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The effects of local medicinal knowledge and hygiene on helminth infections in an Amazonian society

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A B S T R A C T

Social science has long recognized the importance of understanding how interactions between culture and behavior shape disease patterns, especially in resource-poor areas where individuals draw on multiple medical treatments to maintain health. While global health programs aimed at controlling high infection rates of soil-transmitted helminthes among indigenous groups often acknowledge the value of local culture, little research has been able to examine this value. This study investigates the association between parental ethnomedical knowledge, parental biomedical knowledge, and household sanitation behavior and childhood soil-transmitted helminth infections among a group of foragers–farmers in the Bolivian Amazon (Tsimane'). During 2007, a parasitological survey was completed for 329 children (≤16 years of age) from 109 households in combination with a comprehensive survey of both of the child's parents to assess biomedical and ethnomedical knowledge and household sanitary environment. Soil-transmitted helminthes were found to be common with 67% of sample positive for hookworm species. Indices that capture a household's relative state of risky and preventive hygienic behavior were significantly associated with risk of hookworm infection. Mother's but not father's ethnomedical knowledge was also negatively associated with a child's probability of being positive for hookworm infection. The effect was stronger for young children and boys. Like many rural populations, Tsimane' actively draw upon multiple medical systems to respond to health challenges. Integration into markets and national societies is likely to affect local medical systems by increasing the use of biomedicine as formal education prioritizes biomedical over ethnomedical systems. This study underscores the value of considering both ethnomedical knowledge systems and household hygiene in public health campaigns to treat and control soil-transmitted helminths. There is no question that providing medication is critical, but this study demonstrates that poverty is not synonymous with either poor hygiene or the lack of valuable ethnomedicinal knowledge.

Introduction

Soil-transmitted helminth infections are a common, pervasive problem that has affected human populations from our archeological past (Hurtado, Frey, Hurtado, Hill, & Baker, 2008) and continue to be a major public health problem today (Hotez, Bottazzi, Franco-Paredes, Ault, & Periago, 2008; Hotez, Brindley et al., 2008). Although the three major soil-transmitted helminths (i.e., *Ascaris lumbricoides*, *Trichuris trichiura*, and the hookworm species *Ancylostoma duodenale/Necator americanus*) and other "neglected diseases of neglected people" have recently received attention (Ehrenberg & Ault, 2005), research shows that the prevalence of helminth infections in indigenous communities in South America is still astonishingly high (Hurtado, Frey et al., 2008; Hurtado, Lambourne et al., 2005; Tanner, Leonard et al., 2009). High infection levels among indigenous communities likely reflect a myriad of causes including underlying biological vulnerabilities and poor access to sanitation and medical treatment (Hurtado, Lambourne et al., 2005).

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Social science and anthropology have long recognized the importance of local perceptions, practices, social expectations, and behaviors as critical in shaping infectious disease patterns (Brown & Inhorn, 1990; Dunn & Janes, 1986; Helman, 2007; Nichter, 2008). For example, recent research has demonstrated that local botanical knowledge can be associated with improved child health (McDade, Reyes-García, Leonard, Tanner, & Huanca, 2007). Similarly, ethnomedical knowledge, or the health related beliefs, knowledge, and practices of a cultural group, has been shown to play an important role in understanding individual behaviors and responses to many diseases ranging from diarrheal disease (Smith et al., 1993) to malaria (Williams & Jones, 2004). This information serves as a guide for how people perceive disease risk, understand symptoms, and make decisions about when and how to seek treatment (Nichter, 2008). While ethnomedical research on parasitism has focused on ideas that worms are unavoidable or necessary for normal body functioning (Vecchiato, 1998), little research has considered if individual variation in expertise is associated with health outcomes.

In the context of helminth infections, mass drug administration programs may fail to address relevant behaviors affecting disease risk and local medical beliefs or practices related to prevention or treatment. A complementary, more culturally sensible approach would be to consider local systems of medicinal knowledge related to helminth infection as a base for helminth control programs. But before such an approach can be adopted, researchers need to know whether local medicinal knowledge systems are effective against infections.

