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Original Research Article

The Effect of Rainfall During Gestation and Early Childhood on Adult Height in a Foraging and Horticultural Society of the Bolivian Amazon

RICARDO GODOY,[1*] SUSAN TANNER,[2] VICTORIA REYES-GARCÍA,[1,3] WILLIAM R. LEONARD,[4] THOMAS W. MCDADE,[4] MELANIE VENTO,[4] JAMES BROESCH,[5] IAN C. FITZPATRICK,[6] PETER GIOVANNINI,[7,8] TOMÁS HUANCA,[9] AND NAVEEN JHA[1] BOLIVIAN TAPS STUDY TEAM[10]

[1]*Heller School for Social Policy and Management, Brandeis University, Waltham, Massachusetts 02454*
[2]*Department of Anthropology, University of Georgia, Athens, Georgia 30602*
[3]*ICREA and Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona, 08193 Bellatera, Barcelona, Spain*
[4]*Department of Anthropology, Northwestern University, Evanston, Illinois 60208*
[5]*Department of Anthropology, Emory University, Atlanta, Georgia 30322*
[6]*Institute of Social and Cultural Anthropology, University of Oxford, Oxford OX2 6PE, United Kingdom*
[7]*Center for Pharmacognosy and Phytotherapy, School of Pharmacy, University of London, London WC1N 1AX, United Kingdom*
[8]*Department of Pharmacology, School of Pharmacy, University of London, London WC1N 1AX, United Kingdom*
[9]*CBIDSI-Centro Boliviano de Investigación y de Desarrollo Socio Integral, Correo Central, San Borja, Beni, Bolivia*
[10]*Tsimane' Amazonian Panel Study (TAPS), San Borja, Beni, Bolivia*

ABSTRACT Recent research documents the effects of adverse conditions during gestation and early childhood on growth responses and health throughout life. Most research linking adverse conditions in early life with adult health comes from industrial nations. We know little about the plasticity of growth responses to environmental perturbations early in life among foragers and horticulturalists. Using 2005 data from 211 women and 215 men 20+ years of age from a foraging–horticultural society of native Amazonians in Bolivia (Tsimane'), we estimate the association between (a) adult height and (b) rainfall amount and variability during three stages in the life cycle: gestation (year 0), birth year (year 1), and years 2–5. We control for confounders such as height of the same-sex parent. Rainfall amount and variability during gestation and birth year bore weak associations with adult height, probably from the protective role of placental physiology and breastfeeding. However, rainfall variability during years 2–5 of life bore a negative association with adult female height. Among women, a 10% increase in the coefficient of variation of rainfall during years 2–5 was associated with 0.7–1.2% lower adult height (1.08–1.93 cm). Environmental perturbations that take place after the cessation of weaning seem to leave the strongest effect on adult height. We advance possible explanations for the absence of effects among males. Am. J. Hum. Biol. 20:23–34, 2008.

Recent research documents the effects of adverse conditions during gestation and early childhood on growth responses and health throughout life (Barker, 1995, 1998, 2001; Barker et al., 2002; Kuzawa and Pike, 2005). Impaired fetal development, maternal smoking during pregnancy, absence of breast-feeding, birth season, and high salt consumption in infancy increase the risk of coronary heart disease in adulthood, including higher systolic and diastolic blood pressure (Blane et al., 1996; Cruickshank et al., 2005; Huxley et al., 2000; Lawlor and Smith, 2005) and reduce longevity (Doblhammer and Vaupel, 2001). Childhood obesity and low birth weight are associated, respectively, with stiffness of arteries (Juonala et al., 2005) and with a greater propensity to develop non-insulin-dependent diabetes (Barker, 1998) as an adult. In the United States, birth weight and family income during early childhood bore a negative association with school achievement, which, in turn, affects adult health (Behrman and Rosenzweig, 2004; Case et al., 2005).

Most research linking early life conditions with adult health comes from industrial nations. We know little about the plasticity of growth responses to environmental perturbations early in life among more foragers and horticulturalists (Wilson, 1994; Worthman and Kohrt, 2005). Evidence from full-time smallholders in developing nations suggests that adverse environmental conditions early in life are associated with lower adult height and higher mortality. Alderman et al. (2006) found that children in Zimbabwe 6 months to 6 years of age affected by the droughts of 1982–1984 attained 0.72 lower z scores of height-for-age by the time they reached 17–18 years of age. Maccini and Yang (2006) estimated the effect of rainfall amounts during birth year on adult height in rural Indonesia, and found that rainfall amounts bore a positive association with height, but only among women. Women born during years with 20% more rainfall relative to the regional norm were 0.14 cm taller than their peers born during drier years. They hypothesized that rainfall contributed to height through higher farm output and more food. Rose (1999) found that favorable rainfall conditions in rural India during the first 2 years of life raised the probabilities that girls would survive to reach school age.

Drawing on data from a foraging–horticultural society of native Amazonians in Bolivia (Tsimane'), we extend this line of research to accomplish two aims. First, we test hypotheses about the separate effects of (a) the (1) amount of annual rainfall and (2) the intraannual monthly variability during gestation (year 0), birth year (year 1), and years 2–5 of life on (b) adult height (outcome). Second, we identify the stage in the early life cycle during which peo-

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*Correspondence to: Ricardo Godoy, Heller School for Social Policy and Management, Brandeis University, Waltham, MA 02454-9110. E-mail: rgodoy@brandeis.edu

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ple might be most vulnerable to rainfall risks and assess whether placental physiology and breastfeeding provide adequate protection.

Prior research has focused on the amount of rainfall as an indicator of environmental stress, but we distinguish between the amount and the variability of rainfall because they tell different stories. Extremes of rainfall aside, the annual amount of rainfall should increase farm output and thereby contribute to taller stature, particularly in areas that rely on rain-fed agriculture, as Maccini and Yang (2006) found. However, among foragers in the rain forest, rainfall amounts will hamper visibility and physical activity while collecting plants, hunting, and fishing. As a result, the amount of rainfall will bear a negative association with foraging productivity, thereby undermining food availability and health. In societies practicing a mix of foraging and horticulture, the net effect of rainfall amounts experienced early in life on adult height will be ambiguous and will depend on the offsetting effects that rainfall amounts produce on horticultural and foraging productivity (*Hypothesis 1*).

Monthly intraannual variability in rainfall will produce fluctuations in physical activity, exposure to pathogens, consumption of clean water, and in the foods consumed. The fluctuations will subject the body to more wear and tear and push adaptive regulatory mechanisms to work harder and more often. Furthermore, the biological and behavioral unpredictability associated with rainfall variability will produce additional strain on the human body. Constant variability in the environment will subject the organism to more and more drastic perturbations and undermine homeostasis (Godoy et al., 2005b; Lewontin and Levins, 2000). The fluctuations will reduce height because they will: (a) make it harder to stabilize food consumption and defend against infectious diseases, (b) increase investments in immunological defense mechanisms, and (c) decrease investment in growth. As a result, we expect a negative association between rainfall variability early in life and adult height (*Hypothesis 2*).

