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Tsimane' Amazonian Panel Study Working Paper # 56

Adult Body Mass and Body Fat Associated with Consumption of Traditional Food and Good Health: Evidence from Native Amazonians

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ABSTRACT Until recently, conditions of adult overweight and obesity were confined to industrial nations. Over the last decade these conditions have become increasingly prevalent in poor nations. Little is known about the initial triggers for gains in body mass and body fat in foraging-horticultural societies in the early stages of continual exposure to the modern world. We formulate six expectations about the initial triggers, and estimate whether the expectations are borne out by using data from a native Amazonian population (Tsimane'). 350 non-pregnant females and 385 males ≥20 years of age from all 311 households in 13 villages were measured annually during five years. The sample was representative of the Tsimane' population in adult body mass and body fat. Five measures of body morphology were used as outcomes: body-mass index, weight for age Z score, waist circumference, sum of four skinfolds, and body fat. We ran random-effect and fixed-effect panel multiple regressions separately for females and males of the five outcomes against 18 covariates linked to the expectations. Consumption of traditional food was positively associated with weight among males and females. Height was positively associated with weight among females and the bed-ridden days from illness was negatively associated with weight among males. Results support previous findings that diet is associated with increased body weight and adiposity in rural areas of poor nations and also suggests that improvements in health might be another initial trigger of increased body weight and fat during the early stages of continual contact with the modern world.

Key words: Bolivia, BMI, Tsimane' Amazonian Panel Study (TAPS), weight, obesity, overweight

Until recently, conditions of adult overweight and obesity were confined to industrial nations (Kopelman, 2000). Over the last decade, however, these conditions have become increasingly prevalent in poor nations (Caballero, 2001; Monteiro et al., 2004, Méndez et al., 2005; Filozof et al., 2008; Kelly et al., 2008). Gains in body mass and body fat during adulthood increase risks for many chronic diseases (e.g., hypertension, type 2 diabetes) (Gray et al., 2000; James et al., 2001; Whitlock et al., 2009). In spite of differences between body mass and body fat, many common factors contribute to their increase. For brevity, in the rest of the article we use "weight gain" to refer to increased body mass or increased body fat or both, where the distinction between them is unnecessary.

Recent years have seen an explosion of research on the covariates of weight gain, mostly in industrial societies and to a lesser extend in poor nations (Popkin and Gordon-Larsen, 2004). Standard covariates of weight gain and increased adiposity in industrial societies include food intake, physical activity, alterations in sleep patterns, and the stresses and negative emotions of modern life. Growing evidence from poor nations suggest that higher socioeconomic status (SES) is associated with weight gain because people of higher socioeconomic status 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). As self-sufficient rural communities in poor nations enter the market economy, many socioeconomic changes take place, along with changes in diet, physical activity, and stress levels. Previous research leaves unanswered whether socioeconomic status by itself drives weight gain in such societies or whether the association between weight gain and socioeconomic status wanes after controlling for standard covariates.

Studies of native Amazonian foraging-horticultural societies in the early stages of continual contact with the modern world provide an apt setting to examine the initial drivers of weight gain. First, preliminary evidence suggests that adults in these societies are gaining weight, and becoming overweight and obese (Coimbra et al., 2002; Benefice et al., 2008; Lourenço et al., 2008; Welch et al., 2009). For example, 58.5% of females and 62.4% of males among the Suruí of Brazil (Lourenço et al., 2008) and 40.3% of female native Amazonians in the department of Beni, Bolivia, were classified as overweight or obese (Benefice et al., 2008). Among the Xavante of Brazil, 25% of adult males and 22% of adult females were classified as obese (Welch et al., 2009). Second, such studies allow us to understand the sequencing of covariates of weight gain. The same bundle of covariates might produce weight gain across societies at different levels of socioeconomic complexity, but some covariates may become more noticeable or wane as societies and economies modernize.

Drawing on panel data collected annually during 2002-2006 (inclusive) from a foraging-horticultural society of native Amazonians in Bolivia, the Tsimane', in the early stages of continual exposure to the modern world, here we try to reach two aims. First, we describe changes in adult weight over the five years of the study. Impetus to the first aim comes from the shortage of panel studies of adult weight change in rural areas of poor nations, particularly among foragers undergoing rapid lifestyle changes (Leonard and Godoy, 2008). Inferences about changes in adult weight and fat over the lifecycle based on cross-sectional data can produce misleading conclusions because they do not allow one to separate cohort effects from age effects (Friedlaender and Rhoads, 1982). The second aim consists of quantifying the relative importance of a broad range of covariates in weight gain in the early stage of modernization, but doing so with multivariate analysis of panel data to control for the simultaneity of covariates and to control for confounders that are more challenging to handle with cross-sectional data.

We use two types of outcomes. First, we use five indicators of body morphology: *(i)* body-mass index (BMI=body weight in kg/standing height in m^2), *(ii)* weight for age Z score, *(iii)* sum of four skinfolds measured in mm (triceps, biceps, subscapular, and suprailiac), *(iv)* percent body fat measured with bioelectrical impedance, and *(v)* waist size. *(i)-(ii)* are measures of relative body weight, *(iii)-(iv)* are measures of excess body fat and adipose tissue, and *(v)* describes a pattern of body fat. Second, we use extreme values of three indicators: *(a)* BMI, *(b)* waist size, and *(c)* percent body fat. The extreme values capture overweight and obesity and proxy for health risks. We limit the main analysis to *(1)* people ≥20 years of age to enhance comparison with other studies of adults in poor nations and *(2)* non-pregnant females. We include lactating females in the main analysis because there is evidence suggesting that lactation does not affect body weight (Valeggia and Ellison, 2003). Lactation increases energetic demands on women (Frisancho, 1993; Hatsu et al., 2008), but the effect on body weight and composition is ambiguous, particularly in the early period of postpartum (Lederman, 2004). Women might compensate for increased energetic demand in various ways (e.g. decreasing physical activity, increasing food intake, adjusting metabolism). To prevent a reduction in the sample size, we decided to keep lactating women in the main analysis, but then present additional analysis in which we control for lactation.

EXPECTATIONS AND COVARIATES

Prior research suggests that body morphology is associated with the following: *(a)* diet, *(b)* stress, *(c)* age, and *(d)* socioeconomic status. Among native Amazonians in the early stages of continual contact with the modern world, body morphology is also likely associated with *(e)* acculturation and *(f)* improvement in general health. In this section we present six expectations (E), one each for *(a)-(f),* and the covariates to measure *(a)-(f)*. For ease of exposition, we discuss separately each expectation. The evidence suggests that *(a)-(f)* interact, overlap, and act simultaneously on body morphology (Krieger, 1994; Orden and Oyhenart, 2006; Candib, 2007).

a. Diet

Changes in diet away from fresh vegetables and fruits, or away from crops and animal produced by households or collected in the wild toward processed foods denser in calories and nutrients contribute to changes in body weight (Popkin and Gordon-Larsen, 2004). The new diets differ markedly from the diet developed by humans as pre-historic hunters and gatherers (Eaton et al., 1997; Leonard 2002, 2008). Rural people are undergoing the nutrition transition (Popkin, 2001) and buying more foods, principally refined grains and sugars, salt, saturated fats, and processed food (Carrasco et al., 2004; Pérez-Cueto and Kolsteren, 2004; Romaguera et al., 2007; Samson and Pretty, 2006; Welch et al., 2009; Leonard and Thomas, 1988)[i]. Eating these more energy-dense foods increases overall caloric intake, and thus contributes to weight gain (Bell et al., 2001; Orden and Oyhenart, 2006; Chiriboga et al., 2008).

E1. Eating more food, particularly food obtained in the market, will be associated with weight gain.

b. Stress

Stress and the behaviors and the negative emotions (e.g., depression, anxiety) associated with stress contribute to weight gain in industrial societies (Goodman and Whitaker, 2002; Onyike et al., 2003; Goodman et al., 2004;). Chronic stress, neurobiological mechanisms, and alterations in the hypothalamic-pituitary-adrenal axis partially explain the link from stress and its manifestations to weight gain (Goodman and Whitaker, 2002), such as accumulation of visceral adiposity. Severe negative emotions during adulthood are positively associated with adult obesity in industrial nations (Simon et al., 2009), including indigenous populations in such nations (e.g., Maori in New Zealand)(Scott et al., 2007). In industrial nations mild forms of depression do not bear a significant or consistent association with weight gain (Shioiri et al., 1993; Carter et al., 1994; Rosmond et al., 2000; Berlin and Lavergne, 2003).