In this article we address the issue by investigating the potential value of local knowledge and household behavior in resource-poor settings where people select between multiple medical systems when making health decisions. Specifically, we study the association of 1) parental ethnomedical knowledge, 2) parental biomedical knowledge, 3) risky hygienic behaviors, and 4) preventive hygienic behaviors in explaining the presence of helminth infections in 329 children and adolescents (<16 years of age). For the case study we use a unique set of data collected during 2007 among Tsimane', an indigenous Amazonian group of hunter–horticulturalists. The study focuses on hookworms, the most common parasite documented in the study area.

Helminth infections: health consequences and treatments

Research shows that the prevalence of helminth infections in indigenous communities in South America is surprisingly high and is likely to be partially responsible for commonly observed short- and long-term heath problems (Hurtado, Frey et al., 2008; Hurtado, Lambourne et al., 2005; Tanner, Leonard et al., 2009). In their recent review, Hurtado, Lambourne et al. (2005) found that 67% (59 of 88) of published studies of intestinal pathogens in indigenous South American groups had prevalence rates over 25%. Prevalence rates of helminth infections are often higher in indigenous communities than in non-indigenous rural communities. For example, in a comparative study among Brazilian schoolchildren, Scolari and Torti (2000) found that 93% of indigenous children but only 22% of non-indigenous children were positive for some soil-transmitted helminth with over 50% of the indigenous children being positive for both *A. lumbricoides* and hookworms. Because helminth parasites drain hosts of important micro and macronutrients, dampen immune responses that are aimed at bacterial and viral infections (Crompton & Nesheim, 2002; Hurtado, Hurtado, & Hill, 2003), and enhance nutritional stress (reviewed in Brooker, Bethony, and Hotez (2004)) they have many negative impacts on an individuals' immediate and long-term health. If infections are left untreated, they may result in multi-year, chronic infections that have the potential to reduce school attendance and educational performance (Miguel & Kremer, 2003). Over the life course, such chronic infections are likely to have negative effects on adult's earning potential and labor productivity (Gilgen & Mascie-Taylor, 2001).

Due to the existence of cheap and effective medication, most helminth control programs have emphasized annual or semi-annual treatment (Hotez, 2009; Smits, 2009) combined with training in preventive strategies (WHO, 2006). While medication can be highly effective, barriers to distribution and the potential for reduced efficacy due to drug resistance are major challenges to programs relying solely on mass drug administration. For example, in a recent evaluation of the success of a large school-based drug treatment program throughout Zanzibar, Knopp and Mohammed (2009) found that infection levels decreased by up to 48% for *T. trichiura* and 80% for *A. lumbricoides* and infection intensities decreased by up to 95% since the programs' inception in 1994. Chemotherapy clearly reduces the level and intensity of infections, but Knopp and Mohammed (2009) also note that limitations of drug treatment alone include missing children who do not attend school regularly and failure to address the behaviors that result in initial infection. Similarly, Smits (2009) argues that, to achieve long-term success and to avoid the threat of emerging drug resistance, drug treatment programs must be complemented with community-based health education and participation.

A complementary approach has been the dissemination of information about health education and preventive sanitary practices. Information about basic sanitary practices including hand washing, latrine and soap use, and consumption of water from clean sources has been clearly associated with reduced helminth infection levels (Olson, Samuelsen, & Onyango-Ouma, 2001; Scolari & Torti, 2000). In a review of sanitation and health education programs conducted from 1976 to 2000, Asaolu and Ofoezie (2003) conclude that, while providing drug treatment is critical, sanitation improvements and health education are necessary to sustain the benefits of drug treatment programs.

The Tsimane'

One of the largest Amerindian groups in the Bolivian Amazon, the Tsimane' number ~8000 (Censo Indígena, 2001), live in ~100 villages mostly in the department of Beni, and have been in continuous contact with Westerners since the 1940s. Tsimane' reside in villages of ~20 households concentrated along rivers and logging roads (Fig. 1). Tsimane' subsistence is based on slash-and burn-farming supplemented by hunting, gathering, and wage labor in logging camps, cattle ranches, and in the homestead of colonist farmers. The chief cash crops in the area are thatch palm from the forest and cultivated rice. Although no village has access to running water or electricity, some have year round road access and obtain water from community pumps or wells.