In impoverished settings around the world, infant growth only falls off precipitously relative to the reference median once exclusive breastfeeding ceases (McDade and Worthman, 1998). When infants breastfeed intensively (most likely to happen for the first 6 months, and then to continue, with supplemental foods, until the next child), they are buffered from poor nutrition and pathogen exposure. Furthermore, maternal physiology partially buffers the developing fetus against environmental insults. Children of weaning age are particularly at risk for malnutrition and growth failure for several reasons. Young children have much higher energy and nutrient requirements per unit body weight than adults because of the high metabolic demands of growth and development (FAO/WHO/UNU, 1985; Institute of Medicine, 2002; James and Schofield, 1990). In addition, the weaning foods in many traditional societies are relatively low in protein and key micronutrients (Allen et al., 1992; Berti et al., 1997; Leonard et al., 2000), and are thus unable to sustain rapid rates of physical growth. Infectious diseases also represent a particular problem for post-weaning children because of both higher exposure to pathogens (from food and water) and the loss of passive immunity acquired from the mother's breast milk. In fact, infectious diseases are a primary cause of death early in life (WHO, 2002). Poor dietary quality interacts synergistically with both acute (i.e., diarrhea and respiratory infections) and chronic infections (i.e., gut helminth infections) to produce compromised linear growth patterns (Schrimhaw, 2003; Stephenson, 1999).

For these reasons, we hypothesize that rainfall patterns after the cessation of breastfeeding will be more likely to leave an imprint on adult height than rainfall patterns during gestation or birth year (*Hypothesis 3*).

ESTIMATION STRATEGY

For the statistical analysis, we estimate the parameters of Eq. (1) separately for women and men over 20 years of age:

$$\begin{aligned}\ln Y_{iy=2005} = {} & \alpha + \beta \mathrm{XB}_{\mathrm{yob}-1} + \delta \ln \mathrm{CVB}_{\mathrm{yob}-1} + \beta' \mathrm{X}_{\mathrm{yob}} \\ & + \delta' \ln \mathrm{CV}_{\mathrm{yob}} + \beta'' \mathrm{XC}_{y=2-5} \\ & + \delta'' \ln \mathrm{CVC}_{y=2-5} + \theta \mathrm{IK}_{iy=2005} + \Phi \mathrm{S}_{iy=2005} \\ & + \Omega \mathrm{SP}_{ipy} + \sigma \mathrm{DOB}_i + \varepsilon \qquad (1)\end{aligned}$$

In Eq. (1) Y captures the standing height of person i during the year of the survey ($y = 2005$). XB and CVB reflect the total annual amount of rainfall (XB) and the coefficient of variation (CV = standard deviation [SD]/mean) of rainfall during gestation (CVB). We define gestation as the year before the person's birth (year of birth minus one, yob − 1, or year 0). The annual coefficient of variation for a year refers to the intraannual monthly variability of rainfall. X and CV stand for the total amount of annual rainfall and for the coefficient of variation of annual rainfall during the person's year of birth (yob or year 1). XC and CVC stand for the mean annual total amount of rainfall and for the mean annual coefficient of variation during years 2–5 of life ($y = 2$–5 or years = 2–5).

Several authors have hypothesized that adverse environmental conditions early in life affect pathways such as income and the accumulation of human capital of subjects and their parents, and that it is the erosion of these paths that contributes to lower income and shorter stature as an adult (Case et al., 2005; Jensen, 2000; Maccini and Yang, 2006). For instance, environmental perturbations might lower parental income or erode parents' ability to accumulate human capital and, in so doing, undermine their child's nutritional status. Environmental perturbations might erode children's cognitive abilities and economic productivity, thereby undermining their growth trajectory. We have no measure of income for subjects while they were young, but we have proxy variables of human capital for subjects and their parents. In a foraging–horticultural society, human capital refers to indigenous knowledge of the environment and to formal schooling. Recent research suggests that own and parental indigenous knowledge of plants might bear a positive association with own and child health (McDade et al., 2007). To control for some of these path variables, we include the following variables for subjects and their parents [in Eq. (1) the subscript p refers to parents]: own indigenous knowledge of plants (IK), own schooling (S), and parental attributes (SP).

IK includes three forms of indigenous knowledge of plants for person i: (1) theoretical knowledge of medicinal plants, (2) theoretical knowledge of edible plants, and (3) practical knowledge of medicinal plants. S stands for the maximum school attainment of person i. SP includes a vector of three variables for parental attributes of subject i: two variables that capture subject's perceptions of whether their mother or father had any schooling and the measured height of the same-sex parent. Since we do not have instrumental variables for schooling or indigenous knowledge, we cannot infer causality from parameter estimates of IK, S, and parental schooling.

Following standard practice in studies of adult height (Godoy et al., 2006a; Komlos, 1994), we include a vector of dummy variables for decade of birth (DOB) to control for secular (long-term) trends in height. As the Tsimane' gained increasing exposure to the market economy and the modern world starting in the late 1940s and early 1950s, their height might have changed in relation to time-dependent variables associated with human growth. Examples of such variables include changes in the availability of game, wild foods, amount of rain forest available for farming, and the relative price of foods and medicines. Dummy variables for birth decade sweep away the effect of time-dependent confounders and allow for more precise estimates of the link between rainfall and height.

To ease the reading of results, we took natural logarithms (*ln* in Eq. (1)) of all variables except for the following: (a) practical indigenous knowledge of medicinal plants, (b) variables for DOB, (c) amount of rainfall, and (d) schooling variables. We left variables in their raw form to avoid producing missing values (as with (a)) or because the variables are easier to interpret in raw form (as with (b–d)).

Hypothesis 1 says that the amount of annual rainfall will bear an ambiguous relation with adult height, so parameters β, β', and β'' should be indistinguishable from zero. *Hypothesis 2* says that monthly intraannual rainfall variability will bear a negative association with adult height, so parameter δ, δ', and δ'' should be <0. *Hypothesis 3* says that for any type of rainfall measure (amount or coefficient of variation), the parameters for years 2–5 will be larger than the parameters for gestation or birth years (e.g., $\delta'' > \delta$).

DATA AND METHODS

Information comes from a survey done during June–September 2005 among all households ($n = 252$) in 13 Tsimane' villages along the Maniqui River, province of Beni, Bolivia. The survey formed part of a panel study in progress dating back to 1999 (Godoy et al., 2005c). The 2005 survey was conducted by experienced interviewers and translators who had participated in the study since its inception.

The villages surveyed differed in their proximity to the town of San Borja. With a population of ~19,000 people and a local airport built during the mid 1930s, San Borja is the most important market town and administrative center for the Tsimane' along the Maniqui River. The average village in the sample was 25.96 km in a straight trajectory from San Borja (SD = 16.70; min = 5.71 km; max = 47.74 km).

