Ethnobotanical knowledge is associated with indices of child health in the Bolivian Amazon

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Culture is a critical determinant of human behavior and health, and the intergenerational transmission of knowledge regarding the use of available plant resources has historically been an essential function of culture. Local ethnobotanical knowledge is important for health and nutrition, particularly in rural low-resource settings, but cultural and economic transitions associated with globalization threaten such knowledge. This prospective study investigates the association between parental ethnobotanical knowledge and child health among the Tsimane', a horticulturalist and foraging society in Amazonian Bolivia. Anthropometric data and capillary blood samples were collected from 330 Tsimane' 2- to 10-year-olds, and mothers and fathers were interviewed to assess ethnobotanical knowledge and skills. Comprehensive measures of parental schooling, acculturation, and economic activities were also collected. Dependent variables included three measures of child health: (*i*) C-reactive protein, assayed in whole-blood spots as an indicator of immunostimulation; (*ii*) skinfold thickness, to estimate subcutaneous fat stores necessary to fuel growth and immune function; and (*iii*) height-for-age, to assess growth stunting. Each child health measure was associated with maternal ethnobotanical knowledge, independent of a wide range of potentially confounding variables. Each standard deviation of maternal ethnobotanical knowledge increased the likelihood of good child health by a factor of >1.5. Like many populations around the world, the Tsimane' are increasingly facing the challenges and opportunities of globalization. These results underscore the importance of local cultural factors to child health and document a potential cost if ethnobotanical knowledge is lost.

acute-phase response | culture | growth and development | maternal behavior | child nutrition

Cultural factors are critical and widely recognized determinants of human behavior and health (1). Culture, defined here as socially transmitted systems of shared knowledge, beliefs, and/or practices that vary systematically across groups, is a fundamental component of the human adaptive strategy and a primary reason why our species has been able to exploit an impressive range of habitats (2). The intergenerational transmission of knowledge regarding the potential utility of local plant resources has historically been an important adaptive function of culture (3).

Ethnobotanical knowledge, which in many ways resembles scientific knowledge accumulated through inductive methods (4), serves as a guide for activities central to survival and well-being, including effective habitat management, strategies for subsistence and food procurement, and attempts to prevent and cure disease (5, 6). However, globalization currently poses a threat to such knowledge to the extent that formal schooling and integration into emerging market economies devalue folk knowledge, prioritize alternative sources of information, and provide access to substitute products not made from local resources (7).

The World Health Organization (WHO) estimates that one in four children globally suffers from undernutrition and that infectious diseases are responsible for 63% of all child deaths (8, 9). Poor nutrition and infection exert synergistic effects on growth and survival, and growth faltering early in life has negative effects on reproductive performance, work capacity, cognitive function, and health throughout the lifespan (10, 11). Measures of nutritional status and infectious disease in childhood can therefore serve as barometers for the current and future well-being of a population and help identify individuals in suboptimal care-giving environments who may be at risk for adverse outcomes later in life (12).

The Tsimane', an indigenous Amazonian population of lowland Bolivia, are increasingly facing the challenges and opportunities of globalization. Like other remote rural populations around the world, they have limited access to commercial foods and medicines and must rely on their ability to exploit local natural resources to maintain the health of their children. The Tsimane' have wide knowledge of local plants and use them daily for medicine, firewood, construction, tools, and food. Wild and domesticated plants account for >50% of the total value of household consumption, whereas purchased goods account for <3% (13). However, many Tsimane' are pursuing new economic opportunities that may undermine this aspect of their culture.

As a population in the early stages of market integration, the Tsimane' provide an excellent opportunity to evaluate the importance of local ethnobotanical knowledge (LEK) to child health and to consider the potential consequences of lost knowledge. In prior work we have shown that acculturation and certain forms of market participation are associated with lower LEK (7, 14). In this paper we investigate the potential cost of lost knowledge to child health. Specifically, we address three questions: First, do parents with greater LEK have healthier children? Second, is this association independent of potentially confounding processes related to acculturation and market integration? And third, which matters more to child health, mother's knowledge or father's knowledge? In answering these questions we link culture and health at the level of the individual and document an adaptive, but threatened, function of local knowledge.