Previous publications provide descriptions of many aspects of Tsimane' life, including their traditional ecological knowledge and Tsimane' infant and adolescents health (Foster et al., 2005; Godoy, Reyes-García, Byron, Leonard, & Vadez, 2005; McDade et al., 2005). So, in the next paragraphs we summarize the most important aspects related to those topics, and then focus in two, less studied, topics: the relations between ethnomedical and biomedical knowledge among Tsimane' and Tsimane' knowledge and perception of intestinal parasites.

Researchers have measured local knowledge of wild and semi-domesticated plants finding that Tsimane' have extensive local knowledge of plants and natural resources management (Huanca, 2008; Reyes-García, Godoy et al., 2003), including medicinal plant knowledge. For example, Reyes-García, Huanca, Vadez, Leonard, and Wilkie (2006) identified 26 plant-treatments for diarrhea, 12 for stomach pain, seven for intestinal parasites, and two for

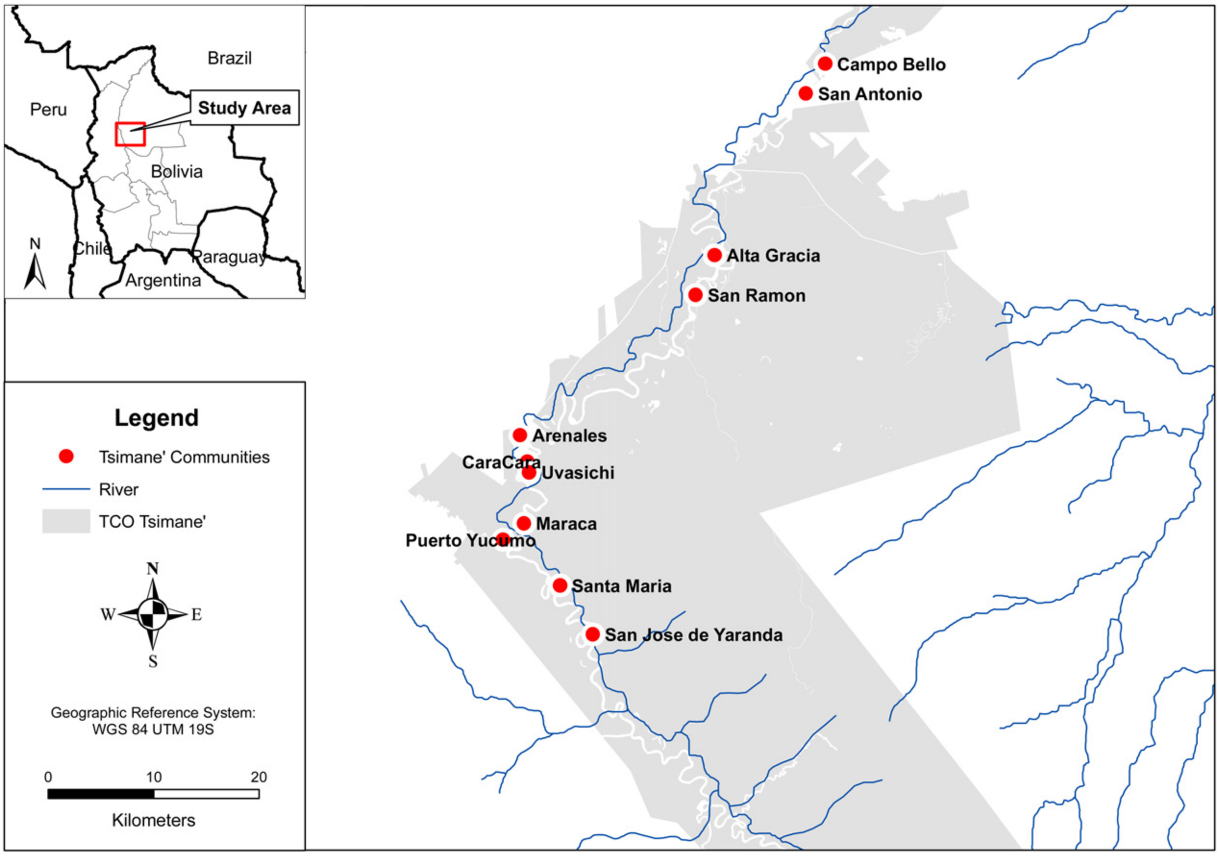

Fig. 1. Map of study area.

paleness. Researchers have also found that Tsimane' local ecological knowledge correlates with better child health (McDade et al., 2007) and adult nutritional status (Reyes-García, McDade et al., 2008).

