger sample in terms of age, gender, BMI, number of times they were surveyed, and the reported yield of agricultural crops. However, the sub-sample did report a statistically smaller hunting/fishing average yield (full mean = 0.45 kg; parasite sample mean = 0.26 kg, t = −2.77; P = 0.007) and had smaller measures of body fatness (Z Skinfold mean in full = 0.57; parasite sample mean = −0.42; t = 2.14, P = 0.035) than the full sample.

Infection levels of the soil-transmitted helminths are unfortunately high among rural and indigenous South American children and adults and, in this sample, soil-transmitted helminth infections were observed in 86% of adults (75 of 86) (Table 1). Eighty-three percent of adults surveyed were positive for hookworm species (*Necator americanus* or *Ancylostoma duedonale*). Other infections observed in this sample include *Ascaris lumbricoides* (16%), *Trichurius trichuria* (10%), and strongloides (5%). Multiple species infections were observed in 24% (n = 21) of adults.

Table 2 shows the results of bivariate associations between helminth infection status and both agricultural and hunting/fishing yields. Hookworm infection was associated with a non-statistically significant reduction in average quantity of agricultural crop yields reported for both men and women. For example, the presence of a hookworm infection was associated with a smaller average quantity of crops reported in a 24-h period (uninfected 6.8 kg vs. infected 4.4 kg; z = 1.45; P = 0.146). Tobit regression analysis (full results not shown) confirm the negative association for both women (B = −4.16; P = 0.769) and men (B = −3.89; P = 0.249) after controlling for covariates in the model, although they do not achieve statistical significance at the 5% level. Similarly, regression analysis also suggests that infection with multiple species was associated with a reduction in average reported agricultural yields for both men (B = −9.04; P = 0.051) and women (B = −1.24; P = 0.882). While these associations are also not statically significant at the 5% level, they could indicate a meaningful reduction in household food availability. With respect to hunting and fishing

TABLE 3. Tobit regression of association between BMI and reported daily average of agricultural and hunting/fishing yields among Tsimane' men and women

	1. Agricultural crops			2. Hunting/fishing		
	B	SE	*P*-value	B	SE	*P*-value
A. Men (n = 163)						
BMI	0.152	0.73	0.835	−0.268	0.115	0.021
Age (years)	2.075	0.794	0.010	0.301	0.089	0.001
Age^2	−0.021	0.008	0.019	−0.003	0.001	0.002
Height (cm)	0.392	0.340	0.250	−0.020	0.046	0.065
Count (no. survey)	1.243	0.354	0.001	0.57	0.078	<0.001
B. Women (n = 157)						
BMI	0.072	0.486	0.882	0.041	0.083	0.622
Age (years)	0.479	0.491	0.331	0.047	0.070	0.498
Age^2	−0.002	0.005	0.631	−0.001	0.001	0.392
Height (cm)	0.457	0.341	0.183	0.021	0.048	0.629
Count (no. survey)	1.029	0.376	0.007	0.176	0.048	<0.001

Robust standard errors are reported. All models include a constant term.

TABLE 4. Tobit regression of association between body fatness (Z Skinfold) and reported daily average of agricultural and hunting/fishing yields among Tsimane' men and women

	1. Agricultural crops			2. Hunting/fishing		
	B	SE	p-value	B	SE	p-value
A. Men (n = 163)						
Skinfold z-score	−3.08	2.58	0.235	−1.04	0.500	0.039
Age (years)	1.997	0.817	0.016	0.199	0.082	0.016
Age^2	−0.202	0.009	0.026	−0.002	0.001	0.017
Height (cm)	0.441	0.343	0.201	−0.022	0.046	0.639
Count (no. survey)	1.128	0.361	0.001	0.337	0.076	<0.001
B. Women (n = 157)						
Skinfold z-score	3.181	2.624	0.227	−0.035	0.369	0.924
Age (years)	0.493	0.450	0.275	0.059	0.072	0.415
Age^2	−0.002	0.005	0.627	−0.001	0.001	0.329
Height (cm)	0.398	0.343	0.248	0.025	0.044	0.570
Count (no. survey)	1.025	0.369	0.006	0.180	0.048	<0.001

Robust standard errors are reported. All models include a constant term.

yields, there were no consistent patterns or statistically significant differences in agricultural or hunting/fishing yields reported by infected and uninfected adults.