A range of interview-based and observational methods were used to quantify individual variation in LEK and plant use among Tsimane' adults. We recognize that such knowledge has multiple theoretical and practical dimensions and therefore constructed a summary index of LEK based on five measures: agreement with

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Abbreviations: CRP, C-reactive protein; LEK, local ethnobotanical knowledge; ZSF, *z* score sum of skinfold measurements; HAZ, height-for-age *z* score; OR, odds ratio; CI, confidence interval.

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local experts on plant uses, botanical knowledge, skills in using plants, total number of plants used, and diversity of plants used.

We investigated LEK in relation to three objective measures of child health: concentrations of C-reactive protein (CRP), skinfold thickness, and stature. CRP is a central component of innate immunity that increases in concentration in response to a range of pathogenic agents, making it a potentially useful marker of infectious burden and the degree of immunostimulation (15). Although much research on child health relies on caregiver reports of disease symptoms, the direct measurement of acute-phase proteins such as CRP has the advantage of providing an objective assessment of morbidity that is not sensitive to recall or reporting bias. Such an assessment also detects subclinical infectious processes that may not manifest as observable symptoms, but that nonetheless involve the activation of energetically costly antipathogen defenses (16).

Skinfold thickness provides an estimate of the size of subcutaneous fat stores, which is directly related to total body fat (17). Measures of body fatness are sensitive to fluctuations in energy balance on the order of weeks or months (18), and we use a standardized measure of skinfold thickness (*z* score sum of skinfold measurement, ZSF) calculated against age- and sex-specific reference values. In nutritionally marginal environments, fat stores are a critical energy supply on which the body can draw to fuel the high metabolic costs associated with growth or mounting immune responses to infectious disease (19). Height-for-age *z* score (HAZ) is a standardized measure of achieved linear growth that is commonly used as an indicator of prior nutritional and/or health status. Stunting results from extended periods of inadequate dietary intake, frequent morbidity, or both (12). These three measures of health were selected because they are well validated indicators of current and future child well-being and because they represent multiple pathways and time courses through which care-giving environments may affect health.

Our analyses were guided by a conceptual framework in which cultural and socioeconomic factors, as well as more proximate aspects of environmental quality, are all recognized as important determinants of child health (20, 21). We expected child health to be related to three sets of variables: (*i*) LEK of mothers and fathers; (*ii*) individual child attributes (e.g., age and sex); and (*iii*) parent-, household- and village-level variables associated with acculturation and market integration. The latter set of variables includes a wide range of commonly evaluated socioeconomic and environmental quality variables that may confound or mediate associations between LEK and child health. Statistical analyses proceeded in three stages. First, we explored the bivariate associations between parental LEK and each child health outcome. Second, we investigated the extent to which these associations were independent of potentially confounding variables by evaluating the association between LEK and child health in maximum-likelihood regression models that included a comprehensive set of parent-, household-, and village-level variables. Last, we compared the importance of maternal and paternal knowledge as predictors of child health.

Results

The geometric mean CRP concentration for the entire sample ($n = 330$) was 0.70 mg/liter, indicating a relatively high level of immunostimulation (15). Anthropometric measures of nutritional status reveal substantial levels of growth stunting but little evidence of wasting, a pattern similar to that found previously (22).

Mothers and fathers reported very similar levels of knowledge and utilization of local ethnobotanical resources and, on average, have lived in their current communities for nearly 20 years (data not shown). For the most part, we found similar patterns of correlation between various lifestyle and contextual variables and measures of maternal and paternal LEK (Table 1). The correlation between maternal and paternal LEK is 0.76 ($P < 0.001$). All variables were inspected for covariation with LEK and none approached significance except for those identified in Table 1.