Outcome: Height

We used the protocol of Lohman et al. (1988) to measure height. We recorded standing physical stature to the nearest millimeter using a portable stadiometer or a plastic tape measure. We found evidence of rounding error or digit heaping in our measures of height. Among women, heaping occurred with the digit 0 and among men it occurred with the digit 5 ($\chi^2 = 17.91$, $P = 0.03$). Measures of height ending in the digit 0 accounted for 20.36% (rather than ~10%) of observations among women and for only 12.07% of observations among men. Measures of height ending in the digit 5 accounted for 15.09% of observations among men and for 9.05% of the observations among women. We did not correct for digit heaping to retain fidelity to the raw data, but later discuss the consequences of the measurement error.

Since some adults had parents in the sample, we could include the height of the same-sex parent as an explanatory variable (SP in Eq. (1)). About half (51.65%) the women and 42.79% of the men did not have a same-sex parent in the sample, so the number of observations for the regressions with the height of the same-sex parent as a covariate is about half as large as the regression without the height of the same-sex parent. Missing values for the height of the same-sex parent explain why we do not control for the height of both parents; only 36.01% of the women and 38.60% of the men had data on the height of both parents.

Rainfall

Measures of rainfall came from Bolivia's national aeronautical agency and refer to the airport of San Borja (see Appendix). Rainfall records cover 1944–2005 and came aggregated by month. The level of aggregation made it impossible to estimate the dates of onset and end of the rainy season (Marengo et al., 2001).

Ideally, we should have had rainfall data over time for each of the 13 villages of the survey. Since we only have time-series data on rainfall for the airport, we need to establish that monthly rainfall amounts in the airport reflect rainfall amounts in the villages surveyed, particularly in villages farther away from the airport.

As part of the panel study, we measured daily rainfall during October 1999–October 2000 in two villages: San Antonio and Yaranda. Among the villages of the panel study, Yaranda and San Antonio are, respectively, the most remote and one of the closest villages to the town of San Borja. In a straight trajectory from San Borja, Yaranda lies 47.74 km away and San Antonio lies 10.34 km away. Two separate regressions of monthly rainfall amounts in San Borja (outcome) on monthly rainfall amounts in the (1) nearby village of San Antonio and (2) remote village of Yaranda produced positive and statistically significant coefficient at the 99% confidence level (coefficients: San Antonio = 0.89, Yaranda = 0.52). The findings suggest that rainfall data from the airport is reliable and reflects accurately rainfall levels in the villages surveyed.

We used monthly rainfall data from the airport to compute the following: (a) total amount of annual rainfall, (b) intraannual monthly coefficient of variation of rainfall, (c) z score of (a) or standardized deviations from the mean annual rainfall of the airport for 1944–2005, (d) natural logarithm of (b), (e) average of (c) and average of (d) for years 2–5 of life, and (f) lagged values of (c)–(d) by one year. Values under (f) capture rainfall during gestation (XB and CVB in Eq. (1) or year 0), values under (c) and (d) capture rainfall during birth year (X and CV in Eq. (1) or year 1), and values under (e) capture rainfall during years 2–5 of life (XC and CVC in Eq. (1) or years 2–5).

Theoretical and practical indigenous knowledge of plants

We focus on indigenous knowledge of wild and semidomesticated medicinal and edible plants rather than on other types of indigenous knowledge (e.g., soils) because of their obvious link to long-run nutritional status. We measured two dimensions of indigenous knowledge: theoretical and practical (Sternberg et al., 2001). Theoretical knowledge refers to information about plants learned listening or observing and can be assessed by asking subjects to name or identify plants. Practical knowledge or skills refers to the ability to use theoretical knowledge.

To measure theoretical knowledge of plants, we collected similarity judgments using a multiple-choice test of 15 plants selected at random from a list of 92 plants developed in an earlier study (Reyes-García, 2001). In the test people were asked whether they could use the plants for food or medicine. We used cultural consensus analysis (Reyes-García et al., 2003; Romney et al., 1986) to calculate the most common response among people age 55+ because elders likely know more about plants than do the young (Reyes-García et al., 2005). We used the most common response of elders as the answer key to calculate scores of theoretical knowledge of medicinal and edible plants. To measure practical knowledge of medicinal plants, subjects were asked whether they had ever used three medicinal plants. None of the questions was purposefully false. We added the number of positive responses to arrive at a total score.

No subject received a zero in either of the two tests of theoretical knowledge so taking logarithms did not reduce the sample size of the variables. Half the sample of women and men had a score of zero in the test of practical knowledge, so we did not take logarithms to avoid producing missing values.

Schooling

We asked subjects about the maximum school attainment of themselves and each parent. Since 11.95% of the sample knew that their parents had attended school but did not know the precise school attainment, we created two dummy variables, one for the mother and one for the father. The variables took the value of one if subjects perceived the parent had any schooling and zero otherwise.

Age, birth year, and birth decade

We asked subjects to estimate their age in years. Because many adults did not know their exact age, many provided educated guesses, which produced random measurement error in the age variable (Godoy et al., 2006a). We calculated birth year by subtracting the person's age (in years) from the survey year (2005), and used the person's birth year to: (a) link attributes of the person with rainfall data and (b) create five dummy variables for birth decade (1940, 1950, 1960, 1970, and 1980). Close to a quarter (25.82%; $n = 117$) of the adults surveyed (women $= 62$; men $= 55$) did not know their month of birth, so we do not use birth month to get more precise links between rainfall and adult height. Lack of birth month data means that estimates of rainfall's impact will contain random measurement error because of some mismatch between year of rainfall and birth.

Final sample

We limit the analysis to people 20–60 years of age for two reasons. First, Tsimane' stop growing at about age 20 (Godoy et al., 2006a); by limiting the analysis to Tsimane' over age 20, we raise the likelihood of including people who had reached their final height. Second, since rainfall data starts in 1944 and we need to lag rainfall variables by one year to pick up conditions during gestation, we had to limit the analysis to people born during or after 1945; during the year of the survey (2005) people born in 1945 were 60 years old. The final sample with the requisite data to estimate Eq. (1) (except parental height) included 211 women and 215 men from 228 households. Table 1 contains definition and summary statistics (divided by sex) of height and explanatory variables.

THE TSIMANE': ETHNOGRAPHIC BACKGROUND

The Tsimane' number ~8000 people and live in 100+ villages along river banks and logging roads, mostly in the department of Beni. Subsistence centers on hunting, plant collection, fishing, and slash-and-burn horticulture (Vadez et al., 2004). Because they do not have irrigation to water their crops, Tsimane' depend on rain to farm. Rain also affects the likelihood of fishing, hunting, and collecting wild plants.

