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Adult obesity: Panel study from native Amazonians

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ABSTRACT

This paper examines three morphological indicators measuring obesity among a native Amazonian population of foragers-farmers in Bolivia (Tsimane') and estimates the associations between them and standard covariates of obesity (e.g., socioeconomic status [SES]). We collected annual data from 350 non-pregnant women and 385 men $\geq$20 years of age from all 311 households in 13 villages during five consecutive years (2002–2006). We used three indicators to measure obesity: body-mass index (BMI), waist circumference (WC), and body fat using bioelectrical impedance analysis (BF-BIA). We ran separate individual random-effect panel multiple regressions for women and men with wealth, acculturation, health, and household food availability as key covariates, and controlled for village and year fixed effects and village $\times$ year interaction effects. Although BMI increases by a statistically significant annual growth rate of 0.64% among women and 0.37% among men over the five years, the increase does not yield significant biological meanings. Neither do we find consistent and biologically meaningful covariates associated with adult obesity.

1. Introduction

Until recently, conditions of adult overweight and obesity were confined to industrialized nations (Kopelman, 2000; Komlos et al., 2009; Komlos and Baur, 2004; Lakdawalla and Philipson, 2009; de Saint Pol, 2009). Over the last decade, the conditions have become increasingly prevalent in industrializing nations (Caballero, 2001; Monteiro et al., 2004; Méndez et al., 2005; Filozof et al., 2008; Kelly et al., 2008; Nagata et al., 2009; Ackerson et al., 2008; Dasgupta et al., 2008; Huffman and Rizov, 2007) and have drawn public concern because obesity during adulthood increases risks for many chronic diseases, such as diabetes, hypertension, and coronary illnesses (Gray et al., 2000; James et al., 2001; Whitlock et al., 2009; Koch, 2011).

Recent years have seen an explosion of research on the determinants of obesity, mostly in industrialized nations, but also in industrializing nations (Popkin and Gordon-Larsen, 2004). Standard covariates of obesity in industrialized nations include food intake, physical activity, alterations in sleep patterns, and stress (Bell et al., 2001; Orden and Oyhenart, 2006; Goodman and Whitaker, 2002; Goodman et al., 2004; Williamson et al., 1993; Wells et al.,

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2008). Additionally, cross-sectional evidence from industrializing nations suggests that higher socioeconomic status (SES) is associated with obesity because people of higher SES eat more without incurring all the energy costs of obtaining the additional food (Monteiro et al., 2004; Brown and Konner, 1987; Gremillion, 2005; Bindon, 1995). The results of cross-sectional studies in foraging populations suggests that SES is also positively associated with obesity (Lourenço et al., 2008; Dangour, 2003).

When rural communities in industrializing nations enter and gain a stronger foothold in the market economy, changes in SES are usually accompanied by changes in standard covariates of obesity, such as diet, physical activity, and general health (Ulijaszek, 2003; Chrzanowska et al., 2007; Reyes-García et al., 2010; Valeggia et al., 2010). For example, with improvements in income, food availability, and SES, people in rural and urban areas of industrializing nations change their diet. The change has been called the nutrition transition (Popkin, 2001) and consists of an increase in the consumption of foods that are high in fat and dense in energy (Carrasco and Pérez, 2004; Pérez-Cueto and Kolsteren, 2004; Romaguera et al., 2007; Samson and Pretty, 2006; Welch et al., 2009; Leonard and Thomas, 1988). The increased consumption of these foods takes place in part because of changes in relative prices; fats, oils, and processed food become cheaper relative to traditional foods because the former are mass produced, so changes in relative prices of foods induce a shift in the diet away from the relatively more expensive traditional foods. All else held constant, an increase in the consumption of these commercial foods contributes to weight and fat gain (Bell et al., 2001; Orden and Oyhenart, 2006; Chiriboga et al., 2008).