Table 1. Pairwise correlations between LEK and individual, household, and village attributes

Variable	Correlation	
	With mother's knowledge	With father's knowledge
Age	0.212***	0.226***
Duration of residence	0.104*	0.085
Formal education	−0.056	−0.203***
Spanish proficiency	−0.192***	−0.216***
Frequency of travel to San Borja	−0.109†	−0.137*
Attitude toward traditional Tsimane' lifestyles	0.178**	0.250***
Household wealth	−0.040	0.014
Household cleanliness	0.035	−0.053
Distance to water source	0.005	0.019
Size of agricultural plots	0.074	−0.026
Village distance to nearest commercial center	0.486***	0.453***

†, $P < 0.10$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

LEK and CRP. Overall, 36.5% of the sample have concentrations of CRP ≥1 mg/liter, with equal distributions across boys and girls but a higher likelihood of CRP elevation among younger children. Children with elevated CRP have mothers and fathers who report significantly lower levels of LEK [see Supporting Information (SI) Fig. 2 for the bivariate association between LEK and each of our child health measures]. In a maximum-likelihood model including child age and gender, overall maternal LEK was significantly associated with reduced risk of elevated CRP (Table 2, model 1). This association was not altered by the addition of several maternal, household, and village covariates (Table 2, model 2). A 1 SD decrease in a mother's LEK is associated with a 52% increase in the risk of a child's having elevated CRP, controlling for a wide range of potentially confounding variables.

A similar, but weaker, association is evident when paternal factors are considered separately from maternal knowledge. When one controls for child age and sex, paternal LEK is significantly associated with a lower likelihood of elevated CRP (Table 2, model 3). The addition of household and village covariates does not substantially alter this association (Table 2, model 4). Children whose fathers are 1 SD below average on LEK are 38% more likely to have elevated CRP.

Last, we considered a combined model to evaluate the relative importance of maternal and paternal LEK in predicting elevated CRP (Table 2, model 5). The association between child CRP and maternal LEK was strengthened with the addition of paternal variables, whereas the association with paternal LEK was entirely eliminated, suggesting that the association reported above is mediated primarily by maternal knowledge.

Other maternal predictors of elevated child CRP include frequency of travel to San Borja, ratings of the value of traditional Tsimane' lifestyles, and years of formal schooling, although the latter is of marginal statistical significance. CRP is more likely to be elevated in children whose mothers travel more frequently to San Borja, have fewer years of formal education, and are more conservative in their orientation toward Tsimane' lifestyles. Frequency of travel to San Borja was the only significant predictor of child CRP for fathers. As with mothers, the likelihood of elevated CRP is higher for children whose fathers travel more often.

Additional predictors of child CRP include the distance of the household from its water source and the presence of nurses and ethnomedical healers in the village. On average, each household is ≈8 min from its water source, and more distant sources are associated with reduced CRP, perhaps reflecting the quality of these sources. Although options for healthcare are limited for the Tsimane', the presence of a village resident with basic healthcare training is associated with lower risk of elevated CRP, and the presence of ethnomedical healers is associated with higher risk.

Table 2. Results of maximum-likelihood models predicting the likelihood of CRP >1 mg/liter

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Mother's LEK (standardized)	0.67**	(0.50,0.90)	0.66***	(0.53,0.82)					0.63**	(0.46,0.87)
Father's LEK (standardized)					0.71*	(0.54,0.94)	0.73**	(0.58,0.91)	1.04	(0.77,1.40)
Child's age	0.90***	(0.86,0.95)	0.88***	(0.83,0.93)	0.90***	(0.85,0.95)	0.89***	(0.84,0.94)	0.87***	(0.82,0.93)
Sex (male = 1)	1.17	(0.73,1.90)	1.11	(0.67,1.85)	1.17	(0.69,2.01)	1.11	(0.64,1.91)	1.11	(0.64,1.93)
Distance to water source, min			0.93*	(0.88,0.98)			0.93*	(0.88,0.99)	0.93**	(0.88,0.98)
No. of traditional healers			1.99***	(1.59,2.48)			1.84***	(1.38,2.47)	2.05***	(1.71,2.45)
Presence of biomedically trained residents			0.65**	(0.48,0.87)			0.63*	(0.41,0.99)	0.60***	(0.47,0.77)
Mother's schooling, yr			0.73†	(0.51,1.05)					0.69†	(0.47,1.02)
Mother's cultural attitudes			1.35*	(1.06,1.72)					1.35*	(1.07,1.71)
Mother's frequency of travel to San Borja			1.55***	(1.21,1.97)					1.31*	(1.02,1.68)
Father's frequency of travel to San Borja							1.58**	(1.16,2.16)	1.41*	(1.06,1.88)

OR, odds ratio; CI, confidence interval. †, $P < 0.10$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

To facilitate interpretation of the association between CRP and LEK, we calculated the predicted probability of elevated CRP based on regression coefficients from our final maximum-likelihood model. We set LEK to 1 SD both above and below average to represent high and low levels of knowledge, respectively, and retained individual values for other covariates. In effect, this procedure allows us to estimate the independent association between LEK and elevated CRP while controlling for potentially confounding factors. For children whose mothers have high LEK, approximately one in four will have CRP ≥1 mg/liter. The likelihood of elevated CRP nearly doubles for children of mothers with low LEK (Fig. 1).