Similar to other lowland South American indigenous populations (Dufour, 1992), Tsimane' children commonly experience the interrelated problems of growth stunting, anemia, and infectious disease. Previous work has shown that 47% of Tsimane' children under 10 years of age are stunted (Height-for-Age Z-score ≤ -2) when compared to the standards of the USA National Center for Health Statistics (NCHS) (Foster et al., 2005; Hamill, 1979). Hemoglobin levels are also low among Tsimane', with 59% of children under 10 years being anemic (Lindsay et al., 2003). Unpublished work in progress shows that household diets are adequate in energy (calories) and proteins to meet nutritional needs, further suggesting that the poor patterns of childhood growth described above reflect chronic childhood infection rather than malnutrition.

Ethnomedical and biomedical treatments available to the Tsimane'

Tsimane' have access to two types of medical treatments: drugs and hospitals or medicinal plants and traditional healers. Tsimane' choice of medical treatment is related to cost and availability, but also to the perceived cause of the illness. Common illnesses, caused by the natural world, can be cured by medicinal plants or drugs, whereas illnesses caused by spiritual beings can only be cured by the intervention of a traditional healer (Calvet-Mir, Reyes-García, Tanner, S., & TAPS study team, 2008). When a person gets sick, she is first treated as if she suffered from a common illness. Plants and pharmaceutical remedies are administered sequentially or simultaneously, often without consultation from any expert. Tsimane' often self-medicate and typically stop treatments (with plants or drugs) once the disease symptoms disappear irrespectively of doctors' advice or information from the drug manufacturing company. If the condition persists, after self-medication, the Tsimane' typically ask the elder and more knowledgeable people of the village for advice. Tsimane' start being suspicious that an illness is caused by witchcraft if the patient's condition becomes aggravated or if it does not improve after using several treatments, in which case, they seek the help of a traditional healer.

Tsimane' obtain biomedical treatments from pharmacies or stores in local market towns, from traders who visit their villages, or from occasional visitors (i.e. researchers, vaccination campaigns). Tsimane' have access to a hospital in the town of San Borja and a clinic at Horeb (30 min walking from San Borja), but, because of linguistic, economic and social barriers, they often go to the hospital only when facing a serious health problem that has not responded to other treatments. Anthelmintic medication is readily available in the area as is often given free of charge during childhood vaccination. Anthelmintic medication can also be purchased in pharmacies or from traders.

Tsimane' perception of intestinal worms

Ethnomedical knowledge and treatment beliefs provide key insights into how a culture identifies and evaluates the importance of infectious disease (Berlin & Berlin, 1996; Vecchiato, 1998). From previous research on the topic, we know that Tsimane' recognize and have a classification system for intestinal worms (Tanner, 2005). Tsimane' language has two commonly recognized terms for worms. The term *oya* is the most commonly used and recognized term for worms. It can serve as both a general term to refer to all types of worms and, more specifically to *A. lumbricoides*.

A second term, *capinaty*, likely refers to tapeworms. In addition, a few individuals are able to provide terms and descriptions of up to five classes of worms with corresponding terms in Tsimane' and Spanish (Tanner, 2005).

In general, Tsimane' consider worm infections an unavoidable but mild health problem. In a large survey conducted in 2004, Tsimane' participants ($n = 1030$) were asked if they thought they were infected with worms at the time of the interview. Eighty per cent (or 823 respondents) reported that they thought they were infected (Tanner, 2005). In contrast, during the same survey, when asked to report illness that had affected them in the past two weeks, only 5 respondents (less than 1%) spontaneously reported they had intestinal worms. Furthermore, only one individual had been sick enough to seek medicine for the helminth infection. These data suggest that most people feel they are chronically infected, but only a very small number of individuals consider helminth infections a reportable health concern.