In parallel to the nutrition transition, one finds that general health improves in populations experiencing chronic infections. Economic growth in industrializing nations contributes to improvements in hygiene and in access to modern medical services (e.g., vaccinations) (Batty et al., 2009). Improved health probably contributes to weight gain since the body can divert energy to growth or to weight gain rather than to combat infections (Frankenberg and Thomas, 2001).

In this article we explore the factors associated with obesity in a society in the early stages of economic development. To achieve this aim we address two questions:

(1) Do standard covariates (e.g. wealth) that affect body weight and body fat in industrialized nations also play a role in a low-income rural setting in the early stages of economic development?
(2) Besides standard covariates of obesity, are there other factors (e.g., improvements in general health) that could contribute to obesity in such as setting?

To address the two questions we collect and use panel data composed of five annual surveys (2002–2006) from the Tsimane', a foraging-farming society of native Amazonians in Bolivia. Panel or longitudinal data has two advantages over cross-sectional data. First, it allows us to control for unmeasured and unobserved variables that do not change over time. For example, current health might affect current weight, but both current weight and current health might be associated with an unobserved variable such as genetics. Cross-sectional data does not allow one to control for these types of individual-level variables that remain fixed over time and that might be hard to measure. Failure to control for such variables will likely bias parameter estimates. Second, unlike cross-sectional data which provides only a snapshot of body weight at one point in time, panel data allows one to describe changes in body weight over time using the person as their own control.

The Tsimane' provide an ideal setting to examine weight changes in a society during the early stages of economic development. Relatively isolated until the early 1950s, the Tsimane' started having sustained contact with the outside world after the arrival of Protestant missionaries, on or about the early 1950s (Huanca, 2008; Ringhofer, 2010). Beginning during the 1970s, the construction of new roads from the highlands attracted many different types of intruders (e.g., loggers) into the Tsimane' territory (Leonard and Godoy, 2008). The last two decades have seen the spread of primary schools in much of the Tsimane' territory and a growing trend toward the monetized economy. More and more Tsimane' find it necessary to obtain monetary income by selling crops or forest products, or by working in logging camps or cattle ranches. This said, the Tsimane' are also unique in some respects. Perhaps because they control their territory and outside encroachment has been moderate, they have managed to retain much of their traditional forms of subsistence centered on hunting, fishing, plant foraging, and slash-and-burn agriculture. Furthermore, most Tsimane' still practice preferential cross-cousin marriage, so they retain a high degree of ethnic endogamy. Though Spanish is making slow inroads, all Tsimane' speak fluent Tsimane' and none (to our knowledge) is monolingual in Spanish. Thus, the Tsimane' are a society that is slowly gaining a foothold in the market economy, but so far that mode of incorporation has been at arm's length; they still decide how much of the outside world to incorporate into their daily life – and this despite nearly half a century of exposure to Westerners.

2. Methods

2.1. Sample selection and data

We collected data from participants in the Tsimane' Amazonian Panel Study (TAPS), which follows 962 females and 1033 males of all ages from all households ($n = 331$) in 13 Tsimane' villages along the Maniqui River, department of Beni (Leonard and Godoy, 2008).[1]

[1] The complete data and its documentation, along with publications from the TAPS project, are available for public use at the following web address: http://www.tsimane.org/research/pgs/panel.html. Before enrollment in the study we obtained assent from participants. The institutional review board for research with human subjects of Northwestern University (project number 0007) and the Great Tsimane' Council approved the study.

We limited the main analysis to the following groups: (1) people ≥20 years of age to enhance comparison with other studies of adults and (2) non-pregnant women. We included lactating women in the main analysis to avoid a reduction in sample size, but in the sensitivity analyses we controlled for lactation, and we also repeated the main analysis without lactating women because lactation might affect weight (Valeggia and Ellison, 2003; Frisancho, 1993; Hatsu et al., 2008; Lederman, 2004). The final sample used in this article contains 735 people ≥20 years of age (women = 350; men = 385).