Like other native Amazonian groups, Tsimane' rarely marry people outside their ethnic group. Only five people or 1.40% of the sample belonged to another ethnic group. Except for a few Tsimane' who work as school teachers or for logging firms, most Tsimane' subsist from foraging or from farming their own plots.

Mean daily personal income, calculated from monetary earnings and the value of goods they produce for their own consumption, is US$2.35–3.25, above the international poverty line of US$1–2/day and on par with the national income of Bolivia, one of the poorest Latin American nations. Besides having low income, the Tsimane' display much economic self-sufficiency (Godoy et al., in press-a).

In recent publications, we provide ethnographic and historical background information on the Tsimane', including analysis of their indigenous knowledge (Reyes-García et al., 2005), measures of income and consumption (Godoy et al., in press-a), absence of girl–boy disparity in parental investments, health, or school achievement (Godoy et al., 2006c), absence of a secular change in adult height for people born during 1920–1985 (Godoy et al., 2006a), effect of income inequality and empowerment on anthropometric indicators of nutritional status (Godoy et al., 2005a, 2006b), and coping strategies against mishaps that strike only the person or household as opposed to mishaps that strike many villages (Godoy et al., in press-b).

Since we have covered general background information elsewhere, in this section we discuss three topics that bear directly on this article: (a) growth stunting, (b) rainfall patterns, and (c) paths through which rainfall might affect adult height.

Growth stunting

Tsimane' are growth stunted (Foster et al., 2005), probably from high levels of pathogen exposure early in life (McDade, 2005a,b; Tanner, 2005). Dietary consumption

TABLE 1. Summary statistics of variables used in regression analysis for Tsimane' born 1944–1985 (20+ years of age at time of survey in 2005)

	Women			Men		
Definition of variables	*N*	Mean	SD	*N*	Mean	SD
Dependent variable						
Height: standing physical stature in cm using protocol by Lohman (1988)	211	151.13	4/86	215	163.05	4.89
Explanatory variables						
Theoretical indigenous knowledge about the medicinal use of 15 wild and semidomesticated *plants*	211	11.30	2.97	215	12.13	2.58
Theoretical indigenous knowledge about the edibility of 15 wild and semidomesticated *plants*	211	10.54	2.90	215	11.02	2.80
Practical indigenous knowledge of the use of three *medicinal plants*; range 0–3	211	0.65	0.76	215	0.65	0.76
Mother's schooling as reported by subject: 1 = any schooling; 0 = no schooling	211	0.13	0.34	215	0.17	0.37
Father's schooling as reported by subject: 1 = any schooling; 0 = no schooling	211	0.36	0.48	215	0.36	0.48
Own schooling: top school level achieved by subject	211	1.31	1.54	215	3.12	3.07
Parental height (cm)[a]						
Mother	109	149.81	5.00	[b]	[b]	[b]
Father	[b]	[b]	[b]	92	161.91	4.53

Variables measured in 2005. Except for schooling and practical indigenous knowledge, all variables have been transformed into natural logarithms for the regressions.
[a]Based on actual measures, but only for subjects with parents in the sample (see height).
[b]Variable intentionally left out.

appears adequate in energy and protein, but may be limiting in key micronutrients (Godoy et al., 2005c). Mild–moderate under-nutrition and high infectious disease load in childhood contribute to small adult body size by diverting energy that would otherwise fuel growth (McDade et al., 2005a). Adult Tsimane' women and men are both ~1.78 standard deviations below the median height of their age and sex peers in the United States. Though short by United States' standards, Tsimane' are tall compared with native Amazonian populations (Godoy et al., 2005c). In the middle two lines of Figure 1, we plot the adult height of women and men by birth year (1944–1985). The figures show variation in adult height by birth year, but no clear secular change, consistent with results of statistical analysis presented elsewhere (Godoy et al., 2006a).

Rainfall patterns

Figure 2 shows the mean amount of rainfall for each month during 1944–2005. The figure shows two seasons: a dry season between May and September and a wet season between October and April. The top line of Figure 1 shows the total amount of annual rainfall for each year. Mean annual rainfall is 1743 mm (SD = 494; min = 872 mm; max = 3907 mm). The years with complete annual rainfall data that had the lowest rainfall included 1945, 1946, 1962, 1969, and 1970 and the years that had the most rainfall included 1958, 1973, 1975, and 1980–1981. The bottom line of Figure 1 shows the intraannual monthly coefficient of variation of rainfall (mean = 0.74; SD = 0.15; min = 0.35; max = 1.19), with low points during 1947, 1957, 1970, and 1972, and high points during 1966–1968, 1980, and 1984.

Tsimane' clear the forest during the dry season and let the underbrush and logs dry before burning (Vadez et al., 2003). They burn the debris and then plant crops such as plantains, rice, maize, and manioc. Planting takes place with the onset of the rainy season (August–December). If they cut the forest too early or if they wait too long to cut (or if rains arrive early), the debris does not burn well to: (a) deposit nutrients into the soil, (b) maximize the amount of space available for crops to grow, and (c) "minimize the amount of labor required to prepare the field for planting" (Baksh and Johnson, 1990; Wilkie et al., 1999). The abovementioned facts (a)–(c) reduce crop yields.

The Tsimane' calendar starts in May when many edible fruits in the forest ripen. Wild animals gain weight starting in May and provide ideal prey; the gain in weight of animals stimulates lone and group hunting. The dry season is also the time when Tsimane' use plant poison to fish, often in a group. Rainfall lowers foraging productivity. When it rains hunting dogs do not go out of the house and rivers become too turbid for fishing with bows and arrows and plant poison since these forms of fishing require that the person see well. Among crops, plantains and manioc appear to remain impervious to amounts of rain, but rice, the main cash crop, does poorly with little rain.

Paths through which rainfall might affect adult height

We evaluate three overlapping paths through which rainfall might affect adult height: (a) pathogen exposure, (b) foods consumed, and (c) idle time. The paths are suggestive because the associations we discuss next refer to