E2. Higher levels of stress and the behaviors and negative emotions of stress will be associated with more weight.

c. Age

In industrial nations, female and male body weight and body fat increase during middle age (Robert and Williamson, 2002), but in remote rural populations of poor nations the trend is less clear. Friedlander and Rhoads (1982) drew on panel data collected from adults during 1966, 1968, 1970, and 1978 in six societies of the Solomon Island and Papua New Guinea that varied in degree of acculturation. Among the less acculturated groups, they found no change in body weight over the adult life cycle of males, but they found slight weight loss among females. Among the more acculturated groups, they found a slight increase in weight from an increase in body fat among females, but they found no change in weight among males. Dangour (2003) did a cross-sectional study with 345 Patamona and 186 Wapishana adults > 20 years of age in a remote region of Guyana and found an inverted U-shaped relation between weight and age. BMI increased until people reached 50 years of age and then decreased. The same pattern reported by Dangour (2003) for Guyana has been observed in the USA (Williamson, 1993).

E3. *(a)* Body mass and body fat will display no trend over the adult life cycle; *(b)* if they do, trends will resemble an inverted U and will be more marked among females[ii].

d. Socioeconomic status (SES)

The vast literature on socioeconomic status and weight (Monteiro et al., 2004), and the many ways to measure socioeconomic status (Goodman et al., 2007) make it necessary to limit the review to studies linking weight to socioeconomic status in foraging populations. In his study of native Amazonians in Guyana, Dangour (2003) created an index of household wealth based on eight goods (e.g., mosquito nets, axes) and found that wealth bore a positive association with BMI after controlling for age, age^2, sex, height, and ethnicity. Lourenço et al. (2008) did a cross-sectional study with 127 females and 125 males ≥ 20 years of age among the Suruí. Like Dangour, they created a wealth index based on physical assets of the household (e.g., number of rooms) and found that females (but not males) in households with more assets had higher BMI. Females of low, medium, and high socioeconomic status had an average BMI of 25.7, 26.9, and 29.4.

E4. Higher socioeconomic status measured through wealth in physical assets will be associated with more weight. This expectation fits with the evidence just reviewed and with the recent review of Monteiro et al. (2004) suggesting that in poor nations weight is positively associated with economic status.

e. Acculturation

By acculturation we mean values and forms of human capital (e.g., language skills) of a majority group incorporated by a minority group. The large literature on acculturation and weight among immigrants in industrial nations make it necessary to limit the review of acculturation and weight to poor nations.

Acculturation could affect body weight in at least three ways. First, members of a minority group might acquire new concepts of ideal body size and shape and try to change their weight (Frisancho, 2003; Monarrez-Espino et al., 2004; Gremillion, 2005). Second, members of a minority group might feel marginalized by the majority, and such feelings might contribute to stress, and to weight change via stress (Fudmin, 2009). Third, higher cultural consonance with group norms about the ideal body might be associated with lower stress and its manifestations and with lower weight. In a recent study in urban Brazil, Dressler et al. (2008) found that - after controlling for family income, drug use, and food intake - higher cultural consonance with local norms in lifestyle and in prestigious foods (but not in ideal body) was associated with a thinner waist and with lower BMI, but only among females. Researchers have often used schooling levels and fluency speaking the national language to measure acculturation, and have found that the measures are associated with heavier bodies (Friedlaender and

Rhoads, 1982; Pérez-Cueto and Kolsteren, 2004; Romaguera et al., 2007; Redwood et al., 2008; Nagata et al., 2009).

E5. In societies in the early stages of continual exposure to the modern world, acculturation into the norms of the majority group will be associated with weight gain (via stress).

f. Improvements in general health

Improved general health due to better hygiene and access to modern medical services (e.g., vaccination, de-worming) in populations experiencing chronic parasitic and other infections tend to improve weight since the body can divert energy to growth or weight gain rather than to combat infection. Frankenberg and Thomas (2001) found that between 1993 and 1997 putting one more trained midwife in a rural community of Indonesia was associated with an increase in the BMI of females (but not of males) of reproductive age. If successful, programs to improve child nutrition in poor nations might accelerate the growth rate of children, particularly of children with low birth weight and hasten the onset of puberty (Picket et al., 1995). A rapid growth rate during childhood, in turn, is associated with higher levels of adult BMI, fat mass, and abdominal fat (Dunger et al., 2005; Dunger et al., 2006; Corvalan et al., 2007; Victora et al., 2008).

E6. Improved general health should be associated with greater body mass and body fat since the improvement allow the body to deflect energy away from combating illness toward growth or weight gain.

ADULT WEIGHT AMONG TSIMANE'

Recent publications in this journal contain descriptions of the geography, history, socioeconomic self-sufficiency, and ethnography of the Tsimane' (Brabec et al., 2007;

Gurven et al., 2007; Godoy et al., 2008, 2009a; Sharrock et al., 2008; Tanner et al. 2009), so we limit the discussion of this section to what we know about Tsimane' adult weight based (mainly) on cross-sectional data collected during the past decade.

In a worldwide comparative study of life histories in 22 foraging-horticultural societies, Walker et al. (2006) compiled data on weight for people ages 15-25 (p. 300). Their review contains data on seven native South American populations in tropical rainforests (including the Tsimane'). Their data suggests that Tsimane' females and males were slightly above their South American peers in average weight. On average, Tsimane' females and males weighed 51 kg and 61.30 kg, compared with their peers who weighed 49.98 kg and 58.85 kg. From this we tentatively conclude that Tsimane' weight is in line with the weight of other South American Indian populations inhabiting tropical rainforests.

Using different cross-sectional surveys and multivariate analysis, in past work we have estimated the association between BMI and female empowerment (Godoy et al., 2006a), household income (Godoy et al., 2005c), and village inequality in monetary income (Godoy et al., 2005a) and found no significant results. We have also tested the association between *(a)* cultural consonance in material and social lifestyle and *(b)* weight, waist circumference, and BMI and found no significant results after controlling for individual fixed effects (García et al., 2009b). By individual fixed effects we mean unchanging (fix) attributes of the person (e.g., genetics, early life history) linked with body morphology and with its covariates.

Using cross-sectional data, we found that BMI bore a significant positive association with village social capital (Brabec et al., 2007), social rank (Reyes-García et al., 2008b), ethnobotanical knowledge (Reyes-García et al., 2008a, 2009a), schooling, and wealth (Godoy et al., 2005c). The associations were small, sometimes unrealistic, and must be interpreted with caution because most of the studies did not control for individual fixed effects or for attributes of the village (e.g., distance to town) that remained fixed during the study (village fixed effects). For instance, doubling an adult's plant knowledge or wealth, or doubling the amount of village inequality in social rank was associated with changes in a person's BMI of only +6.3% (knowledge), +1.0% (wealth), and -6.7% (rank inequality). We say the estimates are "unrealistic" because one is unlikely to double an adult's stock of knowledge or wealth, and even then the effect is small. Using a panel composed of data from five consecutive quarters (2002-2003), we found that BMI bore a positive association with mirth. Adults who smiled, smiled and laughed, and laughed openly during interviews had 2.4%, 3.1%, and 5.4% higher BMI than people who neither smiled nor laughed (Godoy et al., 2005b), even after controlling for village (but not for individual) fixed effects.

Recently we used multivariate regressions to estimate annual trends in BMI over five consecutive years (2002-2006) and found that among Tsimane' ≥ 16 years of age, the BMI of non-pregnant females increased by 0.56%/year and the BMI of males increased by 0.85%/year (Godoy et al., 2009b), even after controlling for village and for individual fixed effects. Hence, there is some evidence that Tsimane' are gaining weight.