2.2. Outcome variables: body mass and body fat

Several indicators have been used to measure obesity, including: body-mass index (BMI = body weight in kg/ height $(\mathrm{m})^2$), body fat measured with bioelectrical impedance analysis (BF-BIA), and waist circumference (WC). BMI and WC are proxy measure of body fat. Each indicator has strengths and limitations (Kopelman, 2000; Burkhauser et al., 2009). BMI is easy to calculate, but does not distinguish fat from muscle. BF-BIA is a simple and convenient way to measure body fat, but is confounded by body hydration and body temperature. Another limitation of BF-BIA has to do with the reference values, which often come from industrialized countries (Gallagher et al., 2000). To the best of our knowledge, these values have not been computed in industrializing nations. If so, we may underestimate the prevalence of obesity in the study sample when reporting descriptive statistics. However, because the values may be systematically different, we would expect less bias when estimating regression parameters. WC measures upper body fat deposition but does not accurately reflect intra-abdominal fat. Recognizing the limitations of any one measure, we use these three indicators to measure obesity: (i) BMI, (ii) BF-BIA, and (iii) WC.

To minimize errors when taking anthropometric measures, we asked participants to wear light clothing and to take off their shoes and hat. We used most of the protocol of Lohman et al. (1988) to measure standing physical stature (height). We used a portable stadiometer to take one reading of height, which we recorded to the nearest 0.1 cm. Elsewhere (Godoy et al., 2008, 2009a) we provide more details on how we measured height. We used a Tanita BF522W scale (Tanita Corporation of America, Inc) to measure both weight (recorded to the nearest 0.1 kg) and body fat using bioelectrical impedance analysis (BF-BIA), and used Gulick fiberglass tape to measure WC (recorded to the nearest 0.1 cm). Before the actual measurements, one person was measured with all the Tanita scales used in the study to calibrate them. The readings of scales for BF-BIA were compared with each other and adjusted if there were discrepancies. Thus, the measures from different scales were comparable even though we used different scales to measure BF-BIA. As a validation of accuracy of BF-BIA, we examined the correlation between BF-BIA and skinfold and found that these two indicators were highly correlated with a correlation coefficient of 0.72 ($p < 0.000$). Three permanent surveyors of the TAPS team were trained to take anthropometric measures during the early surveys of the panel study. Each surveyor worked with a translator. The team of surveyor and translator typically followed the same people and households to reduce the likelihood of increasing measurement errors from changes in data collectors.

After measuring the three outcomes we created dichotomous variables to indicate whether an individual's measure exceeded the upper limit of the normal range, using reference values for each of the three outcomes. For BMI, the reference value is 25 (National Institutes of Health, 1998). For BF-BIA, we used the reference value for Asia reported by Gallagher et al. (2000) to define the dichotomous variable. For WC, the reference value is 88 centimeters (cm) for non-pregnant women and 102 cm for men (National Institutes of Health, 1998). Although the reference values could be different between industrialized and industrializing countries, using reference values from industrialized countries in the regression analysis is less problematic. As long as the distribution curves of the three outcomes are similar between industrializing and industrialized nations, the regression results should be valid because the reference values will affect only the constant.

2.3. Key covariates

The four main types of covariates in the regressions were wealth, food availability (the first two categories for question 1), acculturation measured by schooling and fluency speaking Spanish, and general health measured by bed-ridden days due to illness (the last two categories for question 2). To examine question 1 we would have liked to include a measure for physical activity, but we did not collect such data. We use italics to refer to the name of variables in the regression models.

2.3.1. Wealth

We measured a person's wealth, or the monetary value (adjusted for inflation) of 22 physical assets owned by the person at the time of the interview. The 22 physical assets included: (1) five assets made from local materials (e.g., arrows, canoes), (2) 13 physical assets acquired in the market (e.g., guns, metal cooking pots), and (3) four domesticated animals (e.g., chickens, cattle). The assets were selected to cover the range of wealth differences between rich and poor people and to cover differences between women and men (Huanca, 2008; Martínez-Rodríguez, 2009; Reyes-García, 2001). For example, only the wealthier Tsimane' own cattle, but most Tsimane' own chickens. Women tend to own metal cooking pots but only men own guns. To estimate the value of a person's wealth, we asked subjects how many of the assets they owned at the time of the interview, and multiplied the quantity of each asset by the current price of the asset in the village or in the nearest town. We then added the value of the 22 assets to arrive at an overall measure of a person's wealth in physical assets.