Adult nutritional status. We use three indicators to examine whether adult nutritional status is related to the quantity of food that an adult reported bringing into the household: (a) BMI, (b) z-score of the sum of two skinfolds (Z Skinfold), and (c) FFM (kg). Table 1 contains summary statistics for the 320 adults included in the anthropometric sample. Average BMI in this sample was 23.5 m/kg^2 and chronic under nutrition was nearly absent. According to the WHO BMI classifications, less than 1% (3/320) of adults in the sample would be classified as underweight (BMI below 18.5), 76% had a normal BMI (244/320), 20% overweight BMI (65/320), and 3% could be classified as obese with a BMI $\geq$ 30 (8/320). Consistent with previous reports, adults are relatively lean and women have higher average skinfold measurements than men (33.6 vs. 19.6 mm). When converted to z-scores, women also had significantly higher Z Skinfold scores than men (−0.47 for women vs. −0.66 for men; t = 3.13 (318); P = 0.002).

Tobit regression analysis demonstrated mixed associations between nutritional status and our measures of adult productivity. Table 3 suggests that, although the associations are not statistically significant, BMI was positively associated with reported agricultural crop yields in both men and women. In contrast, BMI was inversely associated with hunting/fishing yields among men, with an one point increase in BMI associated with a 0.3 kg reduction in reported hunting and fishing yields (Table 3, Model A2, P = 0.021) after controlling for other variables in the model.

Results also indicate that the association between body fatness (Z Skinfold) and agricultural or hunting/fishing yields is stronger for men than women (Table 4). Most notably, skinfold z-score showed a significant and inverse association with reported hunting and fishing yields among men (Table 4, Model A2, P = 0.039) after controlling for covariates in the model. Among women, body fatness was positively associated with reported agricultural yields, but the association did not reach statistical significance (Table 4, Model B1; P = 0.227).

Finally, there were no consistent associations between muscularity (FFM) and either agricultural or hunting/fishing yields among adults (full results not shown). Among men, FFM was positively associated with daily average agricultural crop yields (B = 0.15; P = 0.749) and inversely associated with reported hunting/fishing yields (B = −0.08, P = 0.207). Among women, FFM was inversely associated with both reported agricultural crop yields (B = −0.23; P = 0.578) and hunting/fishing yields (B = −0.08; P = 0.285). These associations did not achieve statistical significance at the 5% level.

TABLE 5. Tobit regression coefficients of association between anthropometric indicators and agricultural and hunting/fishing yields among Tsimane' adults interviewed five or more times during study period

	Agricultural crops		Hunting/fishing	
	Men (n = 74)	Women (n = 66)	Men (n = 74)	Women (n = 66)
Variable	*B*	*B*	*B*	*B*
BMI (kg/m^2)	0.032	−0.545	−0.301	0.029
Z Skinfold (z-score)	−0.357	−1.600	−1.431**	0.020
Fat-free mass (kg)[a]	−0.130	−0.420	−0.020	0.048

Values are regression coefficients of tobit regression models. Covariates include age, age^2, height, and the number of times a person was interviewed. All models include a constant term.
**P < 0.05.
[a]Sample size for fat-free mass is 62 women and 72 men.

In an effort to test the robustness of the regression models, we excluded individuals who had been visited less than five times in the study period, reducing the sample to 140 adults (Table 5). We then re-ran each model and found consistent findings with the results discussed above for men but not women. In the two models assessing the relation between daily reported average yields of agricultural crops and either BMI or body fatness, the effects are attenuated. Both BMI and body fatness remain inversely associated with hunting and fishing yields among men, but only the association with body fatness (Z Skinfolds) remains statistically significant at conventional levels in both the full and reduced models.