MATERIALS AND COVARIATES

Materials

We use a panel composed of five consecutive annual surveys (2002-2006). The panel, known as the Tsimane' Amazonian Panel Study (TAPS), follows 962 females and 1033 males of all ages from all households (n=331) in 13 out of a total of ~100 Tsimane' villages (Leonard and Godoy 2008)[iii]. We spent 1995-2001 doing background studies among the Tsimane' to identify villages for the panel study, to gain the trust of villagers, and to refine methods of data collection.

We selected the 13 villages to capture geographic variation in closeness to the market town of San Borja (mean=25.96 km; standard deviation=16.70), the only town along the Maniqui River. In capturing variation in distance to the market town we capture variation in market exposure, modernization, and acculturation, which likely bear an association with weight (*E2* and *E5*).

The sample used for this article is representative of the Tsimane' population in adult body fat and body mass. As part of the background studies, in 2000 we surveyed and took anthropometric measures of ~12 adults/village in 59 Tsimane' villages, which included the 13 villages of the panel study. Using data from 2000, we computed four measures of body mass and body fat of adults in the 13 villages of the panel study and for the rest of the villages. The four measures included: body-mass index, percent body fat from the sum of four skinfolds, weight for age Z score, and percent body fat measured with bioelectrical impedance. Results of the comparison (Table 1) suggest that females and males in the TAPS villages resembled their peers in the other villages in body mass and body fat. We did not find statistically significant differences at the 95% confidence level or higher in the indicators of body mass or body fat between people in the villages of the panel study and people in the other villages.

INSERT TABLE 1 ABOUT HERE

The panel study includes a total of 1995 people, but the sample used in this article contains data for 735 people $\geq$ 20 years of age (females=350; males= 385) and for their households. Of the 735 adults, 56.87% were present and surveyed during all five annual surveys, 13.61% were present during only four surveys, 8.84% were present during only three surveys, 13.20% were present during only two surveys, and 7.48% were present during only 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. Females and males had similar *count* rates (χ^2=3.88; p>χ^2=0.42). In the regressions we include the variable *count* as a control because permanent or temporary attrition might bias parameter estimates.

We collected annual data during visits to each village lasting 5-7 consecutive days per village. We reserved most of those days for interviews, but we also set aside at least one day to take anthropometric measures in the village school. Interviews lasted about one hour per adult and took place in the home of the adult. Four Bolivian university graduates did the surveys and took anthropometric measures and four Tsimane' who worked in the panel study from its beginning served as translators.

Outcome variables: Body mass and body fat

There is still disagreement about how to define and measure body morphology, overweight, and obesity (Kopelman, 2000). For this reason, we used five measures of body morphology: BMI, weight Z score, waist circumference, sum of four skinfolds, and body fat measured with bioelectrical impedance. Later we discuss how we defined and measured overweight and obesity.

We computed pair-wise Pearson correlation coefficients for the five measures using the Šidák method to ensure levels of statistical significance took into account multiple comparisons (Table 2). Among females, Pearson correlation coefficients ranged from 0.57 (skinfolds and waist) to 0.83 (BMI and weight Z score) and among males correlation coefficients ranged from 0.52 (weight Z score and skinfolds) to 0.78 (weight Z score and BMI). All correlation coefficients were statistically significant at the 99% confidence level. The wide range of correlation coefficients supports our use of different measures of both body weight and body fat.

INSERT TABLE 2 ABOUT HERE

Measure of covariates associated with expectations

Here we discuss how we measured covariates. Names of covariates or variables used in the regressions are italicized. The appendix has more details on the measure of some covariates and a description of control variables.

E1. Diet: We assessed dietary consumption as energy intakes (kilocalories [kcal]/person/week) from *modern* foods (e.g., sugar, bread) and from *traditional* foods. Energy intake for each of 21 different foods was determined based on the caloric content data (kcal/100 gram edible portion) from food composition tables for Latin America compiled by FAO (Appendix). Intakes were standardized for household size by adjusting for the number of male-adult equivalents in the household (Appendix). Of the 21 foods that were asked about in the household survey, 9 were categorized as *modern* and 12 were categorized as *traditional*.

E2. Stress: We equate stress with three negative emotions and with two behaviors. We asked how often people had been angry, *sad*, or had been afraid during the seven days before the interview and created three variables, one for each emotion. We coded the variable as one if the person had experienced one or more episodes of *anger*, *fear*, or sadness, and zero otherwise. We also asked about consumption of two potentially addictive substances during the seven days before the interview. We asked how many times the person had consumed commercial *alcohol* and we asked another question about how many times the person had consumed commercial *cigarettes*.

E3. Age: We asked people to report their *age* in years or to show us their birth certificate. Some people were unsure about their age. We spent 2008 verifying and correcting questionable ages by comparing the reported age with the age of adults with known birth dates. In the regressions we use the age estimate made by our team. We squared age (age^2) because the association between *(i)* body mass or body fat and *(ii) age* might resemble a parabola (Dangour, 2003).

E4. SES – Wealth: We estimated a person's *wealth* by measuring the real monetary value of 22 physical assets owned by the person at the time of the interview (Appendix). Real refers to monetary values adjusted for (or without) inflation.

E5. Acculturation: We asked people about the maximum grade attained in school (*schooling*). During the interview, surveyor's judged the respondent's ability to speak *Spanish*, Bolivia's national language. Surveyors coded the variable *Spanish* as zero if the person was monolingual in Tsimane' or if the person spoke only some Spanish, and one if the person spoke fluent Spanish.

E6. General health: We used two variables to capture general health: one for short-run health and one for long-run health. *Bed days* refer to the total number of days spent in bed owing to illness during the 14 days before the interview (Appendix). *Height* refers to the standing physical stature of the person in cm. Recent publications in this journal contain descriptions of how we measured height (Godoy et al. 2008, 2009a).

ANALYSIS

For the main analysis we use panel, linear random-effect regressions with village and year fixed effects, clustering by individuals, and with robust standard errors. We use a random-effect regression because some covariates (e.g., *height*) will not vary much over the study period (except for small amounts due to natural shrinkage) so one could not obtain parameter estimates for these covariates if one used an individual fixed-effect regression. In the sensitivity analysis we re-estimate some of the main parameters with individual fixed-effect regressions. We use village fixed effects to remove the role of fixed attributes of the village (e.g., proximity to town; village income inequality) that might affect weight and covariates (e.g., *wealth*). Given variation in prices for foods and crops, weather, and ecological conditions between villages and years, we also used village-year fixed effects by including a full set of interaction variables for village*year. Failure to control for village and for village-year traits could result in biased and inconsistent parameter estimates. With a large number of observations being analyzed (depending on the outcome, females= 690 to 703 and males=710 to 732) and with only 16 covariates in the regressions, we expect a reasonably high statistical power for parameter estimates. Except for the baseline or for first measure of the outcome variable, which we use as an explanatory variable to control for initial conditions of the outcome, the values of outcome and all other covariates refer to the same year.

Stata for Windows, version 10 (Stata Corporation, College Station, Texas) was used for the statistical analysis. Except for expectation #4, other expectations must be tested by examining two or more covariates; thus, when discussing regression results we generally focus on tests of joint significance of covariates linked to an expectation, rather than on the coefficient of a single covariate or its p value.

RESULTS

Visual, bivariate, and descriptive results

For brevity and because much of the literature on weight gain centers on BMI, we limit the visual, bivariate, and descriptive analysis of weight to BMI.

Figure 1 shows that females and males had similar mean and median values for BMI, but females had more variation. Over the five years of the study, females had a mean and median BMI of 23.4 and 23.1 and males had a mean and median BMI of 23.5 and 23.2, but females had a standard deviation of 2.9 and males had a standard deviation of 2.4. A two-tailed t-test comparing the mean BMI between females and males produced a t statistic of only 0.28 (p=0.77) suggesting no noticeable difference in mean BMI between females and males. A variety of tests for the equality of the standard deviations between females and males using different assumptions about the normality of the distributions always showed that females had more variation in BMI than males. Results of all the tests for the equality of the two standard deviations were significant at the 99% confidence level, even after excluding lactating females.