2.3.2. Food availability

We measured food availability in a household using a one-week recall of 21 foods entering the household through the following sources: (1) agricultural and livestock production, (2) hunting and gathering, (3) purchases, and (4) gifts received. We asked the female head of the household to report the amount used of each of the 21 foods. We obtained current prices for the 21 foods in a community survey with key informants (e.g., Tsimane' school teachers). From an unpublished study using 24-h recalls with a subsample of the studied population, we found that the 21 foods accounted for >90% of energy intake in a household. We used Latin American and Andean food composition tables (Flores et al., 1971; Hernandez et al., 1977), which show the energy content for each of the 21 foods (kilocalories [kcal]/100 gram edible portion), to convert the amount of foods (e.g., manioc) to its energy content (kcal/week/household). We then adjusted the food availability in a household for household size and composition by creating a variable named "male adult equivalent", which counts the number of male adult equivalent in the household. The male adult equivalent is calculated for each household member based on standard energy needs of the household member of a given gender and age. For example, an adult woman is equivalent to 0.75 male adults given that the standard energy needs of an adult woman is about 75% of the standard energy needs of an adult man. We divided the total food availability of a household in a week by the number of male adult equivalents in the household and the number of days per week of 7 as a measure of food availability (kcal/day/male adult equivalent) and rescaled it in 10 kcal/day/male adult equivalent. The method does not allow one to quantify individual-level food intake, overestimates food intake in the household because it does not adjust for stored or wasted foods, and excludes foods consumed outside of the home. Despite these limitations, the method has been effective in capturing variation in food availability across households and has been used in other Latin American nations (Leonard et al., 1993, 1994; DeWalt, 1983).

2.3.3. Schooling and fluency in spoken Spanish

We asked people about the maximum number of years (or highest grade completed) of formal schooling they had attained. Protestant missionaries introduced the first schools in the Tsimane' territory, wrote the first textbooks in the Tsimane' language for primary schools, and in cooperation with the Bolivian government, until recently played a dominant role in running the primary schools. At present, all the villages in the panel and over half of the villages in the Tsimane' territory have a primary school (Godoy et al., 2007). To receive middle-school or high-school education, Tsimane' typically move to the main towns in their territory.

During the interview, surveyor's judged the respondent's ability to speak *Spanish*, Bolivia's national language. Surveyors coded the variable *Spanish* as 0 if the person was monolingual in Tsimane' or if the person spoke only some Spanish, and as 1 if the person spoke fluent Spanish. We regard a higher level of schooling or greater Spanish fluency as evidence of more acculturation to Bolivia's national society.

2.3.4. Bed days

The variable *bed days*, a proxy for short-run self-reported health, refers to the total number of days spent in bed from illness during the 14 days before the interview (range: 0–14). We used it to measure the general health of adults. We asked people to report the information directly and accounted for partial days spent in bed.

2.4. Control variables

Control variables included: (a) age, (b) real or inflation-adjusted monetary income, (c) attrition, (d) baseline measures of the outcome variable, and (e) a full set of dummy variables for years ($n = 5 - 1 = 4$), villages ($n = 13 - 1 = 12$), and interaction of years $\times$ villages.

2.4.1. Age

We asked people to report their age in years or to show us their birth certificate. Some people were unsure about their age. A team of Tsimane' and Bolivian researchers spent 2008 verifying and correcting self-reported ages by comparing the self reported age with the date of major historical events or by comparing the estimates with the ages of adults with known birth dates. We use the age estimate made by the TAPS team in the analysis. We squared age (age^2) because the association between (i) body mass or body fat and (ii) age might resemble a parabola (Dangour, 2003).