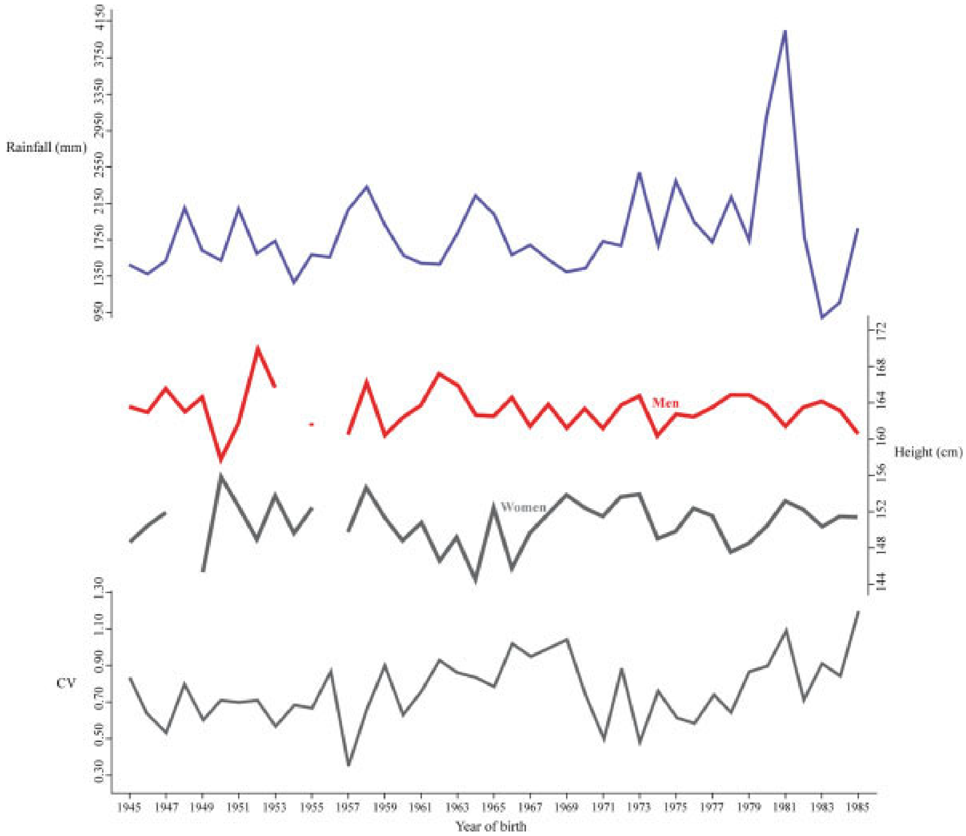

Fig. 1. Annual amount (mm) and intraannual monthly coefficient of variation (CV = SD/mean) of rainfall in the airport of the town of San Borja and adult height (cm) of Tsimane' women and men by year of birth, 1945–1985. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

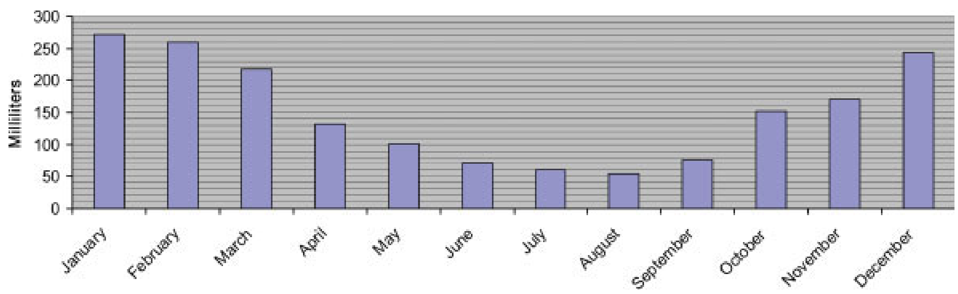

Fig. 2. Average monthly rainfall (mm) in the airport in the town of San Borja: 1944–2005. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

the recent past; those associations should have taken place 20+ years ago to bear directly on our findings.

Pathogen exposure. Tanner (2005); and Tanner et al., (2004) collected fecal samples from ~200 Tsimane' ranging in age from 4 months to 80 years. Data were collected from the same people on two occasions: once during the dry season (July–August 2003) and once during the wet season (December 2003–January 2004). Except for protozoal infections, there were no statistically significant differences in the level of gastrointestinal parasitic infection between seasons. Forty-one percent of the sample either gained or lost protozoal infection between the dry and wet season, but most of these infections resulted from non-pathogenic protozoa. She found no differences in frequency of reported respiratory or gastrointestinal illness between the wet and the dry season in the parasite subset of data. Byron (2003) used five consecutive quarters of panel data (1999–2000) from children and adults in two villages (Yaranda and San Antonio) and found no statistically significant relation between the amount of rainfall and self-reported morbidity, duration of illness, or severity of illness.

Currently, malaria is not a problem in the area. Other vector-borne diseases that are present in the area include leishmaniasis and possibly dengue and yellow fever. As is the case in many other rural areas of developing nations, the most important childhood infections include respiratory infections, such as tuberculosis, pneumonia, and whooping cough, along with gastrointestinal infections including diarrhea and parasitic infections. Gastrointestinal parasitic infections are common with over 85% of children and adults being infected with some form of parasitic protozoan diseases; the most common being the soil-transmitted helminth hookworm (*Ancylostoma duodenale* and *Necator americanus*) although Giardia and nonpathogenic amebae were also present. With regard to seasonality, there does not appear to be a marked seasonal difference in the frequency of soil-transmitted helminth.

Foods consumed. We hypothesized that rainfall amounts would raise farm output but lower foraging output. It is possible that more rainfall would correlate with more crop production and consumption, but lower extraction and consumption of fish and wild animals. Changes in the availability of proteins from wildlife might affect growth.

To explore the association between rainfall amounts and the composition of foods consumed we draw on a combination of surveys and scans or spot observations (Sacket and Johnson, 1998) collected every week during four consecutive quarters (August 2002–November 2003) from the same people in the 13 villages of the panel study. Each week we selected at random both a day and a block of 3 h (between 7 am and 7 pm) to collect information. Every week, half of the villages were scanned 1 day and the other half were scanned on a different day. We did 12 scans in each village each quarter so our measures capture variation in time allocation through the year. Following standard practice (Sacket and Johnson, 1998), we noted what subjects were doing at the instant when we first spotted them. After writing the subjects' activity, we asked them to list all their activities for the previous 24 h. In particular, we asked them about the type and the amount of game, fish, wild plants, and domesticated crops brought to the household during the previous 24 h. On average, we scanned participants 4.1 times each quarter (SD = 3.05). We used the date of the scan to link data from the 24-h recall with monthly rainfall data.

Multivariate regressions (not shown) that controlled for time of day, quarters, and village and individual fixed effects suggests that the amount of monthly rainfall was associated with a lower likelihood of having brought fish or game meat during the previous 24 h, consistent with the ethnographic description presented earlier. The amount of monthly rainfall was associated with a greater likelihood of harvesting domesticated crops from farm plots or wild plants from the forest during the previous 24 h, but the diversity of crops extracted declined with the amount of monthly rainfall. A 10% increase in the amount of monthly rainfall was associated with 0.30 fewer varieties of wild and domesticated plants brought into the household by the person during the previous 24 h. Except for the negative association between monthly rainfall amounts and the diversity of crops collected during the previous 24 h, all the relations mentioned in this paragraph were statistically insignificant at the 95% confidence level.

Idle time. We tested whether the amount of rainfall bore a significant association with the amount of idle time. Greater time spend at home while it rains might raise the likelihood of person-to-person transmission of disease since Tsimane' often remains indoors while it rains. We used a regression similar to the one described in the previous paragraph, except that we included a dichotomous variable for idleness (1 = subject idle during scans, 0 = not idle). We found that the amount of rainfall bore a positive association with the likelihood that the subject was idle at the moment researchers spotted them, but the relation was statistically insignificant.