DISCUSSION

We focus on three findings in this discussion. First, although associations between helminth infections and adult reports of agricultural or foraging yields are generally negative, the findings are not statistically significant. We discuss possible explanations for weak associations. Second, we discuss the overall findings of mixed results when examining associations between adult nutritional status and agricultural and hunting or fishing yields, especially among women. Finally, we discuss the association between low body fatness, as measured through skinfold measurements, and higher game and fish yields among men.

Although infectious disease and illness are common among Tsimane' adults, we did not find any strong associations between soil-transmitted helminth infection and adult agricultural or foraging yields. Ample research has reviewed the nutritional (Crompton and Nesheim, 2002), immunological and metabolic (Hurtado et al., 2008; Stoltzfus et al., 1997a) costs of soil-transmitted helminths in humans. The costs are particularly strong for the hookworm species infection because of complications from hookworm-induced anemia (Stoltzfus et al., 1997b). In light of findings in other studies, a likely explanation for our weak associations is our small sample size combined with the fact that helminth infection levels are high in the area (Tanner et al., 2009, 2011; Vasunilashorn et al., 2010). Consequently, this study may contain an insufficient number of uninfected individuals to detect effects. A second possibility is that adults may be self-treating to keep morbidity to a minimum. Ethnobotanical research has shown that people frequently keep plants with antihelminth properties in household gardens and rely on a mix of plants and pharmaceutical treatments to minimize infections (Eve et al., 1998; Quinlan et al., 2002). Frequent treatment and re-infection could weaken associations between infection and measures of productivity. Previous research in the area has documented that adult ethnobotanical and ethnomedical knowledge is associated with improved child (McDade et al., 2007) and adult (Reyes-Garcia et al., 2008) nutritional status along with a reduced risk of a hookworm infection in children (Tanner et al., 2011). In this context, adults may rely on widely available plants and medications with antihelminth properties to minimize infection levels and, by extension, not experience infections that are severe enough to change their daily activity patterns. Because these explanations both link infection to adult agricultural or foraging yields through their effect on nutrition, we now turn to a discussion of adult nutrition and productivity.

The second important finding is that, in this study, adult nutritional status is not clearly related to adult productivity as measured by the amount of agricultural crops or game and fish that individuals reported bringing into their household, especially for women. Although the results do show potentially meaningful reductions in the reported average daily agricultural yields in males with lower BMI, these differences do not reach conventional levels of statistical significance. We feel the results may be due to the fact that the majority of Tsimane' adults do not show clear signs of acute nutritional stress. Additionally, individuals may have the flexibility to adjust their work efforts and behavior to local conditions without suffering significant losses to productivity. For example, in Papua New Guinea, Ulijaszek (2003) found that Purari women's nutritional status did not relate to the amount of time they spent processing the important food staple sago. Although the current study differs in location and relies on recall of productivity rather than on time allocation, it is possible that linkages between nutritional status, infection, and adult productivity may be buffered when individuals and households have the flexibility to adjust task allocation more closely to current energy balance (Strickland, 2002). Food sharing within the household or between households could provide an additional buffer.