Material and methods

For this article we draw on data collected in 2007. Data collection included individual-level interviews lasting about one hour/person and collection of fecal samples (occurring between two weeks and one month after the interview). The surveys were conducted by three surveyors who have worked with the research team for over five years. While several of the surveyors are fluent in Tsimane', the local language, interviews were conducted in Spanish and four Tsimane' who have worked in with the team for over a decade served as translators. A trained nurse and microbiology Master's student assisted in the collection of fecal samples. The Tsimane' Grand Council and Brandeis University Institutional Review Board for research involving human subjects approved the study protocol.

Sample

During June–September, 2007, all households in 11 Tsimane' villages were invited to participate in the research. Villages were selected to capture a range of variation in the proximity to San Borja, the only large Bolivian town along the Maniqui river. The final sample consists of 109 of the total 250 households in the study communities. Written consent was given to enter the research communities by the Tsimane' Grand Council. Before beginning data collection in each community, permission to work in the community was obtained through a community meeting explaining the project. Finally, the project was explained to individuals privately in their households and oral consent was then obtained from all individual study participants over the age of 16. Parental consent was given for portions of data collection that involved children under 16 years of age. After obtaining consent from parents, a single fecal sample was collected from 400 children (between 1 and 16 years of age, inclusive). Prior to the collection of fecal samples, we conducted a survey to collect information on ethnomedical and biomedical knowledge from both parents and observations about household preventive behavior. The final sample consists of 329 children from 109 households with complete information (i.e., ethnomedical and biomedical knowledge interviews with both parents, household observations, and fecal samples).

Outcome variable

Presence of hookworm

Parasitic infection levels were obtained through the collection and analysis of fecal samples based on the WHO protocol for collecting and preserving fecal samples for parasitological analysis (WHO, 1991). Parasitological data was collected by a research team consisting of a nurse, two Tsimane' translators, and one or two of authors (ST, MCC). All participants were provided with a labeled container and instructions on how to collect and return the sample. We asked participants to bring samples to the researchers the morning after the container was given, but to ensure time for participation, the research team remained in a community for at least three full days. A single sample was collected from each participant. A wet mount microscopic slide was prepared to identify trophozoite forms of protozoan infections and a portion of the sample was preserved using the Kato-Katz method to create a permanently-preserved slide with a known quantity of fecal material (41.7 mg) (WHO, 1991). Because hookworm eggs may degenerate in Kato-Katz preservations, all slides were examined the day they were prepared by a Masters student in parasitology (MCC). Individuals were considered positive for an infection if diagnostic eggs were observed in the wet mount and confirmed in the Kato-Katz prepared slide. Infection intensity (Eggs Per Gram or EPG) was obtained by multiplying the number of eggs observed in the Kato-Katz preparation by the manufacture's recommended multiplication factor (24).

Explanatory variables

We examined the association between presence of hookworm and two individual- and two household-level variables. Individual-level variables measured a) parental ethnomedical knowledge and b) parental biomedical knowledge of intestinal parasites. Household-level variables measured observed c) risky and d) preventive hygienic behaviors.

Ethnomedical knowledge

We measured the ethnomedical knowledge of mothers' and fathers' of all the children in the sample. We measured *ethnomedical knowledge* by reading informants the name of seven medicinal plants selected from a list of Tsimane' medicinal plants (Reyes-García, Huanca et al., 2006). We asked informants whether they knew each plant and whether the plant was helpful for a particular ailment. Four of the seven questions related to plants reportedly used to cure intestinal parasites. Three questions, including questions on intestinal parasites, were purposively false. We used our previous ethnographic research in the area to evaluate informant's answers and then generate a score for each adult consisting in the sum of all correct answers. The score of ethnomedical knowledge ranges from 0 to 7.

Biomedical knowledge

We used a questionnaire that resembled the questionnaire on ethnomedical knowledge to assess biomedical knowledge. Specifically we asked about the use of five allopathic medicines locally available for the Tsimane'. We evaluated participants' knowledge of biomedical treatments by comparing their responses with the information provided by the drug manufacturer. Three of the questions were purposively false. We subtracted one point for each of the false questions that the informant reported as right. Thus the score ranges from −3 to 5.