In sum, although not statistically significant at the conventional 95% confidence level, the results nonetheless hint at the idea that the amount of monthly rainfall produces mixed effects on the composition and quality of the diet and increases idleness (and possibly pathogen exposure).

MAIN REGRESSION RESULTS

Table 2 contains the main regression results. Eight findings merit discussion.

1. None of the rainfall variables—alone (rows I) or jointly (rows VII.A)—bore a statistically significant association with the height of adult men, so when discussing rainfall variables we focus on women.
2. Rainfall variables explained a small share of the variation in adult female height. For example, the R^2 of a regression (not shown) with only rainfall variables as covariates was 0.04. After adding socioeconomic covariates (column [1] of Table 2) the R^2 increased to 0.10.
3. Column [1] suggests that the amount of annual rainfall during gestation, birth years, and years 2–5 did not bear a statistically significant association with female height. Variables related to the amount of rainfall—alone (rows I.A) or jointly (rows VI.B)—were statistically insignificant at the 95% confidence level. The result supports *Hypothesis 1* that the amount of rainfall will likely have ambiguous associations with adult height in a society practicing horticulture and foraging.
4. Rainfall variability during gestation (row I.B.1) and birth year (row I.B.2) bore no statistically significant association at the 95% confidence level or higher with female height, but rainfall variability during years 2–5 of a girl's life was associated with lower height as an adult (row I.B.3). A 10% increase in the coefficient of variation of rainfall during years 2–5 of a girl's life was associated with 0.72% (column [1]) lower adult height (1.08 cm). The association increased from 0.72% to 1.27% less height (1.93 cm) in the regressions that conditioned for heritable factors through mother's height (column 2 under women). A mean decline in the adult height of women of 0.72–1.27% from a 10% increase in rainfall variability is large and significant, amounting to 1.08–1.93 cm. Together, the three variables related to the coefficient of variation of rainfall during years 2–5 were statistically significant at the 97% confidence level (row VI.D). The results provide partial support for *Hypothesis 2* that rainfall variability depresses adult height; support is partial because we found no effect among men.
5. Own indigenous knowledge of plants generally bore no statistically significant association with the adult height of women or men. Two of the three coefficients had the wrong (negative) sign. Although none of the

TABLE 2. Regression results of natural logarithm of adult height (dependent variable) on rainfall variables during gestation, birth year, and years 2–5 of life for Tsimane 20+ years of age during 2005 survey

Explanatory variables	Women [1]	Women [2]	Men [1]	Men [2]
I. Rainfall during person's early life				
A. *Z* score of amount during person's				
[1] Year of gestation (year 0)	0.003	***0.008*****	0.0008	0.001
[2] Year of birth (year 1)	0.003	***0.005****	−0.009	−0.001
[3] Years 2–5 (average z score for years 2–5)	0.004	***0.022*****	0.004	0.001
B. Natural logarithm of annual coefficient of variation (CV) during person's				
[1] Year of gestation (year 0)	−0.021	−0.030	0.004	−0.005
[2] Year of birth (year 1)	−0.016	***−0.028****	0.004	0.007
[3] Years 2–5 (average annual CV for years 2–5)	***−0.07*****	***−0.12*****	0.011	0.016
II. Person's indigenous knowledge of plants				
A. Theoretical				
[1] Medicinal	−0.03	***−0.07*****	0.018	0.001
[2] Edible	0.01	***0.05****	−0.022	0.009
B. Practical—medicinal	−0.0007	0.006	0.002	0.003
III. Own and parental schooling				
A. Mother (1 = any schooling; 0 = no schooling)	0.001	0.01	***0.016*****	***0.022*****
B. Father (1 = any schooling; 0 = no schooling)	−0.002	−0.003	***−0.01*****	***−0.024*****
C. Person (maximum years of school completed)	−0.0009	−0.003	−0.00002	0.0008
IV. Person's birth decade (reference category: <1960)				
1960	0.01	***0.04*****	0.002	−0.016
1970	0.00004	0.006	−0.0009	−0.012
1980	0.01	***0.03*****	0.0009	−0.010
V. Parental height				
A. Mother's height in natural logarithms	a	***0.42*****	a	a
B. Father's height in natural logarithms	a	a	a	***0.494*****
Constant	***5.029*****	***2.87*****	***5.10*****	***2.56*****
R^2	0.10	0.44	0.09	0.37
VI. Test of joint significance of rainfall variables (F and, in parenthesis, p > F)				
A. All variables under I (amount and CV)	1.92 (0.07)	***2.80 (0.01)***	0.59 (0.73)	0.33 (0.92)
B. All variables under I.A (amount)	1.55 (0.20)	***3.77 (0.01)***	0.26 (0.85)	0.17 (0.91)
C. All variables under I.B (CV)	***2.99 (0.03)***	***5.21 (0.002)***	0.53 (0.66)	0.24 (0.87)
D. Stage in the life cycle of person				
[1] Gestation (year 0) (I.A.[1]+I.B.[1])	2.14 (0.11)	***5.15 (0.007)***	0.32 (0.72)	0.12 (0.89)
[2] Birth year (year 1) (I.A.[2]+I.B.[2])	2.48 (0.08)	***4.48 (0.01)***	0.14 (0.86)	0.22 (0.79)
[3] Years 2–5 (I.A.[3]+I.B.[3])	***3.80 (0.02)***	***6.12 (0.003)***	0.82 (0.44)	0.17 (0.84)
VII. Test of joint significance of variables related to indigenous knowledge of plants (F and, in parenthesis, p > F)				
A. All variables under II	***3.80 (0.02)***	***4.86 (0.003)***	1.00 (0.39)	0.54 (0.65)
Sample size	211	109	215	92

Regressions are ordinary-least squares with robust standard errors when $p > \chi^2$ in Breusch–Pagan test <5%.
[a]Variable intentionally left out.
*Significant at ≤5% statistically significant coefficients shown in bold and italics.
**Significant at ≤1%; statistically significant coefficients shown in bold and italics.

three coefficients for indigenous knowledge was individually significantly related to female height, as a group the three variables bore a statistically significant joint association with height. The *F* statistic for the test of significance of the three variables related to indigenous knowledge was 3.80 ($P = 0.02$) (row VII.A). Once we condition for heritable factors (column [2]), we see that indigenous knowledge of medicinal plants bears a negative association with female height (coefficient = −0.07) while indigenous knowledge of edible plants bears a positive association, almost of the same magnitude (coefficient = +0.05). The results of column [2] imply small, unrealistic real effects on height from indigenous knowledge. The coefficients imply that a doubling of indigenous knowledge of medicinal and edible plants among adult women would produce a net decline in height of 2% or ~ 4 cm (−2% = −7 + 5%). Since doubling an adult's stock of indigenous knowledge is unlikely, the implied height change is unrealistic.