LEK and Skinfold Thickness. Approximately 15% of the sample was below 1 SD for age- and sex-standardized skinfold thickness, with girls more likely to be below the cutoff (17.5%) than boys (11.9%). Younger children were also more likely to have lower skinfold thickness. LEK scores are significantly lower in mothers and fathers of children with low ZSF (see SI Fig. 2). When considered in a model with child age and gender, higher maternal LEK is significantly associated with reduced likelihood of low child ZSF (Table 3, model 1). This association strengthens with the addition of maternal, household, and village covariates (Table 3, model 2). Controlling for a wide range of potentially confounding variables, children whose mothers are 1 SD below average in maternal knowledge are 66% more likely to have low skinfold thickness.

We found a similar association between father's LEK and child ZSF, with higher LEK associated with reduced likelihood of low child ZSF, independent of child age and sex (Table 3, model 3). This association is weakened, but remains significant, with the addition of other paternal, household, and village variables (Table 3, model 4). Fathers who are 1 SD below average in LEK are 48% more likely to have a child with low skinfold thickness, independent of potentially confounding variables.

As with CRP, the simultaneous consideration of mother's and father's LEK with significant covariates results in a model where mother's knowledge remains a significant predictor of child skinfold thickness, whereas the association with father's knowledge is eliminated (Table 3, model 5). The only significant, independent paternal predictor of child ZSF was body mass index, with larger fathers less likely to have children with low skinfold thickness. Maternal duration of village residence, distance to water source, village size, and the number of traditional healers were also significant predictors of low ZSF.

When these covariates are controlled, 1 in 10 children of mothers with high LEK will have low skinfold thickness. The predicted probability of low skinfold increases to almost 1 in 5 for children of mothers with low LEK (Fig. 1).

LEK and Growth Stunting. Reflecting the high rates of growth faltering in this population, 44.9% of the sample can be considered growth stunted, with HAZ < -2. Measures of LEK did not predict growth stunting in maximum-likelihood models, with or without the full range of parental, household, and village variables.

Because the impact of parental LEK may be greater at the lower end of the distribution of child growth, we evaluated a series of models predicting the likelihood of severe stunting (HAZ < -3). The prevalence of severe stunting was 12.2%, with higher prevalence among younger children. Severely stunted children have mothers and fathers with significantly poorer LEK (see SI Fig. 2). We first evaluated the association between maternal LEK and severe child stunting in a model including child age and sex, as well as maternal stature. In this model, higher maternal LEK is significantly associated with a lower probability of severe stunting (Table 4, model 1). This association is strengthened slightly by the addition of other maternal, household, and village covariates (Table 4, model 2). The likelihood of severe stunting increases by 76% for each SD decrease in a mother's LEK.

For fathers, considered separately from mothers, higher LEK also predicts lower likelihood of severe child stunting independent of paternal stature and child age and sex (Table 4, model 3). This association strengthens with additional paternal, household, and village variables (Table 4, model 4). Controlling for potentially confounding variables, a 1 SD decrease in a father's LEK is associated with a 57% increase in the likelihood of severe stunting.

As with CRP and skinfold thickness, significant associations between child stunting and father's level of LEK were eliminated in a full model including maternal knowledge (Table 4, model 5). Maternal knowledge remained a significant predictor of severe stunting in children, independent of a wide range of parental, household, and village-level variables. As one might expect, growth faltering was less likely in children with taller mothers and fathers.