Behavior

We trained enumerators to observe four risky and four preventive behaviors at the time of the interview. *Risky behaviors* included 1) the presence of animals inside the kitchen during the duration of the interview, 2) the presence of animals inside the house (where people sleep) during the duration of the interview, 3) ownership of pigs among household domestic animals, and 4) use of pond as a water source (versus alternative water sources such as pumps, wells, the river, and streams). *Preventive behaviors* included 1) shoe ownership,

2) presence of a table in the kitchen, 3) presence of a latrine, and 4) overall cleanliness in the house compound. All the behaviors, except compound cleanliness, were coded as 1 if the enumerator observed the behavior and 0 otherwise. We trained enumerators to assess the overall cleanliness in the house compound from −2 (very dirty) to 2 (very clean). We then constructed two indices. The first index captures the intensity of risky behaviors in a household and ranges from 0 to 4. The second index captures the intensity of preventive behaviors and ranges from −2 to 5.

Control variables

Control variables in our regression model include child, parental, household, and village level variables. Characteristics of the children included the child's sex, age in years, and height in centimeters. Parental control variables included age, education level (or maximum school level attained), and stature of the parent whose knowledge was used as explanatory variable in the regression analysis. Household- and village-level controls included household size (total number of people living in the household at the time of the interview), number of households in the village, and a full set of village dummy variables.

Data analysis

For the empirical analysis, we assess the association between child hookworm infection and 1) parental ethnomedical knowledge, 2) parental biomedical knowledge, 3) household risky hygienic behaviors, and 4) household preventive hygienic behaviors. We differentiate between maternal and paternal knowledge because previous research suggests that mother's and father's knowledge do not have the same protective effect on child health (McDade et al., 2007). We analyzed data using a logistic regression model in which the dependent variable takes the value of one if the child was infected with hookworms and zero otherwise. Since our model estimates odds ratio, numbers lower than one should be read as negative associations whereas numbers higher than one should be read as positive associations. We used clustering by village of residency. Enumerators entered data into Microsoft Access and Excel in Bolivia and data cleaning was conducted by the authors. Data was analyzed using STATA software.

Results

Helminth infection among Tsimane' children and adolescents

Table 1 shows information on the presence of soil-transmitted helminth and protozoan infections among Tsimane' children and adolescents. Hookworm infection was the most common helminth infection, affecting 67.2% of children and adolescents in the sample. All the other infections affected less than 30% of the children and adolescents in the sample. In analysis not shown we found that only 15.8% of the children provided a sample that was negative for parasitic infection, 35.9% of children suffered from one infection only, 25.8% suffered from two infections, and 22.5% suffered from three or more of the parasitic infections assessed.

We use WHO cutoff to determine if participants had signs of mild, moderate, or heavy hookworm infections (Montresor, Crompton, Hall, Bundy, & Savioli, 1998). Only 31.8% of participants were negative for hookworm eggs on the day of the sample. Mild intensity infections affected 62% of the sample. Moderate infections were present in 3.6% of children and indications of severe infections (over 4000 epg) were found in 2.6% children. In other words, slightly more than 5% of children and adolescents in the sample were infected with moderate to severe intensity hookworm infections.

Boys in the sample showed a slightly larger percentage of hookworm infections than girls (69.3% vs 64.7%), although the intensity of the infection seemed to be slightly larger among the female than among the male sub-sample (504 epg vs 432 epg). Results from a Pearson correlation between the age of the children and the number of eggs found in their fecal sample (log transformed) suggest that the severity of the infection increases with age ($r = 0.314$, $p < 0.001$; $n = 308$).

Parental ethnomedical and biomedical knowledge

We collected information on ethnomedical and biomedical knowledge from mothers and fathers of the 329 children in the sample. Since most parents have more than one child in the sample, we collected information on 109 mothers and 103 fathers. The scores of ethnomedical knowledge of mothers and fathers were similar, although fathers had slightly higher scores on biomedical knowledge than mothers (Table 2). Since the score of ethnomedical knowledge ranged from 0 to 7, the average was below the mathematical mid point. The average biomedical knowledge score was above the mathematical mid point of the range (−3 to 5).