2.4.2. Income

We asked people to report their monetary income from the sale of goods and earned wages for the 14 days before the interview. The inclusion of income helps to separate the effect of wealth from the effect of temporary income. We converted nominal measures of income and wealth (see above) into real measures using deflators produced by the Bolivian Government (Godoy et al., 2009b).

2.4.3. Attrition

Of the 692 people in the study, 28.78% were present and surveyed during all five annual surveys, 23.73% were present during four surveys, 15.48% were present during three surveys, 16.21% were present during two surveys, and 15.77% were present during one survey. We created a variable called *count* to capture the total number of times during the five years that we surveyed and took anthropometric measures of a person. We included the variable *count* as a control because attrition might bias parameter estimates.

2.5. Statistical analysis

We first describe changes over time of the three indicators of body morphology. With particular attention to BMI, we examine its trend over time using an individual fixed-effects model with the natural logarithm of BMI as a dependent variable and survey year as an explanatory variable. In the main multivariate analysis we used random-effects models to examine factors associated with obesity. In the sensitivity analyses, we introduce two changes to the models used in the main analysis: we use individual fixed-effects models and exclude lactating women. In further analyses (Section 3.4), we use logistic regressions to identify covariates of obesity.

3. Results

3.1. Descriptive and bivariate results

Table 1 shows changes in the outcome variables and selected covariates between the baseline year (2002) and the last year of data used (2006). The outcomes reveal no clear trend in weight change when considering only the first and the last year of the panel. Among women, one outcome (BMI) increased while another outcome (WC) decreased, and one outcome (BF-BIA) did not change significantly. Among men, two outcomes showed no changes (BMI, WC) and only one outcome increased (BF-BIA). For the two covariates listed in Table 1, we found that wealth improved among women while self-reported poor health declined among men.

Further examination of secular trend of BMI using an individual fixed-effects model, using BMI in natural logs as the dependent variable and year when the measures were taken as the independent variable, suggests that during 2002–2006, BMI increased by an annual growth rate of 0.64% among women ($t = 5.94$, $p = 0.001$) and 0.37% among men ($t = 4.83$, $p = 0.001$).

Table 2 shows the number of people who experienced a change in weight category between 2002 and 2006. In the table we report count data for the number of people whose BMI fell below or above 25 at baseline (2002) and 2006. For example, the number 238 in the top left cell of Table 2 means that there were 238 adults whose BMI <25 in 2002 and who were in the same category in 2006. These figures suggest that between 2002 and 2006, 8.9% (30/336) of adults became overweight or obese, while only 1.5% (5/336) of adults regressed from being overweight or obese to having BMI < 25 (McNemar's χ^2 of 17.8; $p = 0.001$).

Table 1
Comparison of changes in outcome variables and key covariates between baseline year (2002) and last year (2006) of the panel for adult Tsimane' ≥20 years of age: mean and standard deviation.

Variables	2002	2006	Difference[a]
Women			
Outcomes			
BMI	23.09 ± 2.78	23.83 ± 3.44	0.74*
BF-BIA	26.13 ± 6.44	26.53 ± 7.20	0.40
WC	86.99 ± 9.19	83.17 ± 8.61	−3.82***
Covariates			
Wealth[b]	538.11 ± 453.66	733.93 ± 657.82	195.82*
Bed days	1.96 ± 3.96	2.05 ± 2.99	0.09
Men			
Outcomes			
BMI	23.40 ± 2.31	23.75 ± 2.59	0.35
BF-BIA	16.59 ± 4.36	18.18 ± 5.58	1.59***
WC	83.95 ± 6.16	83.53 ± 7.33	−0.42
Covariates			
Wealth[b]	1652.48 ± 1373.95	1803.02 ± 1298.92	150.54
Bed days	2.35 ± 4.78	1.22 ± 2.33	−1.13***

BMI: body mass index; BF-BIA: body fat measured with bioelectrical impedance analysis; WC: waist circumference.
[a] *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$ in two-tailed t-test comparing difference in means between baseline (2002) and last year (2006).
[b] *Wealth* is measured in Bolivianos.