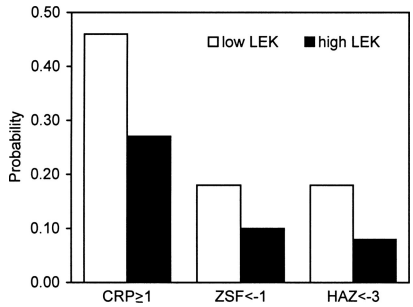

Fig. 1. Predicted probability of a child's having CRP ≥1 mg/liter, ZSF < -1, or HAZ < -3 for mothers with high versus low LEK, controlling for covariates in Tables 2–4.

Table 3. Results of maximum-likelihood models predicting ZSF < −1

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Mother's LEK (standardized)	0.65**	(0.74,0.91)	0.60***	(0.49,0.75)					0.65***	(0.52,0.83)
Father's LEK (standardized)					0.64*	(0.45,0.93)	0.68**	(0.51,0.90)	0.95	(0.59,1.52)
Child's age	0.72*	(0.55,0.93)	0.67*	(0.48,0.94)	0.72*	(0.55,0.93)	0.65*	(0.47,0.90)	0.65*	(0.45,0.92)
Sex (male = 1)	0.60	(0.30,1.18)	0.46*	(0.26,0.84)	0.56†	(0.32,1.01)	0.51*	(0.31,0.85)	0.48*	(0.27,0.83)
Distance to water source, min			0.94***	(0.91,0.97)			0.94**	(0.90,0.98)	0.94**	(0.90,0.98)
No. of traditional healers			1.35*	(1.02,1.78)			1.63*	(1.08,2.46)	1.57*	(1.07,2.29)
Village size, no. of households			1.09***	(1.05,1.12)			1.08***	(1.04,1.13)	1.08***	(1.04,1.13)
Mother's duration of residence			0.98*	(0.96,0.99)					0.98*	(0.96,0.99)
Father's BMI							0.73**	(0.59,0.90)	0.76**	(0.63,0.92)

BMI, body mass index. †, $P < 0.10$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

In addition, severe stunting was less likely in children whose fathers are more proficient in Spanish. Higher interviewer ratings of household cleanliness were associated with reduced stunting.

Based on this model, <1 in 10 children of mothers with high LEK will be severely stunted. The likelihood of severe stunting increases to nearly one in five for children of mothers with low LEK (Fig. 1).

Discussion

Similar to many remote, rural populations around the world, the Tsimane' rely heavily on local natural resources to meet their daily needs, and accumulated knowledge passed down across generations of Tsimane' serves as a guide for drawing on these resources. However, adults vary in the degree to which they possess LEK and in this study we find that mothers with higher levels of plant knowledge and use have healthier children, independent of potentially confounding variables related to education, market participation, and acculturation. Associations are similar across short-term measures of inflammation and medium- and long-term measures of nutritional status, with each SD of LEK increasing the likelihood of good child health by a factor of >1.5.

Bivariate associations between maternal knowledge and child health are strong and are not attenuated by the addition of proxies for environmental quality. The absence of mediation, however, does not discount the importance of these well established proximate determinants of child health, particularly because we find significant associations with child health for measures of household cleanliness and water quality. Rather, it suggests that LEK is operating through alternate pathways and that in environments with high burdens of infectious disease like that currently inhabited by Tsimane' children, LEK may be more important in buffering children from the adverse health consequences of infection rather than preventing exposure. These results underscore the importance of considering cultural factors such as LEK as key contributors to child health, even if the proximate mechanisms linking culture and health are not immediately evident.

The strong associations with maternal knowledge are consistent with prior research in other low-income settings, demonstrating the importance of maternal education to child health (23). Within Tsimane' families, women typically assume primary responsibility for childcare, and it is therefore reasonable to expect that maternal attributes will affect children more directly than paternal attributes. In addition, like formal schooling in other settings, maternal LEK may empower women to create a more salutary care-giving environment despite limited resources.

Alternatively, although mothers and fathers report similar levels of overall LEK, they may differ in their expertise regarding specific applications of this knowledge. For example, women may be experts in using plants to prevent and treat infectious disease, whereas men may possess more knowledge relevant to construction or habitat management. Evaluation of the potentially gendered nature of Tsimane' LEK will require richer domain-specific analyses in future work.