INSERT FIGURE 1 ABOUT HERE

Figure 2 shows that the mean BMI of females and males increased slightly during the five years, from 2002 to 2006. During this period, the BMI of females increased from 23.09 to 23.86 and the BMI of males increased from 23.4 to 23.7. We ran a bivariate regression (not shown) with the logarithm of BMI as a dependent variable and survey year as an explanatory, and controlled for individual fixed effects. The results suggest that BMI increased by 0.64%/year among females ($p=0.001$) and by 0.37%/year among males ($p=0.001$). These estimates of growth rates are not comparable to the estimates reported earlier from the previous study (females: 0.56%/year; males: 0.85%/year) because the earlier estimates control for a wide range of confounders whereas the estimates just presented in this paragraph only control for year and for individual fixed effects.

INSERT FIGURE 2 ABOUT HERE

Figure 3 shows BMI values by age for females and males. Two points stand out. First, females and males had similar trends over the life cycle. The relation between BMI (outcome variable) and age (explanatory variable) resembled an inverted U. The coefficients for regressions of BMI against age and age^2 were 0.168 and -0.0016 for females ($p<0.001$ for both coefficients) and 0.142 and -0.0013 for males ($p<0.001$ for both coefficients). These regressions are not shown. Second, error terms had a heteroskedastic distribution, particularly among males, supporting our use of robust standard errors. The likelihood ratio test for the null hypothesis that the error terms were homoskedastic in the regression of the logarithm of BMI against age and age^2 produced a χ^2 value of 5391.2 ($p=0.001$) for females and 610.1 ($p=0.001$) for males.

INSERT FIGURE 3 ABOUT HERE

Using the BMI values recommended by the World Health Organization (1998) to define under weight (<18.5), normal weight (≥18.5 to 25), overweight (≥25 to 30), and obese (≥30), we found that among females, 3.05%, 70.64%, 22.44%, and 3.88% were underweight, normal, overweight, and obese. Among males, 1.64%, 78.23%, 18.49%, and 1.64% were underweight, normal, overweight, and obese. We examined the progression of weight between 2002 and 2006. 11.2% of people (30 out of 268) who had normal weight in 2002 moved into the categories of overweight or obese by 2006. Only 7.35% of people (5 out of 68) moved from the categories of overweight or obese in 2002 to normal weight by 2006. The progression is statistically significant, with a McNemar's χ^2 of 17.86 (p=0.001). These figures suggest an increase in weight among the study population.

Main regression results

Table 3 contains two noteworthy findings. First, we find partial confirmation for <u>*E1*</u> that food consumption is associated with weight gain among females and males. We say confirmation is partial because we find the expected association only with *traditional* foods not with *modern* foods. For most of the outcomes, the coefficients for *traditional* food have the expected positive sign. Among females, consumption of *traditional* food is associated with gains in weight (Table3a, columns [a] and [c]) and in adiposity (Table 3a, column [b]). Among females, the consumption of one more kilocalorie of *traditional* food in a week is associated with an increase of the following outcomes: 0.01% in BMI (p=0.01), 0.0005 standard deviations (p=0.003) in weight Z score, 0.04% in skinfold (p=0.04), and 0.01% in waist circumference (p=0.007). Among males, consumption of *traditional* food is also associated with gains in weight (Table 3b, columns [a] and [c]) and in adiposity (Table 3b, column [d]). The consumption of one more kilocalorie of *traditional* food in a week among males is associated with an increase of the following outcomes: 0.01% in BMI (p=0.02), 0.0004 standard deviations (p=0.03) in weight Z score, and 0.04% in body fat measured with bioelectrical impedance (p=0.002). The magnitude of the association between *(i) traditional* foods and *(ii)* BMI and weight Z score is similar between females and males.

INSERT TABLE 3a AND TABLE 3b ABOUT HERE

Second, we find partial confirmation for *E6* that good health bears an association with weight. We say partial because among females only *height* is positively associated with outcomes where only among males is *bed day* negatively associated with outcomes. The results of Table 3a suggest that among females, an increase of one cm in *height* is associated with an increase of 0.13% in BMI (column [a], p=0.04), 0.007 standard deviations in weight Z score (column [c], p=0.005), and 0.61% in body fat (column [d], p=0.02). With one exception (column [d]), the results of Table 3b suggests that among males the two variables for health, *bed days* and *height*, bear the expected signs (*bed days* <0; *height* >0) and are jointly significantly associated with weight. For example, in Table 3b, column [a], we find that an additional day in bed is associated with 0.27% lower BMI (p=0.005) and an additional cm in *height* is associated with 0.09 % higher BMI (p=0.15). *Height* by itself is not statistically significantly associated with BMI at the 95% confidence level or higher, but *height* and *bed days* are jointly associated with BMI (χ^2=9.75; p=0.008).

Sensitivity analysis

The mains findings of Table 3 include: *(a)* consumption of *traditional* foods is positively associated with weight among females and males, *(b) height* bears a positive association with weight among females, and *(c) bed days* and *height* bear a significant joint association with weight among males. In this section we report results of additional analysis to ensure that two of the three main findings (*a* and *c*) hold up after controlling for individual fixed effects and for lactation. Because the variable *height* does not vary over the study period, we cannot re-estimate its parameter with individual fixed effects. For brevity, we only report the F value of tests of joint statistical significance. To enhance clarity and because they are linked to the main findings, we report the coefficients for *modern* food, *traditional* food, and *bed days*. To make easier the reading of the coefficient for *bed days* we took its natural logarithm. Table 4 contains the results of the additional analysis.

INSERT TABLE 4 ABOUT HERE

The results of Table 4 provide weaker evidence for *E1* and *E6*. The consumption of *traditional* food continues to bear a positive association with weight among females, except when using skinfolds as an outcome (Table 4, section A, column [b]). Among males, most of the positive associations between the consumption of *traditional* food and outcomes become statistically insignificant, except when using body fat as an outcome (Table 4, section B, column [d]). The negative association between *bed days* and outcomes found among males in Table 3b remains only when using BMI (column [a]) and weight Z scores (column [c]). The coefficients of *bed days* in section B of Table 4 imply that doubling the number of bed-ridden days during the last two weeks is associated with 0.69% lower BMI and with 0.05 lower standard deviations of weight Z score[iv]. We re-estimated the regressions using raw values of *bed days* instead of log-transformed raw values +1 and found a statistically significant association between *bed days* and skinfolds (coefficient=-0.009; p=0.04). The association between *bed days* and

BMI or *bed days* and weight Z scores remains negative and significant even when using raw values.

To ensure that the inclusion of lactating females did not affect results, we included a dummy variable for *lactation* (1=female lactating; 0=female not lactating) and re-estimated the regressions for females of Table 3a. Of the adult females under 46 years of age (n=745), 67.38% were lactating[v]. The new regressions are not shown. Even after including the variable for *lactation*, the coefficients for *traditional* food and *height* remained significant. The new tests of joint statistical significance produced χ^2 and p values similar to those of Table 3a. When we removed lactating females from the analysis, the sample size dropped to 254-260, and then neither *traditional* food nor *height* were statistically significant.

Extensions

In Table 5 we present the results of regressions to identify possible covariates of overweight and obesity, using three definitions for these terms, which are described in the notes to Table 5. BMI proxies for obesity, percent fact measures excess fat and adiposity tissue, and waist circumference describes fat patterning.

INSERT TABLE 5 ABOUT HERE

The results of Table 5 suggest no clear pattern about the covariates of overweight or obesity. For example, among females, those who spoke fluent *Spanish* were 13.95% more likely to be obese (p=0.01) (Table 5; column [I.b]), but only when equating obesity with extreme values of waist size. Contrary to the expectation of *E2*, we fid that among males covariates related to stress bore a significant negative association with overweight or obesity (Table 5, column [II.a]; χ^2=14.70; p=0.01), but only when using BMI to measure overweight or obesity.