Table 2
Progression of weight (BMI) from 2002 to 2006 among Tsimane' adults ≥20 years of age.[a]

BMI distribution in 2002:	BMI distribution in 2006:	
	BMI < 25	BMI ≥ 25
BMI < 25	238	30
BMI ≥ 25	5	63

BMI: body mass index.
[a] The categories are based on guidelines from the National Institutes of Health (1998).

Tables 1 and 2 are adequate as a descriptive first step to set the empirical stage, but need to be read with caution because those estimates rely only on end-year values (2002 and 2006). For example, comparison of women's BMI between 2002 and 2006 in Table 1 reveals an increase between those two years, but ignores information about all the years in between. Furthermore, the sample size of Table 2 is 336 rather than 735 people noted earlier because the balance were people who appeared during the middle years (2003–2005, inclusive), but not during the beginning and the end years of the panel. Because it takes into account all the years of the panel, more credence should be placed on the multiple regression results, presented next. Also, because of attrition one needs to estimate regression parameters conditional on the number of times people were measured and surveyed.

3.2. Main regression results

The results of multivariate regressions suggest that wealth (a proxy for SES) bore an ambiguous association with the three outcomes (Table 3). Wealth was associated with BMI and BF-BIA, but not with WC. A 1%-increase in a woman's wealth was associated with an increase in BMI of only 0.01% ($p = 0.01$). Among men, wealth was associated with increased BF-BIA, but not with BMI (Table 4). A 1%-increase in a man's wealth was associated with an increase of 0.04% ($p < 0.001$) in a man's BF-BIA. Taken together the evidence suggests that wealth was not an important covariate of the three outcomes because: (i) the coefficient for *wealth* was statistically significant in only two of the six regressions and (ii) the effect size for *wealth* was small.

Surprisingly, we did not find an association between (1) obesity and (2) food availability. None of the coefficients for food availability was statistically significant, although the consistent positive sign of the coefficients suggests a potential positive relation between food availability and obesity. The size effect for the coefficient of food availability was small.

We did not find an association between improved general health and obesity. All the coefficients for *bed days* bore the expected sign (<0). However, none of the coefficients for *bed days* showed statistical significance.

Table 3
Random-effects panel linear multiple regressions of Tsimane' adult body morphology.[a]

Covariates[b]	Measure of body mass and fat (dependent variables) in natural logs:		
	BMI	BF-BIA	WC
	[a]	[b]	[c]
A. Women			
Wealth	0.010*	0.017	0.000
Food	0.005	0.011	0.014
Schooling	−0.008	0.016	−0.001
Spanish	0.006	−0.009	0.017
Bed days	−0.000	−0.002	−0.001
N	972	946	961
B. Men			
Wealth	0.003	0.037***	0.003
Food	0.003	0.004	0.005
Schooling	0.003	−0.011	0.003
Spanish	0.001	0.012	0.003
Bed days	−0.001	−0.004	−0.001
N	1013	988	1006

BMI: body mass index; BF-BIA: body fat measured with bioelectrical impedance analysis; WC: waist circumference.
[a] Variables measured annually, 2002–2006 (inclusive). Standard errors have been corrected for individual-level clustering and heteroskedasticity. These regressions also control for: (i) baseline measure of the outcome, (ii) *count*, (iii) individual real monetary income, (iv) *age* and *age*^{2}; and (v) dummy variables for years, villages, and interaction of year × village.
[b] *Wealth* is measured in Bolivianos in natural logs; *food* is measured in 10 kcal/day/male adult equivalent; *schooling* is measured in years; *Spanish* is coded as 1 if an individual speaks fluent Spanish and as 0 otherwise; *Bed days* is measured in days.
* $p \le 0.05$, ** $p \le 0.01$, *** $p \le 0.001$.