There are several plausible mechanisms linking maternal LEK and child health. First, informed adults may be more efficient exploiters of local natural resources, allowing them to provide their children with diets that are superior in terms of quality as well as quantity. Better diets supply the macro- and micronutrients that build body fat stores, fuel linear growth, and bolster immune defenses against infectious disease (12, 24).

Second, local plants may have direct pharmacological properties that help prevent or treat common child ailments. Indeed, plants are a central part of the Tsimane' ethnomedical tradition (25) and they may play a particularly important role in protecting health because effective commercial medicines are expensive and difficult for the Tsimane' to procure. If remedies derived from local plants are effective in preventing or treating illness, this would contribute not only to lower levels of inflammation but also to improved linear growth and body fat stores by reducing allocations of energy to fueling immunity and fighting infection (16, 26).

Third, although we infer a direct association between maternal knowledge and child health, it is possible that the associations are mediated in part by the child. Tsimane' children as young as 4 and 5 years spend much of their time away from the supervision of their parents, playing and foraging in small peer groups. We have

Table 4. Results of maximum-likelihood models predicting HAZ < −3

	Model 1		Model 2		Model 3		Model 4		Model 5	
Variable	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Mother's LEK (standardized)	0.60*	(0.38,0.93)	0.58**	(0.39,0.88)					0.57**	(0.39,0.84)
Father's LEK (standardized)					0.71*	(0.50,1.00)	0.63**	(0.46,0.87)	0.84	(0.55,1.28)
Child's age	0.79***	(0.71,0.88)	0.81***	(0.73,0.89)	0.80***	(0.70,0.90)	0.80***	(0.70,0.91)	0.80***	(0.71,0.90)
Sex (male = 1)	2.1*	(1.12,3.88)	2.12*	(1.12,4.01)	1.95*	(1.01,3.77)	2.04†	(0.91,4.26)	2.19*	(1.12,4.25)
Cleanliness			0.73*	(0.57,0.93)			0.75*	(0.57,0.98)	0.69**	(0.53,0.90)
Mother's stature	0.86**	(0.77,0.96)	0.85**	(0.76,0.95)					0.87**	(0.78,0.96)
Father's stature					0.90**	(0.85,0.96)	0.88***	(0.83,0.94)	0.88***	(0.83,0.93)
Father's Spanish fluency							0.46**	(0.25,0.82)	0.56*	(0.34,0.92)

†, $P < 0.10$; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$.

observed instances where older children have used plants for medicinal purposes for themselves or for younger children. It is therefore feasible that adults transmit their LEK and skills to children at a relatively young age and children who use this information are able to more effectively provide for or medicate themselves, at least in part.

Last, it is possible that there is no direct causal association between maternal LEK and child health. We collected data on child health after assessing maternal attributes and it is not likely that differences in child health are causing differences in parental knowledge. Of greater concern is omitted variable bias, in which LEK stands in for correlated, but unmeasured, attributes of children, parents, or their households. However, we considered a comprehensive set of variables that represent plausible alternative pathways linking LEK and child health. In most cases, adding these variables to multivariate models did not substantially change, but in fact strengthened, the association between maternal knowledge and child health. This stability stands in marked contrast to the pattern of results with fathers and increases our confidence that the effect of mother's knowledge is not being driven by unmeasured variables or measurement error. In addition, we find consistent results across three distinct child-health measures, further suggesting that a mother's ability to use local plant resources contributes directly to the well-being of her children. Additional research with more fine-grained measures of LEK and the proximate mechanisms connecting it to child health will be required to verify this claim.

A strength of this study is the explicit attempt to link culture and health at the level of the individual. Culture is, by definition, an aggregate shared property of a group that exists in the minds and actions of individuals, but that is given meaning collectively (27). This poses a significant challenge to measurement, particularly for quantitative, epidemiological analyses of biological outcomes that require an individual-level operationalization of "culture." Although culture matters to health on multiple levels, this challenge has limited our ability to document the importance of cultural factors and to inform interventions and policy accordingly.

Culture is not a monolithic homeostatic whole, but rather a set of dynamic models pertaining to different domains of beliefs and behaviors (27, 28). This conceptual foundation provides a basis for empirically defining a specific cultural model that may be relevant to health and for locating an individual with respect to that model (29). We draw on this perspective to characterize the accumulated knowledge collectively possessed by the Tsimane' and then rank individuals with respect to this knowledge. In this way we are able to move from culture as a shared property of the group, to culture as an attribute of the individual that is predictive of child health in a multivariate framework.