Risky and preventive hygienic behavior among Tsimane' households

The most commonly observed risky behavior was the presence of animals in the kitchen at the time of the interview (68.5% of the households). The other three risky behaviors were less frequent, as they were observed in less than one third of the households in the sample (Table 3). Commonly observed preventive behaviors included the presence of a table in the kitchen (75.2%) and shoe ownership (73.4%). Only 26.6% of the household compounds in the sample were rated as clean or very clean by enumerators. Households scored an average of 1.2 (SD = 0.9) in our index of risky behavior and 1.8 (SD = 1.3) in our index of preventive behavior (Table 2).

Association between preventive and curative knowledge and prevalence of hookworms

In Table 4 we show the results of two logistic regressions of parental knowledge and household risky and preventive behavior against the variable that measures whether the child had a hookworm infection. In column [A] we use mother's ethnomedical and

Table 1
Presence of soil-transmitted helminth and protozoan infections among Tsimane' children and adolescents ($n = 329$).

Genus or species	%[a]
Soil-transmitted helminth	
Hookworm (*Ancylostoma or Necator*)	67.2
Ascaris lumbricoides	10.0
Trichuris trichiura	3.6
Strongyloides stercoralis	0.03
Protozoan or flagellate	
Giardia lamblia	4.3
Blastocystis hominins	22.2
Nonpathogenic protozan	
Chilomastix mesnili	3.0
Entamoeba coli	16.7
Endolimax nana	27.7

[a] Numbers do not add to 100% due to overlap of infections.

Table 2
Descriptive statistics of variables used in regression analysis.

Variable	Definition				
Explanatory variables					
		Maternal ($N = 109$)		Paternal ($N = 103$)	
Knowledge		Mean	SD	Mean	SD
Ethnomedical knowledge	Score in a text on Tsimane' medicinal plants (0–7)	2.6	1.5	2.5	1.5
Biomedical knowledge	Score in a text on common pharmaceutical products (−3 to 5)	2.8	1.4	3.1	1.4
Behavior ($n = 109$)		Mean		SD	
Risky behavior	Household score on risky behavioral observations (from 0 to 4)	1.2		0.9	
Preventive behavior	Household score on preventive behavioral observations (from −2 to 5)	1.8		1.3	
Control variables					
		Maternal		Paternal	
Parental characteristics		Mean	SD	Mean	SD
Parental age	Reported age of the mother/father of the participant, in years	37.2	13.0	42.1	14.2
Parental education	Years of completed school for the mother/father of the participant	1.2	1.5	2.7	3.4
Parental stature	Height of the mother/father of the participant, in cms	150.7	4.4	162.3	4.9
Children's characteristics ($n = 329$)		Mean		SD	
Treated	Children recently (in last 3 months) treated for helminth infections, in percentages	7.6		26.5	
Male	Sex of the children, male = 1. In percentages	54.4		49.9	
Age	Reported age of the participant, in years	7.1		3.8	
Stature	Height of the participant, in cms	112.5		21.5	
Household and village characteristics					
Household size	Number of people living in the household at the time of the interview ($n = 109$)	7.1		2.4	
Village size	Number of households in a village ($n = 11$)	31.1		12.1	

biomedical knowledge as explanatory variables and mother's attributes as control. Column [B] resembles column [A] except that we use father's attributes. Three findings stand out. First, mother's ethnomedical knowledge bears a negative and weakly statistically significant association with the probability of a child having hookworm infection. Conditioning for household risky and preventive behavior, children, parental, household, and village level characteristics that might affect the outcome variable, we found that an increase of one point in the maternal score in the test of ethnomedical knowledge reduced the odds of the child having a hookworm infection by about 15% (=1-0.848; $p = 0.09$). The statistical association is weak and the magnitude is low in real terms. We tested for the joint significance of maternal ethnomedical and biomedical knowledge. The two variables had a statistically significant negative association with the probability of a child having hookworm infections ($F = 5.49$; $p > F = 0.06$).