Table 4
Individual fixed-effects panel linear multiple regression of Tsimane' adult body morphology.[a]

Covariate[a]	Measure of body mass and fat (dependent variable) in natural logs:		
	BMI	BF-BIA	WC
	[a]	[b]	[c]
A. Women			
Wealth	0.006	0.012	−0.001
Food	0.012	0.026	0.020
Schooling	−0.017	−0.029	−0.023
Spanish	0.004	−0.025	0.011
Bed days	−0.002	−0.005	−0.005
N	972	946	961
B. Men			
Wealth	0.002	0.040*	0.004
Food	0.003	0.017	0.012
Schooling	0.005	0.048	0.001
Spanish	0.000	−0.001	0.000
Bed days	−0.004	−0.022*	−0.004
N	1013	988	1006

BMI: body mass index; BF-BIA: body fat measured with bioelectrical impedance analysis; WC: waist circumference.
[a] Same notes as in Table 3. Regressions are identical to regressions in Table 3, except here they are run with individual fixed-effects and with the natural logarithm of *bed days* +1 to facilitate the discussion of results in the text.

Neither did we find an association between (i) acculturation and (ii) obesity. None of the coefficients for *schooling* or for *Spanish* were statistically significant.

3.3. Sensitivity analyses

Table 4 shows the results of individual fixed-effects regressions. The coefficients of the regressions with individual fixed-effects continue to point in the same general directions as those already discussed, with still small size effects.

After controlling for individual fixed-effects, the positive association between *wealth* and BMI disappears among women, but remains positive and significant among men when using BF-BIA as an outcome (Table 4). Food availability continues to bear no association with obesity among women. Unlike the results from the random-effects models that *bed days* bore no association with any outcomes, the results from the fixed-effects regressions suggests that *bed days* was negatively associated with BF-BIA (Table 5, $p = 0.05$), but only among men. The coefficients of *bed days* in section B of Table 4 imply that a 1% increase in the number of bed-ridden days among men would be associated with only ∼0.02% lower BF-BIA. We re-estimated the regressions using raw values of *bed days* and found that the association between *bed days* and BF-BIA remained negative and statistically significant

Table 5
Odds ratios from random-effects panel logistic multiple regressions among Tsimane' adults.[a]

Covariate[a]	I. Women			II. Men		
	BMI	BF-BIA	WC	BMI	BF-BIA	WC[b]
	[a]	[b]	[c]	[a]	[b]	[c]
Wealth	1.26	0.87	0.10	2.12*	1.34	2.50
Food	1.11	1.70	1.59	0.82	1.70	0.31
Schooling	0.79	1.18	1.28	0.87	0.70	0.03
Spanish	6.96	0.64	3.25*	1.73	1.81*	11.04
Bed days	0.78*	1.03	0.96	1.00	0.98	0.79
N	972	946	961	1013	988	1006

BMI: body mass index; BF-BIA: body fat measured with bioelectrical impedance analysis; WC: waist circumference.
[a] Same notes and explanatory variables as in Table 3, except here dependent variables are dummies. For creation of dichotomous dependent variables, see Section 2.2.
[b] Because of convergence problems, the logistic regressions for WC do not include village fixed effects.

(coefficient of *bed days* = −0.009; $p = 0.02$). This result is small in biological terms.

Of the adult women <46 years of age ($n = 745$w), 67.38% were lactating.[2] After including the variable for *lactation*, the coefficient for *wealth* remained significant when using BMI as an outcome. When we removed lactating women from the analysis, the sample size dropped from 946–972 to 378–391, and then the coefficients for *wealth* was no longer statistically significant.[3] *Food availability*, *schooling*, speaking *Spanish*, and *bed days* also showed no statistical significance.