The value of this approach is evident in the strength and consistency of the association between child health and a mother's LEK. In contrast, schooling and household wealth, two commonly investigated predictors of child health, accounted for little, if any, variation in three measures of child health in this population. There is no question that education and economic security are critical determinants of population health globally, but when levels of schooling are low and economic opportunities are limited, as they are currently for the Tsimane', the loss of adaptive cultural resources for protecting health may come at a significant cost.

Materials and Methods

Study Site and Data Collection. The Tsimane'** are an indigenous Amazonian population of ≈8,000 in the Department of Beni in lowland Bolivia (30) (see SI Fig. 3 for a map of the study site and SI Figs. 4–7 for photographs). Slash-and-burn farming is the primary means of subsistence, supplemented with hunting and gathering, with relatively new and increasingly available opportunities for wage labor in logging camps or cattle ranches, or the sale of crops and forest goods. At the time of our survey, electricity and running water were not available to any household and only half of the surveyed communities were accessible by road. Thirteen communities were selected that vary in distance from the town of San Borja, the regional commercial center (population ≈19,000). Analyses focus primarily on data collected in the wet season (November–December 2002 and January 2003) when comprehensive measures of LEK were first introduced to the survey. We limited our analyses to children between the ages of 2 and 10, inclusive, because our health measures are most sensitive during this period and because the well-being of children is most dependent on their caregivers during this time. An attempt was made to recruit every resident of the 13 villages over the age of 2 years into the study. Anthropometric measures and finger-prick whole-blood samples were collected in 1 or 2 days and virtually everyone who was present was included in the sample. Health data were collected after assessing LEK and other explanatory variables. The study protocol was approved by the Northwestern University Institutional Review Board for research involving human subjects. The Tsimane' Grand Council also approved the study and parental consent and child/adolescent assent were obtained before enrollment.

Measures. ***LEK.*** Measures of LEK are based on prior work in this population (31). Cultural consensus methods (28) were used to evaluate the degree to which knowledge regarding the usefulness of local plant species was shared among the Tsimane' and to characterize this knowledge. First, a free-listing exercise with 50 study participants resulted in a list of 92 plants judged to be useful, from which 21 were randomly selected for further evaluation. All participants were then asked, in a multiple-choice format to report on whether each plant could be used for the following: construction, firewood, food, medicine, and/or other. Multiple uses per plant were allowed. Analysis of the resulting plant-by-plant-use matrix indicated a high degree of agreement across individuals regarding the specific uses for each plant (31) (mean cultural competence = 0.58, SD = 0.20). In effect, this analysis produces an "answer key" that reveals the shared Tsimane' cultural model for how plants can be used and that presumably guides exploitation of plant resources in their environment. Because elders are commonly recognized as repositories of local ecological knowledge, we derived a cultural model for plant use based on responses from individuals >55 years of age. We then compared study participants' ratings of plant uses to this model to derive a quantitative measure of their knowledge relative to local experts.

We also used cultural consensus methods to characterize variation in local botanical knowledge by posing questions regarding the attributes of 10 randomly selected plants. For example, we asked: "Which is the color of the mahogany flower? (a) red, (b) green, or (c) white." We confirmed the existence of shared botanical knowledge and then assessed the degree to which an individual's responses were in agreement with the most frequent responses of the group to define an individual-level measure of botanical knowledge (mean cultural competence = 0.55, SD = 0.18).

To collect information on individual variation in practical skills in using plants, in addition to knowledge regarding their uses and attributes, we asked participants to report whether they had ever made 18 different plant-based objects. The list included nine objects that are more commonly made by men, nine that are more commonly made by women, six items that are considered easy to make, six items of medium difficulty, and six items that are considered difficult to make. A measure of plant skills for each individual was created by summing the number of objects made.