DISCUSSION

We found no significant association between weight changes and age, socioeconomic status, stress, or acculturation. The weak association between weight and *age* could reflect random measurement error with *age.* The weak association between weight and socioeconomic status could relate to widespread patterns of sharing and reciprocity (Brabec et al., 2007). When people can borrow each other's assets, then a neighbor's assets might contribute to one's weight and dilute the association between a person's own socioeconomic status and a person's own weight. Low stress levels might explain the absence of an association between weight and self-reports of negative emotions. For instance, in a recent study Nyberg (2009) found that diurnal cortisol profiles among the Tsimane' were dramatically lower than those reported from both industrialized and poor nations. Alternatively, the proxies for self-reported stress used in this study, such as negative emotions, may not be highly correlated with objective biomarkers of the stress response, such as cortisol. If acculturation affects weight through stress and we control for stress, then this could explain the absence of a significant association between weight change and acculturation. We next turn to the two main findings.

Consumption of traditional food and weight gain

At least two questions need addressing: Why is the consumption of *traditional* food associated with weight gain and why is the association stronger for females?

Traditional food bears a larger and more significant association with weight gain than *modern* food for at least three possible reasons. First, if the quantity consumed of traditional food and if the conversion factors used to transform quantities of food into kilocalorie are more accurate with traditional food than with modern food, then the association between weight and *traditional* food will be stronger than the association between weight and *modern* food. Second, the consumption of *traditional* food had more variation than the consumption of *modern* food. The variance of energetic equivalents was 2350 ($kcal^2$) for *traditional* food and 525 ($kcal^2$) for *modern* food. In further analysis not shown we identified the *traditional* foods driving the results. We regressed BMI against the 21 foods and found that rice was the *traditional* food most strongly associated with weight gain among females and males. Third, the positive association between weight and *traditional* food might reflect biases from omitting accurate measures of physical activity. *Traditional* food often contains more fat and protein. If physical activity is negatively associated with *traditional* food and with weight, then the omission of physical activity will inflate the parameter estimates for *traditional* food. Partial support for the interpretation comes from a study by Jago et al. (2004). They found an inverse relation between physical activity and energy intake from fat among Africa-American girls.

We have no convincing explanation for why the association between weight and the consumption of *traditional* food is more marked among females than males. The nature of the dietary data – a household rather than an individual-level measure – does not allow us to directly address this concern. This caveat aside, one possibility is that females have more control over the consumption of traditional food since they prepare meals. Another possibility is that females and males differ in food preferences owing to cultural norms or to differences in metabolic requirements (Berbesque and Marlowe, 2009).

Good health and weight gain

Taller females and healthier males are heavier than shorter females or than self-reported sicker males. The association can probably be explained by the role of energy in fighting disease. An increase in *height* or a decrease in the number of days confined to bed owing to illness imply that the body has (or had) energy available for growth rather than to fight disease. Among native Amazonians and other lowland South American Indian populations, infectious diseases, such as respiratory and parasitic infections, are widespread, reaching 75% in some populations (Oyhenart et al., 2003; Hurtado et al., 2005; Tanner et al., 2009). Infectious diseases reduce growth and nutritional status through several joint paths, including: *(1)* increasing metabolic requirements associated with fever, *(2)* competing for energy and nutrients with the infectious agent, *(3)* reducing absorption of nutrients due to diarrhea and damage to the gastrointestinal tract, and *(4)* reducing appetite (anorexia). As remote populations of native Amazonians gain increasing access to modern health care to combat infectious diseases, they likely experience lower incidence of these diseases (Gurven et al., 2007), allowing for more energy and nutrients to be allocated to growth and to gains in body mass. In a recent article in this journal, Gurven et al. (2007) describe the spread of modern medicines among the Tsimane'.

But why should *height* only be associated with female weight and why should *bed days* only be associated with male weight? The positive association between *height* and weight found only among females could reflect the omission of a variable only relevant to females. For instance, if the number of children ever born to a female is associated with lower *height* (Brennan et al., 2005) and with lower current weight, then failure to control for variables related to the reproductive history of females could inflate the estimated association between female weight and *height*.

At least three reasons might explain why we found a negative association between weight and *bed days* only among males. First, random measurement error in reported morbidity could vary between the sexes. If females are more likely to guess when answering questions about *bed days*, then the estimate of the coefficient for *bed days* among females would have a greater attenuation bias than the coefficient for *bed days* among males. Second, *bed days* might not reflect well female health. Among males, the number of bed-ridden days fell from 2.35 days in 2002 to 1.22 days in 2006, but among females the number of bed-ridden days remained stabled, increasing slightly from 1.96 days in 2002 to 2.05 days in 2006. We examine another proxy of morbidity, *illness*, defined as the number of person-days with an illness or symptoms of an illness during the 14 days before the interview. A person reporting having had a headache and a fever during each of the last 14 days would have a value of 28 for *illness*; if the person had not been bed ridden during the last 14 days, that person would have a value of zero for *bed days*. We find that among females the mean value for *illness* fell from 6.16 in 2002 to 4.71 days in 2006, in line with the secular improvement in self-reported health found among males when using *bed days* to define morbidity. We re-estimated the regressions of Table 3a with the variable *illness* instead of the variable *bed days* and found that one more day of *illness* among females was associated with 0.09% lower BMI (p=0.02) and with 0.08% thinner waist (p=0.03). This last finding is consistent with the results found among males in Table 3b when using *bed days* as a measure of morbidity. The additional analysis suggests that the absence of a significant link among females between weight and self reported health might have to do with the measure of morbidity.

CONCLUSION

We had two motivations behind the article: to describe changes over time in adult weight using panel data and to estimate the association between weight change and canonical covariates in a foraging-horticultural native Amazonian society in the early stages of continual contact with the modern world. We found that females and males had a mean BMI of ~23 and an annual growth rate in BMI during 2002-2006 of ~0.60%[vi]. If all remains constant, these values imply that in another 12 years the average Tsimane' adult will enter into the overweight or obese category. The use of panel data allows us to appreciate how a small annual growth rate in an anthropometric indicator might have important long-run consequences for the nutritional status of a population. These inter-temporal dynamics are impossible to discern using cross-sectional data.

The use of a multivariate approach with panel data allows us to rule out many standard culprits of weight change, particularly socioeconomic status. Instead, we find that the initial triggers of weight change might have to do with the consumption of traditional foods and with improvements in general health, and that the triggers might affect females and males differently. The results hint at an intriguing question: might the expansion of improved health care in rural areas of poor nations have the unintended consequence of contributing to weight gain?

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TABLE 1. Comparison of adult (≥20 years of age) body mass and body fat measures by sex, in Tsimane' Amazonian Panel Study (TAPS) villages (n=13) and other Tsimane' villages (n=46), based on survey during 2000. In none of the comparisons between people in the TAPS villages and people in the other villages were differences in the indicators of weight statistically significant at the 95% confidence level or higher.

	BMI[1]		% fat from sum of four skinfolds[2]		Weight Z score[3]		% body fat (impedance)[4]	
	TAPS	Other	TAPS	Other	TAPS	Other	TAPS	Other
Females								
Mean	23.63	23.63	31.50	30.85	-0.92	-0.81	23.74	26.83
SD[5]	2.89	2.87	5.73	5.74	0.53	0.49	6.77	6.44
N[5]	33	164	33	164	33	164	19	82
Males								
Mean	23.68	23.71	18.04	17.29	-1.07	-1.16	17.22	17.54
SD[5]	1.92	2.20	4.93	5.87	0.47	0.52	4.12	4.47
N[5]	51	206	51	206	51	206	35	130

[1] BMI = weight in kg/standing height in m^2

[2] Sum: triceps, biceps, subscapular, and suprailiac

[3] Weight Z score: weight for age Z score using norms of Frisancho (1990)

[4] Percent body fat with bioelectrical impedance

[5] N = observations; SD = standard deviation.

TABLE 2. Correlation among five measures of body mass and body fat: Females and males[1]

	BMI	Four skinfold	Weight Z score	% body fat	Waist
BMI	1.000	0.667	0.784	0.721	0.741
Four skinfold	*0.757*	1.000	0.522	0.534	0.608
Weight Z score	*0.832*	*0.659*	1.000	0.534	0.614
% body fat	*0.763*	*0.633*	*0.728*	1.000	0.614
Waist	*0.730*	*0.576*	*0.587*	*0.697*	1.000

[1] Correlation coefficients for females are in italics, flushed to the left, and are in the bottom of the diagonal line (northwest-southeast) of the matrix; correlation coefficients for males are underlined, flushed to the right, and are in the top of the same diagonal line.