6. The schooling level of women or men bore no statistically significant association with their own adult height (rows III.C). Among women, perceived parental schooling bore no association with the adult height of daughters (rows III.A–B), but among men parental schooling bore both positive and negative associations with the adult height of sons. If we focus on the regression results of column [1] for men we see that having a mother with any schooling was associated with a son being 1.6% or 2.76 cm taller as an adult, but having a father with any schooling was associated with a son being 1.0% or 1.78 cm shorter as an adult.
7. The height of an adult daughter bore a strong positive association with the height of her mother, and the height of an adult son bore a strong positive association with the height of his father (columns [2], rows V.A and B). Among women, a 1% increase in mother's height was associated with a 0.42% increase in a daughter's height (0.63 cm) and among men a 1% increase in father's height was associated with a 0.49% increase in

a son's height (0.81 cm). Separate regressions (not shown) for women and men of own height (dependent variable) on the height of each parent as two separate covariates produced an R square of 0.48 for women and 0.47 for men. The result supports studies noting that 10–30% of the variability of adult height reflects socioeconomic conditions, with the rest accounted for by heredity (Henneberg and van den Berg, 1990). For women, the parameter for the coefficient of variation of rainfall during years 2–5 almost doubled from −0.07 in column [1] to −0.12 in column [2] after conditioning for heritable attributes.

8. The regression for women that controls for mother's height (column [2]) suggests that rainfall patterns during gestation and birth year bore an association with the adult height of women, but the effect was small. An increase of one standard deviation in the amount of rainfall during gestation was associated with 0.8% taller stature (1.2 cm) and the same increase in rainfall during birth year was associated with 0.5% taller stature (0.7 cm). A 10% increase in the coefficient of variation of rainfall during birth year was associated with 0.28% lower height (0.4 cm).

In section VI.D for women we test *Hypothesis 3* about the stage in the life cycle during which environmental perturbations might leave most lasting effects. We find that rainfall variables during years 2–5 (row VI.D.3) produced larger F statistics than variables during gestation (row VI.D.1) or birth year (row VI.D.2). In row VI.D.3 of column [1], we see that only rainfall variables during years 2–5 bore a statistically significant association with height. We therefore conclude that rainfall perturbations during the critical window of years 2–5 in life produce greater adverse effects on adult female height than rainfall earlier in the life cycle.

TEST FOR SELECTION BIAS

If rainfall variability undermines health and increases adult mortality, then the parameter for the coefficient of variation of rainfall that we estimated would contain a bias since we would only observe a self-selected sample of people who survived adverse climate conditions by the time the interview took place. To check for selection bias, we follow Maccini and Yang (2006) and test whether rainfall variables bore an association with the subject's parents being dead or alive at the time of the interview. A strong association between rainfall variables (particularly rainfall variability) and parental mortality would hint at sample selection and might also point to a possible path linking exposure to rainfall early in life with adult height.

We ran four probit regressions (not shown): two for females and two for males. For each sex, we had two dichotomous dependent variables: (i) whether the subject's mother was alive at the time of the interview and (ii) whether the subject's father was alive at the time of the interview. The variables took the value of 1 if the parent was alive, and 0 otherwise. As explanatory variables we included the six rainfall variables of section I, Table 2, plus dummy variables for birth decade. None of the rainfall variables bore a statistically significant association at the 95% confidence level or higher with parental mortality. The results suggest that rainfall during gestation and early childhood probably did not create a significant selection bias through parental mortality.

ANALYSIS OF ROBUSTNESS FOR FEMALES

We did further analysis to ensure the robustness of the main results. First, we created different lead periods. In the regressions of Table 2, we used a measure of rainfall for years 2–5 of a girl's life; in the sensitivity analysis we used separate annual measures of rainfall for years 2, 3, 4, and 5 of life (along with rainfall during gestation and birth year). Second, we took out the six rainfall variables and put instead two dummy variables, one for the five wettest and one for the five driest years to assess whether floods or droughts bore an association with height; in those regressions we did not condition for rainfall variability. Third, we corrected for age-related shrinkage for people over 30 years of age by applying the Trotter and Glesser (1951) correction of 0.06 cm/year of age to subject's height. Fourth, we controlled for 4.76% of the sample that had grown in areas abutting the Maniqui basin. Fifth, we included the height of both parents (not just the height of the same-sex parent) to the regressions of column [2]. Sixth, we split the sample above and below the median distance to the airport in San Borja to assess whether results would differ as one got closer to the airport with its better rainfall data. Last, we tested whether rainfall early in life bore an association with levels of parental schooling, fluency speaking Spanish, writing skills, or math skills under the assumption that rainfall shocks might erode parental human capital and so harm the health of the offspring.

Most of the basic findings remained unchanged. We found no age threshold for the timing of rainfall, suggesting that it is the combined effect of rainfall variability during years 2–5 of a girl's life that is likely implicated with lower height. We also included year-by-year rainfall variables (amount and coefficient of variation) for the first 10 years (plus year of gestation), and found that only one of the 22 rainfall variables was statistically significant at the 95% confidence level suggesting, again, that it is the combined effect of rainfall over several years that likely causes shrinking. The variables for drought and floods bore no statistically significant association with adult female height, hinting that it is the variability rather than the level of rainfall (however large or small) that matters most for adult height. Correcting for age-related shrinkage, and either adding a dummy variable for or excluding people raised outside of the Maniqui basin did not change results. Adding father's height reduced the sample size of the regressions from 109 to 74 and made all the rainfall variables statistically insignificant at the 95% confidence level, with one exception: the coefficient of variation of rainfall during years 2–5 declined from −0.12 in column [2] of Table 2 to −0.08 in the new regression but remained statistically significant ($P = 0.04$). Breaking up the sample by proximity to the airport produced statistically insignificant results for rainfall variables, probably from the smaller sample size. Last, none of the six rainfall variables bore a statistically significant association with parental human capital.

STRENGTHS AND LIMITATIONS

Ours is among the first study to formally test the association between (a) rainfall amounts and variability during gestation and early childhood and (b) adult height in a rural setting of a developing nation and a part-time foraging group. The study relies on a modestly large sample (n = 426) of observations for a field-based biocultural anthropological study, and years of field experience. The data allows us to control for unobserved attributes of households (by conditioning on perceived parental human capital) and individuals (by conditioning on the measured height of same-sex parents). Data on parental mortality lets us rule out one type of selection bias as a possible reason for the finding.

The study has several limitations: (1) We used the amount and variability of rainfall because that is the only time-series data on climate we had, but other climate variables (e.g., temperature), including the timing of rains, might play a stronger role in determining adult height. (2) Random measurement error in the variable for birth year increases random measurement error for rainfall variables and random measurement errors in height inflate standard errors, weakening results. These two measurement errors imply that the inverse relation between rainfall variability and adult female height that we found likely understates the magnitude of the true relation. Given measurement errors, a sample size of only 211 women and 215 men may have been too small to detect effects, particularly if true effects are modest, as might be the case among men.