Two additional measures of plant usage were derived from household visits in which the number and diversity of plants brought into the household were observed. On a day chosen at random, each adult present in the household was asked to report all of the wild

**The Tsimane', along with the neighboring Moseten, represent a distinct linguistic group in the Beni that is related to languages of the MacroPano family.

plants he/she had brought into the household during the previous 24 h. A measure of total plant use was created by summing the total number of plants brought into the household. Diversity of plant use was defined as the total number of different plant species brought into the household.

Because these measures are correlated and because we are interested in ethnobotanical knowledge more broadly, we constructed a summary variable based on the above measures. Also, by evaluating one summary variable as a predictor of child health rather than five related variables, we reduced the chances of type I error. Separate standardized variables were constructed for a child's mother (or primary female caregiver) and father (or primary male caregiver), with mean = 0 and SD = 1. Chronbach's alpha was 0.68 for mother's LEK and 0.60 for father's LEK (see SI Table 5 for additional information on the association between each individual LEK/plant-use measure and child health).

Child health. Concentrations of CRP were measured in dried blood-spot samples, collected by placing at least one drop of free flowing capillary whole blood on standardized filter paper (Whatman no. 903, Middlesex, U.K.), following a simple finger prick with a sterile, single-use microlancet. Samples were analyzed by using an ELISA protocol previously validated for use with blood spots (32). Subscapular and tricep skinfold thickness were measured to the nearest 0.5 mm with precision Lange calipers (33). The sum of triceps and subscapular skinfold were standardized as z scores (standard scores) relative to age- and sex-specific U.S. references (34). Linear growth measurements were taken with a portable stadiometer and recorded to the nearest millimeter according to standard protocols (33). Sex-specific standardized z scores for HAZ were calculated in EpiInfo [version 3.2, Centers for Disease Control and Prevention (CDC), Atlanta, GA] by using the CDC/WHO 1978 reference curves recommended for international use (35).

Data Analysis. All statistical analyses were conducted with Stata for Windows, version 8.0 (StataCorp, College Station, TX). A series of maximum-likelihood logistic regression models were used to predict the likelihood of: (*i*) CRP $\geq$1 mg/liter; (*ii*) ZSF <-1; (*iii*) HAZ <-2; and (*iv*) HAZ <-3. A cut-off of 1 mg/liter was used for CRP because prior research in this population has shown that CRP concentrations above this threshold indicate significant activation of inflammatory pathways that are prospectively associated with deficits in height gain (26). A cut-off of -1 was chosen for ZSF to identify the group of children with low body fat stores, and therefore the highest risk for subsequent infection and/or growth faltering. HAZ scores of -2 and -3 were used to represent the presence of stunting and severe stunting, respectively (17).

We considered the following parent-level variables: age, duration of residence in current village, years of formal education, literacy, proficiency in spoken Spanish (an official language of Bolivia and of growing importance to the Tsimane'), income from wages and barter over the preceding 2 weeks, frequency of travel to the local town of San Borja, stature, and body mass index. We also evaluated attitudes toward "traditional" aspects of Tsimane' culture by asking respondents to rate their level of agreement with practices and beliefs historically common among the Tsimane' (10 Likert-style questions using a 3-point scale; higher scores indicate more conservative cultural attitudes and lower scores indicate a preference for non-traditional Western lifestyles). These variables provide proxies for education and market participation, orientation toward and experiences with acculturation, and health endowments that may confound associations between parental ethnobotanical knowledge and child health.

We considered the following household-level variables: household size (number of residents) and density (residents per m^2), wealth (summary of 18 physical assets), size of agricultural plots, presence of a latrine in the compound, water source (river, well, etc.), distance to water source (minutes walking), distance to nearest neighbor (minutes walking), and interviewer rating of household cleanliness. Village-level variables included the following: village size (number of households), distance from San Borja (measured in hours of travel time), number of teachers in residence, the presence of one or more residents with basic healthcare training provided by local missionaries, number of ethnomedical healers practicing in the village, and village accessibility by road.

Variables were added separately to models and evaluated for association with child health as well as impact on the odds ratio describing the association between LEK and child health. The "cluster" option in Stata was specified for all models, with village designated as the clustering variable. This option relaxes the assumption that individual observations are independent and requires only that observations be independent across clusters. This procedure adjusts for the fact that individuals were enrolled at the village level and provides robust (and more conservative) estimates of variance around regression parameters.

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