TABLE 3a. Random-effect panel linear multiple regressions results of Tsimane' adult (≥20 years of age) body mass and body fat (dependent variables) in relation to covariates of expectations. Variables measured annually, 2002-2006 (inclusive): Females[1]

Expectation	Covariate	Measure of body mass and fat (dependent variable):				
		Log BMI	Log four skinfold	Weight Z score	Log: % body fat (impedance)	Log waist
		[a]	[b]	[c]	[d]	[e]
1. Diet	*Modern*[#]	0.0001	-0.0004	-0.00004	0.0002	-0.0001
	Traditional[#]	**0.0001***	**0.0004***	**0.0005****	0.0003	**0.0001****
2. Stress	*Sad*	0.008	0.003	0.03	0.008	-0.005
	Fear	0.002	0.010	0.011	0.008	0.008
	Anger	-0.001	0.017	-0.022	0.004	-0.006
	Alcohol	0.005	-0.015	-0.025	**0.072***	0.004
	Cigarettes	0.002	0.006	0.005	**-0.009***	0.003
3. Age	*Age*	**-0.004****	0.004	**-0.012****	-0.0008	-0.0006
	Age^2	**0.00004****	-0.00005	**0.00012****	0.000005	0.000009
4. SES	*Wealth°*	0.021*	0.018	0.060	0.027	-0.003
5. Acculturation	*Schooling*	-0.012	-0.014	-0.025	0.006	-0.005
	Spanish	0.008	-0.020	0.016	-0.008	0.011
6. General health	*Bed days*	-0.0008	-0.005	-0.002	-0.00002	-0.002
	Height	**0.001***	0.004	**0.007****	**0.006***	0.0009
Tests of joint significance of covariates related to each expectation: χ2						
1. Diet		**8.28***	4.43	**9.11***	4.00	**7.42***
2. Stress		4.36	1.91	7.96	10.74	4.94
3. Age		**8.12***	2.07	**8.31***	0.15	3.11
4. SES		**4.33***	0.48	3.32	1.23	0.19
5. Acculturation		2.99	0.92	1.25	0.15	2.27
6. General health		5.01	4.13	**8.20***	5.10	5.43
Number of observations		706	703	706	690	699

TABLE 3b. Random-effect panel linear multiple regressions results of Tsimane' adult (≥20 years of age) body mass and body fat (dependent variables) in relation to covariates of expectations. Variables measured annually, 2002-2006 (inclusive): Males

Expectation	Covariate	Measure of body mass and fat (dependent variable):				
		Log BMI	Log four skinfold	Weight Z score	Log: % body fat (impedance)	Log waist
		[a]	[b]	[c]	[d]	[e]
1. Diet	*Modern*$^{\#}$	0.0001	-0.0001	0.0004	0.0002	**0.0002***
	Traditional$^{\#}$	**0.0001***	0.0001	**0.0004***	**0.0004****	0.00002
2. Stress	*Sad*	0.003	0.011	0.021	-0.022	0.002
	Fear	-0.003	**-0.036***	-0.028	0.008	0.0002
	Anger	0.001	0.017	0.019	-0.005	0.004
	Alcohol	-0.001	-0.008	-0.008	-0.013	-0.005
	Cigarettes	-0.0002	-0.0003	-0.0013	0.0004	-0.0003
3. Age	*Age*	**-0.002***	0.005	**-0.011***	-0.003	0.0003
	Age^2	**0.00002***	-0.00004	**0.0001***	0.00003	-0.000003
4. SES	*Wealth°*	0.006	-0.004	0.028	**0.075****	0.007
5. Acculturation	*Schooling*	0.003	0.020	0.022	0.009	-0.005
	Spanish	0.002	-0.008	0.006	0.008	0.001
6. General Health	*Bed days*	**-0.003****	**-0.008***	**-0.012****	-0.003	-0.002
	Height	0.001	0.002	0.002	0.003	**0.001***
	Tests of joint significance of covariates related to each expectation: $\chi 2$					
1. Diet		**9.33****	0.44	**6.73***	**10.57****	**6.43***
2. Stress		4.12	6.56	10.54	3.54	5.52
3. Age		**6.53***	3.10	5.82	0.79	0.38
4. SES		1.22	0.03	1.02	**9.07****	1.56
5. Acculturation		0.73	0.95	1.14	0.44	1.27
6. General health		**9.75****	**6.37***	**8.95***	2.95	**7.05***
Number of observations		732	724	732	710	727

[1] Regressions include clustering by person and robust standard errors. Not shown are constant and the following covariates: *(i)* baseline measure of the outcome, *(ii) count* (see text), *(iii)* real individual monetary income, *(iv)* two proxies for physical activity, and *(v)* dummy variables for years, villages, and interaction of year*village. ° = variable transformed into natural logarithms. *p ≤ 0.05, ** ≤ 0.01.

TABLE 4. Individual fixed-effect panel linear multiple regression results of Tsimane' adult (≥20 years of age) body mass and body fat (dependent variables) in relation to covariates of expectations. Variables measured annually, 2002-2006 (inclusive): F values for test of joint significance for females and males[1]

Expectation	Measure of body mass and fat (dependent variable): Log BMI [a]	Log four skinfold [b]	Weight_ Z score [c]	Log: % body fat (impedance) [d]	Log waist [e]
A. FEMALES (F values)					
1. Diet	2.60	1.52	**4.03***	1.12	2.44
2. Stress	1.20	1.42	2.04	**3.36****	0.67
3. Age	0.22	0.18	0.00	0.86	2.11
4. SES	0.98	0.57	0.53	0.00	0.87
5. Acculturation	2.39	1.99	1.47	1.25	1.65
6. General health	0.07	1.01	0.07	0.06	2.11
Coefficient for three selected covariates					
Modern	0.0001	-0.0005	-0.0002	-0.00003	0.000004
Traditional	**0.0001***	0.0004	**0.0006****	0.0003	**0.0001***
Bed days	-0.001	-0.012	0.0009	0.003	-0.005
B. MALES (F values)					
1. Diet	0.60	0.22	1.27	**6.69****	0.80
2. Stress	1.91	0.86	**2.26***	1.04	1.28
3. Age	1.50	3.00	1.63	0.61	2.02
4. SES	0.06	2.84	0.02	1.98	2.02
5. Acculturation	0.17	1.03	0.58	0.52	0.09
6. General health	**4.44***	0.82	**9.54****	0.20	3.21
Coefficient for three selected covariates					
Modern	0.0001	-0.0001	0.0005	0.0006	0.0001
Traditional	0.00002	0.0001	0.0001	**0.0006****	-0.00003
Bed days	**-0.007***	-0.012	**-0.014****	-0.006	-0.006

[1] 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 in columns a-b and d-e to facilitate the discussion of results in the text.

TABLE 5. Random-effect panel linear multiple regression results of Tsimane' adult (≥20 years of age) overweight and obese (dependent variable) in relation to covariates of expectations. Variables measured annually, 2002-2006 (inclusive): Females and males[1]

Expectation	Covariate	I. Females			II. Males		
		BMI[2]	Waist[3]	Body fat[4]	BMI[2]	Waist[3]	Body fat[4]
		[a]	[b]	[c]	[a]	[b]	[c]
1. Diet	*Modern*	0.0008	-0.0001	0.0001	-0.0002	0.0003	0.0010
	Traditional	0.0002	0.0004	-0.0001	0.0003	-0.0002	0.0002
2. Stress	*Sad*	-0.0118	0.0236	0.0019	-0.0182	-0.0072	-0.0101
	Fear	0.0250	-0.0148	-0.0076	-0.0312	0.0016	0.0201
	Anger	0.0312	-0.0111	-0.0321	-0.0010	0.0028	-0.0495
	Alcohol	-0.0744	0.0341	0.0831	0.0108	-0.0051	-0.0119
	Cigarettes	0.0068	0.0050	**0.0211***	**-0.0053*****	-0.0007	-0.0007
3. Age	*Age*	**-0.0128***	0.0013	0.0003	0.0046	0.0006	0.0086
	Age^2	**0.0002***	-0.000002	-0.00003	-0.00004	-0.00001	-0.0001
4. SES	*Wealth°*	0.0386	-0.0657	0.0360	-0.0232	0.0127	0.0401
5. Acculturation	*Schooling*	-0.0432	-0.0052	**-0.0803***	0.0250	0.0023	0.0298
	Spanish	0.0127	**0.1395***	-0.0369	0.0452	0.0204	0.0558
6. General health	*Bed days*	-0.0051	-0.0096	-0.0007	-0.0012	-0.0001	-0.0029
	Height	0.0040	0.0033	0.0045	0.0005	-0.0032	0.0033