The third finding that warrants attention is the inverse association between both BMI and body fatness and hunting and fishing yields among men. In our sample, higher values of both BMI and relative body fatness (as measured through z-score of skinfold measurements) were associated with a lower daily average yield of game and fish reported for men. While muscularity (FFM) was also inversely associated with hunting/fishing yields among men, the association was not statistically significant, indicating that relative body fatness and not muscularity is driving the inverse association between BMI and hunting/fishing yields. Interestingly, this finding is consistent with Spurr et al. (1977) who found that increased body fat (measured as percentage body fat) was associated with a reduction in productivity among sugarcane cutters. There are several possible mechanisms that link body fatness to adult productivity. First, body fat reserves are mobilized for physical activity, so low body fat may result from higher levels of recent exertion, possibly due to greater household needs or a smaller number of other adults who are able to contribute to a household food budget. Secondly, agricultural activities are often more onerous than those associated with fishing and hunting (Dufour and Piperata, 2008; Malina and Little, 2008), and this finding might suggest that males with more limited nutritional reserves may be focusing on the less intense activities of hunting and fishing. A final mechanism might be that excess body fat may impede activity, and therefore be associated with a reduction in adult productivity levels. Although we are not able to empirically distinguish between possible mechanism in this study, future research will examine the role of household conditions. Overall, our findings are consistent with the idea that differences in work intensity are likely to be an important factor mediating the influence of nutritional status on productivity (Leonard, 2010; Panter-Brick, 2003).

A caution of this analysis is that the adult productivity data are based on randomly selected blocks of 24-h recall. Recall data, more commonly used to estimate household consumption patterns, allows for a larger sample size but is possibly not as accurate as weighing products brought into the house. We suspect that, like data derived from 24-h recall surveys of diet composition, there is a tendency of individuals with extreme high or low values to report values closer to the group mean. This has been called the flat-slope syndrome in nutrition (Quandt, 1986), and would have the effect of attenuating the results. A second, and likely equally important caution is that the outcome variables (agricultural and hunting/fishing yields) were not measured on the same number of days for each participant. This might result in an excess of daily average yield values of zero, especially among those interviewed only once or twice. Although we have attempted to account for this by including the number of times a person was interviewed as a covariate in our analysis, it is also possible that an excess of zero-values could have the effect of attenuating any associations between nutritional status and adult productivity. A final caution is that observational data presented here demonstrates only associations. It is possible that individuals with higher nutritional reserves are foraging less because they are getting their calories through purchased foods, which are not considered in this data. Previous work has found that the majority of Tsimane' household food is produced by the household and we expect the effect of purchased foods to be reduced in this sample.

CONCLUSIONS

Within the context of human adaptation and life history, energy is the limiting resource linking adult nutritional status and infection levels to adult work capacity, productivity, and reproduction (Ulijaszek, 2001). Energetic trade-offs link stages of the human life cycle (Bogin, 2001; Kuzawa, 2007; Stearns, 1976) and, through food sharing, have been proposed to link adults to children in a pooled energy budget (Kramer, 2010). Therefore additional research examining the connections between adult energetic reserves, adult labor productivity, and household energy budgets is warranted.

Among many indigenous and rural populations, nutritional stress and infectious diseases remain important health challenges (Hurtado et al., 2005), even in the face of rapid increases in non-communicable disease including obesity, Type 2 diabetes, and hypertension (Coimbra et al., 1999; Huss-Ashmore et al., 1992). This study has suggested that associations between adult productivity, under nutrition, and infectious disease may be difficult to detect outside of the context of wage labor and market-oriented activities. If reducing work intensity or pace is, as Panter-Brick (2003) concludes, an adaptation or accommodation to more transient changes in underlying energetic needs associated with infection or moderate malnutrition, that would help explain the mixed relationships observed in this sample of Tsimane' adults between nutritional status and reported quantities of crops, fish, and game they brought into their household. In this context, traditional subsistence practices might allow for flexibility in individual work patterns that could compensate for energy deficits without compromising productive returns. This might include a slower individual work pace or reducing distance between the household and fields or fishing locations. As land encroachment limits subsistence choices and wage-labor becomes more common with integration into national markets, it is possible that the cost of adult infection and under nutrition will become increasingly visible. In order to further examine the potential causes and consequences of adult nutritional and disease stress, additional research linking physical activity levels and metabolic rates to work capacity and productivity at the individual level are needed, in addition to research that carefully considers how household and community characteristics might buffer these ecological and environmental stresses.

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