DISCUSSION AND CONCLUSIONS

Links to other studies

The main finding of a negative association between rainfall variability during early childhood (years 2–5) and the adult height of women agrees with several bodies of literature. The finding that adverse climate conditions harm women more than men complements the finding from our earlier panel study of 1999–2000 among Tsimane', which showed that mishaps affecting only households and individuals (not the entire community) harmed the short-run nutritional status of women but not of men (Godoy et al., in press-b). It also dovetails with a case study of Hazda foragers by Hawkes et al. (1997), who found that women experienced larger changes in body weight between seasons than men. Our finding supports studies by economists who find that adverse climate only affect females (Maccini and Yang, 2006; Rose, 1999) and that their effects persist into young adulthood (Alderman et al., 2006) and adulthood (Maccini and Yang, 2006). More broadly and on a policy level, our finding supports growing consensus among development economists that low-income rural people in developing nations remain poorly insured against environmental perturbations (Townsend, 2002).

Reasons for difference in results between women and men

We present two possible explanations for why rainfall variability during early childhood might bear a negative association with the adult height only of women. One explanation has to do with household allocation of resources in favor of boys during and after mishaps. Though possible, the explanation does not stand well to empirical scrutiny. Elsewhere we tested for girl–boy disparity in anthropometric indicators and school achievement, and found no evidence of girl–boy difference (Godoy et al., 2006c). Furthermore, we found no statistically significant difference between girls and boys in the concentration of C-reactive protein (CRP), a biomarker of inflammation (McDade, 2005a,b), nor have we found significant girl–boy differences in statural growth stunting or low weight-for-age in Tsimane' children (Foster et al., 2005). At least in the short run, child nutritional status seems fully insulated against idiosyncratic mishaps affecting the household (Godoy et al., in press-b). If parental discrimination in favor of boys prevailed in the past, then this would explain why rainfall perturbations affect only females, but we have no way of estimating secular trends in parental discrimination.

The second explanation has to do with the effect of environmental perturbations on path variables that only affect females, such as the onset of menarche. Byron (2003) estimated median age at menarche in a small sample of girls and found it to be early (12–13 years of age). Research in progress among Tsimane' 3–19 years of age suggests that rainfall amounts and variability are associated with lower height but with more weight, both among females and males. Among females, the increased weight early in life might trigger earlier menarche and earlier attainment of final adult height. If so, climate perturbations might lock a female earlier in life into shorter stature as an adult. Among males the increased weight from rainfall perturbations early in life probably has positive or neutral effects on stature growth.

Why years 2–5?

Rainfall variability during gestation and birth year bore a weak association with the adult height of women probably because of the buffering role of placental physiology and breastfeeding. Tsimane' mothers breastfeed their infants until about 2 years of age. We find a negative association between adult female height and rainfall exposure at 2–5 years of age because buffering has attenuated, but children are still growing so losses during this period are not likely to be made up later, particularly during years 2–5 of life.

The interpretation fits with our research in progress on parasitic infections and biomarkers of immune activity. Tanner (2005) found that rates of parasitic infections among Tsimane' increased when children started to walk, peaked in late childhood and adolescence, and remained high throughout old age. Research on C-reactive protein (CRP) as a biomarker of immunostimulation with the Tsimane' suggests that infection rates are highest for children 2–3 years of age (23.3%), decline to 15.2% among children 4–5 years of age, and to $\sim$10% among children 6–15 years of age (McDade et al., 2005a,b). Elevated CRP among children was associated with lower growth rates over the subsequent 3 months, suggesting that infection may contribute to growth faltering. Foster et al. (2005) also found that growth faltering among Tsimane' started $\sim$18 months of age and continued throughout childhood.

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APPENDIX

TABLE A1. Annual Rainfall in Airport of Town of San Borja: 1944–2005

Year	*N*	Total	SD	CV
1944	10	1,171	108.02	0.92
1945	12	1,459	102.34	0.84
1946	12	1,359	72.87	0.64
1947	12	1,501	66.63	0.53
1948	12	2,096	139.10	0.80
1949	11	1,617	88.86	0.60
1950	12	1,509	89.34	0.71
1951	12	2,083	121.16	0.70
1952	12	1,592	93.99	0.71
1953	12	1,723	81.79	0.57
1954	11	1,256	77.80	0.68
1955	12	1,578	88.34	0.67
1956	12	1,500	108.48	0.87
1957	12	2,066	60.58	0.35
1958	12	2,316	128.03	0.66
1959	12	1,906	142.80	0.90
1960	12	1,555	81.06	0.63
1961	12	1,489	94.06	0.76
1962	12	1,472	113.98	0.93
1963	12	1,802	129.10	0.86
1964	12	2,223	156.08	0.84
1965	12	2,011	130.87	0.78
1966	12	1,565	133.42	1.02
1967	12	1,687	133.50	0.95
1968	12	1,515	131.74	1.04
1969	12	1,399	85.81	0.74
1970	12	1,430	59.11	0.50
1971	12	1,737	127.34	0.88
1972	12	1,673	67.40	0.48
1973	12	2,482	156.30	0.76
1974	12	1,683	87.42	0.62
1975	12	2,392	116.24	0.58
1976	12	1,946	120.09	0.74
1977	12	1,703	90.24	0.64
1978	12	2,255	164.16	0.87
1979	12	1,748	131.30	0.90
1980	12	2,904	264.75	1.09
1981	12	3,907	230.80	0.71
1982	11	1,782	146.72	0.91
1983	6	872	122.48	0.84
1984	5	1,003	240.40	1.20
1985	12	1,863	87.10	0.56
1986	10	1,573	114.72	0.73
1987	12	2,024	87.78	0.52
1988	12	2,019	142.33	0.85
1989	11	1,486	92.57	0.68
1990	12	2,061	116.03	0.68
1991	12	1,617	95.54	0.71
1992	12	2,720	128.52	0.57
1993	12	1,715	107.80	0.75
1994	6	895	100.71	0.67
1995		No data available		
1996				
1997	12	1,387	87.23	0.75
1998	12	1,865	128.01	0.82
1999	12	1,363	85.42	0.75
2000	12	1,204	74.84	0.75
2001	12	1,607	78.66	0.59
2002	12	1,283	66.27	0.62
2003	12	1,228	87.43	0.85
2004	12	2,136	134.15	0.75
2005	12	1,563	116.94	0.90

Source: Administración de Aeropuertos y Servicios Auxiliares a la Navegación Aérea (AASANA).
SD, standard deviation; CV, coefficient of variation (SD/mean); *N*, number of months in a year with data on rainfall; Total, total amount of rainfall (mm).