3.4. Extensions

In Table 5 we use logistic regressions to examine the relation between the covariates and obesity. The results suggest no clear pattern about the relation between them. For example, among women, those who spoke fluent *Spanish* had 2.25 times higher odds of exceeding the reference values of WC ($p = 0.03$) compared with women who did not speak fluent *Spanish*. Women who spent one more day in bed from illness in the last two weeks had a 22% lower odds of exceeding the reference value of BMI ($p = 0.05$). Among men, doubling *wealth* was associated with a 112% higher odds of having higher BF-BIA than the reference values ($p = 0.02$). Men who spoke fluent Spanish had 81% higher odds of having higher BF-BIA than the reference values ($p = 0.02$), compared with men who did not speak fluent *Spanish*.

4. Discussion and conclusion

Unlike other native Amazonian populations which have been reported to be experiencing increased obesity (Coimbra et al., 2002; Benefice et al., 2008; Lourenço et al., 2008; Welch et al., 2009), the Tsimane' provide inconclusive evidence about the problem. Bivariate analyses suggests that during 2002–2006 the mean BMI of non-pregnant women and men increased by an annual growth rate of 0.64% and 0.37%, and that between 2002 and 2006, 8.9% of adults entered the overweight or obese category, with BMI > 25. While these statistics suggest that Tsimane' are indeed gaining weight, these results should be interpreted with the caveats that they fail to control for many confounders and rely on values from only the beginning and the end of the panel study.

The regression results did not support conventional explanations of obesity. None of the covariates were statistically significant, consistent between the three outcomes, and biologically and economically meaningful. For instance, unlike other researchers, we found weak and mixed support for the influence of acculturation on obesity (Friedlaender and Rhoads, 1982; Pérez-Cueto and Kolsteren, 2004; Romaguera et al., 2007; Redwood et al., 2008; Nagata et al., 2009). Changes in value orientation that come with acculturation might produce stress and stress-related behaviors, with consequences for morphological indicators. But we found no evidence for a link between measures of acculturation and obesity. Unlike other researchers (Dangour, 2003; Lourenço et al., 2008; Fezeu et al., 2005; Gilberts et al., 1994) we found weak and mixed evidence that wealth (a proxy for SES) contributed to obesity, but we are aware of the contested role of SES in developing obesity in industrialized and industrializing nations (Ball and Crawford, 2005; Sobal and Stunkard, 1989). Recall from the introduction that previous studies suggest that with structural transformations in rural economies of industrializing nations come improvements in income, greater availability of foods, and changes in physical activity, all of which affect body morphology. We found no strong evidence for these links.

The absence of strong, consistent, significant, and meaningful results across outcomes could reflect one or more of the following methodological limitations: (a) omitted-variable bias from lack of data on key covariates of obesity (e.g., physical activity), (b) random measurement error with outcome variables (e.g., digit heaping of weight, height, or both) or explanatory variables (e.g., age), (c) insufficient statistical power due to a large number of independent variables (74 independent variables) in the regression model including interaction terms, (d) insufficient variation in the outcome and explanatory variables during the five years of the study, and (e) the period of five years of this study was relatively short to observe changes of body morphology among a population.

Besides methodological limitations, there may also be a substantive reason for the absence of effects. Structural transformations in rural economies of industrializing nations will likely affect body morphology by changing income, physical activity, and food availability, but only if the transformations are large, deep, and permanent. Despite nearly half a century of contact with outsiders, Tsimane' still live in relatively remote villages, are highly endogamous and monolingual in the Tsimane' language, and have managed to retain much of their culture and much of their traditional forms of social organization and patterns of subsistence. In part because they still control their territory, they decide when and how to take part in the market economy. Their particular form of incorporation into national society might protect them against changes that are more likely to produce weight gain in other, more vulnerable native populations. Thus one should be cautious when interpreting results from observational (particularly cross-sectional) studies about obesity in societies during the early stages of economic development.

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[2] We follow the standard assumption that women can bear children until ∼45 years of age. We added one year to 45 to arrive at the upper age limit for lactation.

[3] The sample size of all regressions varies because of differences in missing observations in the outcome variables.

portions of key Tsimane' food items. We also thank the editor of EHB, John Komlos, and reviewers for their critical comments in several rounds of revisions. The paper has been greatly improved by their comments.

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