TABLE 5 - continued. Random-effect panel linear multiple regression results of Tsimane' adult (≥20 years of age) overweight and obese (dependent variable) in relation to covariates of expectations. Variables measured annually, 2002-2006 (inclusive): Females and males

Expectation	I. Females			II. Males		
	BMI[2]	Waist[3]	Body fat[4]	BMI[2]	Waist[3]	Body fat[4]
	[a]	[b]	[c]	[a]	[b]	[c]
Tests of joint significance of covariates related to each expectation: χ2						
1. Diet	3.29	2.25	0.24	1.68	4.32	4.14
2. Stress	4.15	1.08	8.06	**14.70***	4.55	4.12
3. Age	**6.74***	0.52	2.93	0.89	2.10	4.92
4. SES	1.32	2.48	1.26	0.38	2.20	0.65
5. Acculturation	1.55	**6.41***	5.26	4.20	3.83	3.53
6. General health	2.75	4.13	1.79	0.06	3.04	0.92
Number of observations	706	699	690	732	737	711

[1] Same notes as Table 3, except here dependent variables are dummies.

[2] BMI: overweight and obese. Dependent variable: 1 if BMI≥25 and zero otherwise (National Institute of Health 1998)

[3] Waist: obese. Dependent variable: 1 if females≥88 or males≥102 and zero otherwise (National Institute of Health 1998)

[4] Body fat: over fat or obese. Dependent variable=1 if person is over fat or obese and zero otherwise. Over fat and obese vary by sex and age. Cut-offs come from the following web site: http://www.tanita.co.uk/index.php?id=96 (December 10, 2009).

Fig.1. Body-mass index (BMI) density histogram by sex: Tsimane' adults ≥ 20 years of age

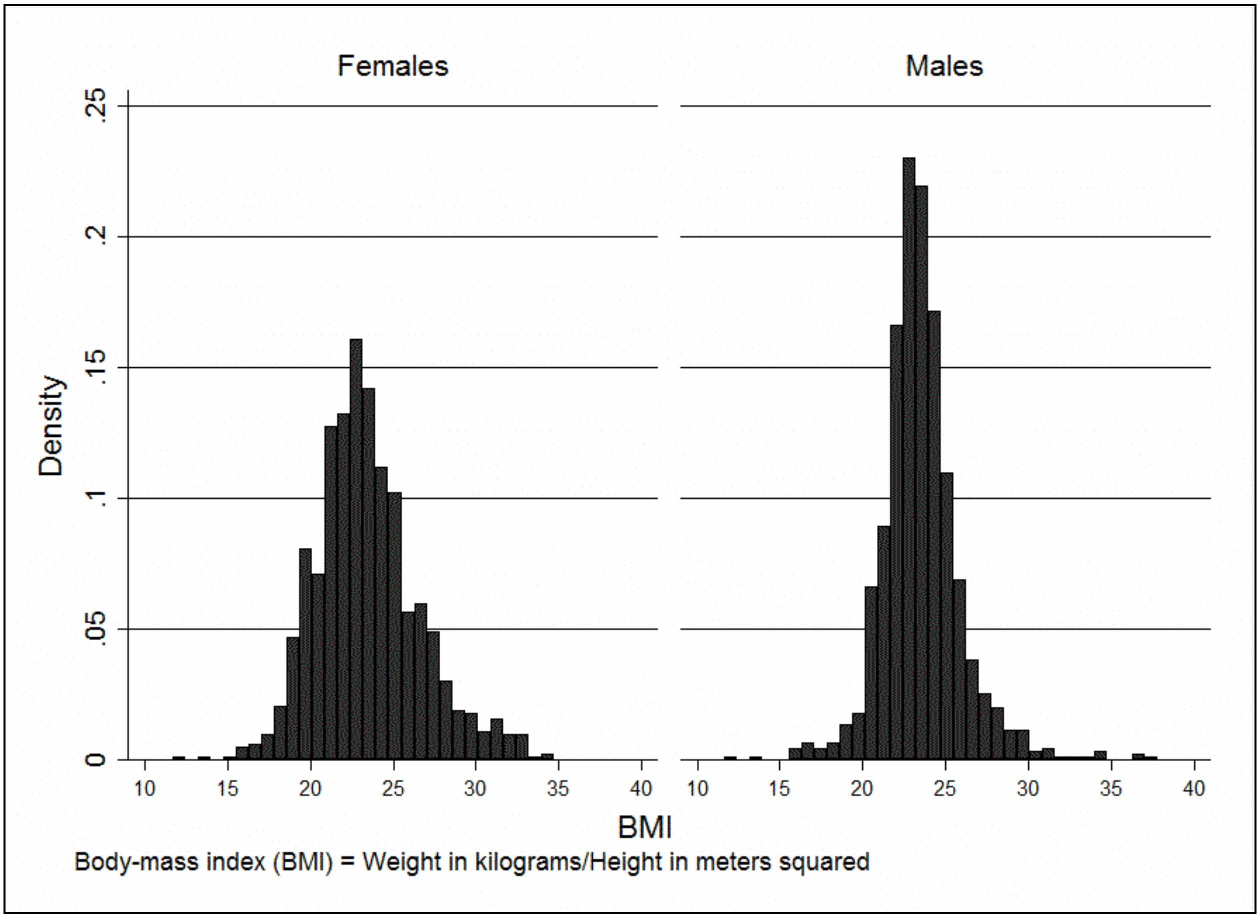
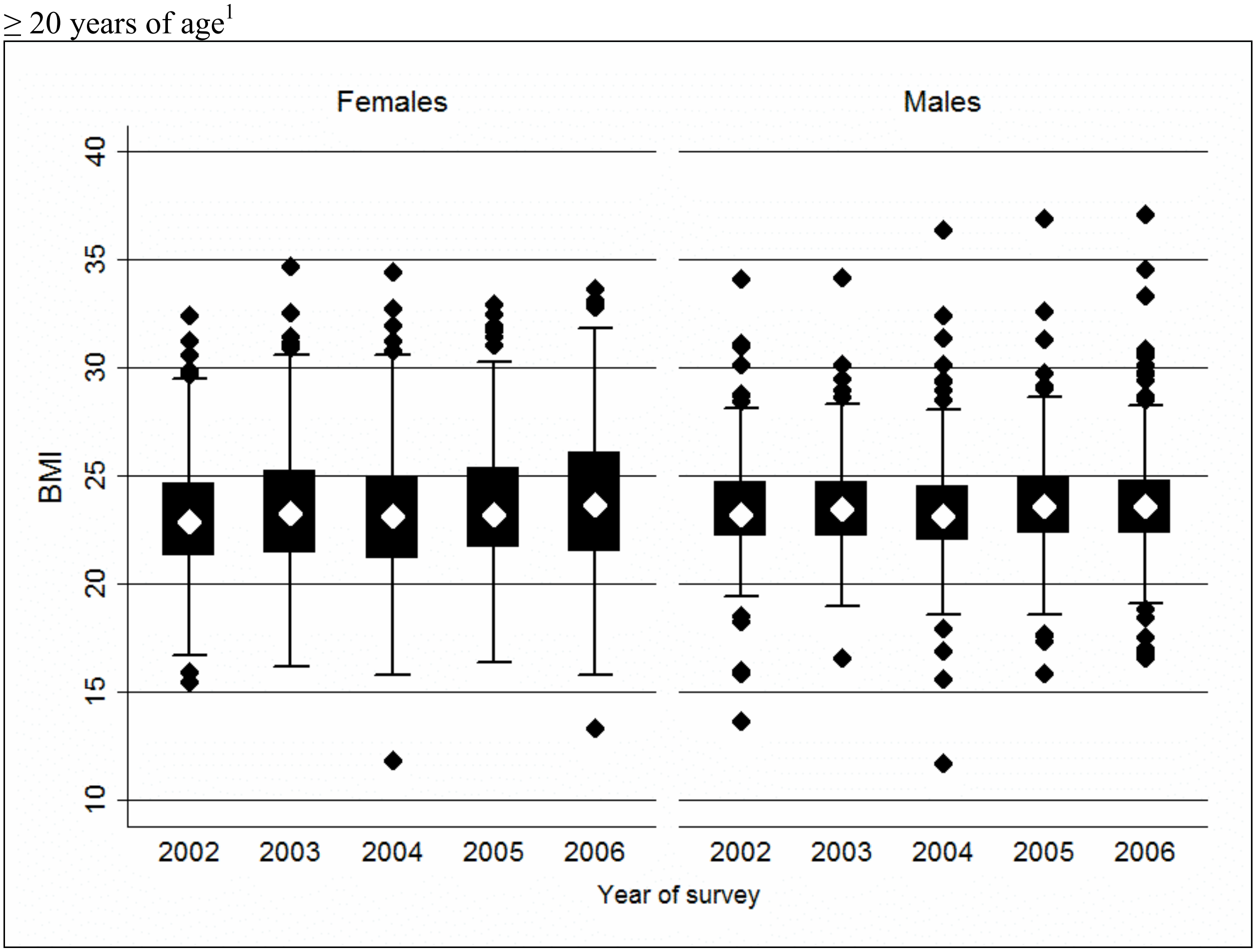


Fig. 2. Body-mass index (BMI) distribution by sex and year of survey: Tsimane' adults ≥ 20 years of age[1]



[1] The diamonds represent the median value, and the top and bottom lined of the boxes indicate the 75 percentile and 25 percentile. The vertical lines coming down from the boxes represent the values until the first quartile minus 1.5 the inter-quartile range, the vertical lines coming up from the boxes represent the values until the third quartile plus 1.5 the inter-quartile range; the dots above or below these lines represent the observations that fall out of this range.

Fig. 3. Body-mass index (BMI) in relation to age by sex: Tsimane' adults ≥ 20 years of age

APPENDIX

E1. Diet. We measured food consumption at the household level by asking the female head of the household about the quantity of 21 foods consumed by the household the seven days before the interview. The 21 foods covered a diverse selection of foods regularly eaten by Tsimane', yielding a reliable indicator of nutritional coverage. The 21 items included foods bought in the market (e.g., cooking oil), common crops grown by Tsimane' (e.g., manioc), animal wildlife, and meat and other products from domesticated animals (e.g., eggs). These food items have been used in other nutritional studies in rural Latin America (Leonard et al. 1993). For each food, we divided the total amount of household consumption by the number male-adult equivalents. Male-adult equivalent refers to the notion that people differ in their energy requirements as a function of their sex and age, so a child might represent a fraction of an adult in energy requirements. We calculated the energy requirements using the most recent FAO-WHO protocol (Godoy et al. 2007). The FAO-WHO method determines energy needs based on body size and on typical activity levels. This has become the preferred approach for determining food and energy requirements since dietary recalls do not accurately reflect variation in food and energy requirements. The reference category for estimating adult equivalents was a male 18–59 years of age.

We then calculated household energy consumption (kcal/week) using standard food composition reference data from Latin America (Chatfield 1949; FAO Oficina Regional para América Latina y el Caribe: http://www.rlc.fao/org/es/bases/alimento/default.htm) following the protocol developed by Leonard et al. (1993). Each of the 21 foods was classified as "traditional" or as "modern" depending on whether it was primarily produced by households (*traditional*) or obtained in the market (*modern*). This allowed for the determination of energy intakes from traditional and modern sources. *Modern* foods included bread, cooking oil, noodles, flour, lard, canned sardines, cow heads, sun-dried meat, and sugar. *Traditional* foods included fish, duck, wild birds, pigeon pea, eggs, pork, bush meat, beef, plantains, maize, manioc, and rice.

E4 SES - Wealth: Nominal refers to the monetary value without adjustments for inflation and real refers to the monetary value adjusted for inflation.

We measured wealth by first adding the nominal monetary value of 22 physical assets owned by the person: *(1)* five traditional physical assets central to their subsistence (e.g., canoes, bows), *(2)* 13 modern physical assets that capture some luxury goods (e.g., radios) and modern technologies for agricultural production (e.g., cutlasses), and *(3)* four domesticated animals (e.g., chickens, ducks) that contribute to consumption and buffer people against adverse mishaps. Based on ethnographic knowledge of the Tsimane' (Huanca, 2008; Martínez-Rodríguez, 2009; Reyes-García, 2001), we selected physical assets that captured wealth differences in the entire sample, and between females and males. For instance, the poorest people own bows, arrows, and small domesticated animals (e.g., chickens), but wealthier people are more likely to own large domesticated animals (e.g., cattle) and expensive industrial goods (e.g., guns). Among the assets measured, we included assets that females own (e.g., bags, pots) and assets that males own (e.g., cattle, guns). We multiplied the quantity of each asset owned times the selling price of the asset in the village to estimate the nominal monetary value of the asset, and then added the value of the different assets to arrive at the nominal value of total wealth for the person. Current nominal values for wealth were transformed into real values.

E6. General health – *bed days*: We broke up the recall period into the 1-7 days and the 8-14 days before the day of the interview. For each of the two recall periods we asked the person about the total number of days spent in bed because of illness. We limited the recall period to two weeks because we found that sickness recalls beyond that period produced unreliable information. A shorter recall period (e.g., one day) might have increased accuracy, but would have reduced variance. We opted to use bed-ridden days to measure morbidity because it is more objective and has a lower likelihood of containing random measurement error. Because of the way we constructed the variable, *bed days* ranged from 0 to 14.

We also asked about days with *illness* and symptoms, again for the last 1-7 and 8-14 days, but do not use the variable in the main analysis. We do not use the variable because of greater likelihood of random measurement error. The variable *illness* could exceed 14 even though the recall period was only 14 days. For example, a person who reported 14 days of fever and 14 days with a headache for the two weeks before the interview would get a score of 28.

Control variables included: *(a)* the real value of personal monetary income from the sale of goods and wage labor earned by the person during the 14 days before the interview, *(b)* measures of the outcome variable during the first year of observation, *(c)* the count variable described in the text (i.e., the number of times the person was measured across the five surveys), *(d)* full set of dummy variables for year, villages, and interaction of year and villages, and (e) proxies for physical activity, described in the next paragraph.

We used two indirect proxies of physical activity because we lacked direct measures of physical activity. First, we used the dependency ratio, or the number of children ≤ 12 years of age in the household divided by the number of people > 12 years of age in the household. Second, we used the total annual area of forest cleared for agriculture divided by the number of possible workers, or people ≥ 16 years of age in the household.

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[i] The nutrition transition refers to increased consumption of unhealthy foods in urban and, to a lesser extent, rural areas of poor nations (Popkin, 2001).

[ii] A confounder in the relation among adult females between age and body weight is parity. In less acculturated groups, parity is often higher, and this is more energetically costly and also more likely to cause morbidity. Unfortunately, we have no data on parity.

[iii] 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.

[iv] As noted in Table 4b, we did not take natural logarithms of bed-ridden days for column [c]. To estimate the effects of doubling bed-ridden days on weight Z score we estimated the mean number of bed-ridden days for the sample of males (mean=1.80; standard deviation=3.8). Since the coefficient of bed-ridden days in column [c] is –0.014, we multiplied this coefficient by twice 1.8 and obtained –0.05. Since the outcome is a Z score, the units are standard deviations.

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

[vi] The mean annual growth rates from the bivariate analysis of this article are 0.64% and 0.37% for females and males, but in another study (Godoy et al., 2009b) we use multivariate individual and community fixed-effect regressions and find that females and males had BMI growth rates of 0.56% and 0.85%. The annual growth rate of 0.60% mentioned in this paragraph is a reasonable middle value.