Our second important finding is that none of the other measures of ethnomedical and biomedical knowledge were associated in a statistically significant way with the probability of a child having a hookworm infection (columns [A] and [B]). This includes no significant associations between father's medical knowledge and the probability of a child being positive for hookworm infection.

Third, the two indexes that measure the presence of risky and preventive hygienic behaviors in a house were statistically associated with the probability of a child suffering from hookworm infections. The two indices bear the expected signs. For example, in the regressions using mother's information, an increase of one risky behavior multiplies the odds of a child having hookworm infection by 1.86 ($p < 0.001$). Conversely, an increase of one preventive behavior reduced the odds of a child suffering from hookworm infection by 31% ($p = 0.01$). The results in the regressions using father's information (column [B]) resemble the results in the regression with mother's information. We also tested for the joint significance of risky and preventive household hygienic behavior. We found that the two variables together had a statistically significant negative association with the probability of a child having hookworm infection ($F = 18.82$; $p > F = 0.0001$ when using mother's attributes and $F = 14.46$; $p > F = 0.0003$ when using father's attributes).

Table 3
Risky and preventive hygienic behavior in Tsimane' households ($n = 109$).

Description		%
Risky behavior		
Presence of animals inside the kitchen at the time of the interview		68.5
Presence of animals inside the house (where people sleep) at the time of the interview		28.4
Ownership of pigs among household domestic animals		19.3
Water brought from a pond		3.7
Preventive behavior		
Presence of a table in the kitchen		75.2
Shoe ownership		73.4
Presence of a latrine		26.6
Household and compound cleanliness	Very dirty	3.7
	Dirty	15.6
	Average	54.1
	Clean	25.7
	Very clean	0.9

Table 4
Logistic regressions testing the association between the presence of child hookworm infection and parental knowledge and household hygienic behavior. Dependent variable: hookworm infection (0/1).

	[A] Mother's	[B] Father's
Explanatory variables		
Ethnomedical knowledge	0.848*	1.088
Biomedical knowledge	1.016	0.891
Risky behavior	1.859***	1.838***
Preventive behavior	0.690**	0.637**
Control variables		
Parental age	1.011	1.023
Parental education	0.988	1.219***
Parental stature	0.963	1.078
Child's sex (male = 1)	1.47**	1.506***
Child's age	1.056	1.098
Child treated	0.727	0.816
Child's stature	1.036	1.029
Household size	0.947	1.001
Village size	1.046***	1.057***
Joint test		
Ethnomedical + biomedical knowledge	5.49*	1.04
Risky + preventive hygienic behavior	18.82***	14.46***
N	330	309
Pseudo R^2	0.23	0.24

Notes: For definition of variables see Table 2. *, **, and *** significant at the 10%, 5%, and 1% level. Coefficients are probabilities of a child suffering from hookworm infection for a marginal change in an explanatory variable above the mean of the explanatory variable. Dependent variable = child suffered from hookworm infection and zero otherwise. Regressions are clustered by village of residency.

Robustness analysis

In subsequent analysis, we tested the robustness of our findings regarding maternal ethnobotanical knowledge (Table 5). First, we changed some of the specifications of the model: in line [2] we ran a tobit regression model to control for censoring; in line [3] we ran an Ordinary Least Square regression (OLS) using the logarithm of the number of eggs in the infection as outcome variable; in line [4] we used clustering by household, rather than by village. Second, we ran the core model only for some groups in the sample, such as children below 10 years of age (row [5]), and the sample of girls (row [6]) and boys (row [7]). Overall, maternal ethnomedical knowledge had a negative and weakly statistically significant relation with the probability of a child suffering from hookworm infection. The effect is larger for children 10 years of age or younger than for older children, and for boys than for girls in the sample. Across the robustness analysis, maternal ethnomedical knowledge is the only type of parental medical knowledge associated with child hookworm infection.

Table 5
Robustness analysis.

	Changes	Explanatory variables	
[1]	Core model	Ethnomedical knowledge	0.848*
		Biomedical knowledge	1.016
[2]	Tobit regression	Ethnomedical knowledge	−0.038
		Biomedical knowledge	0.004
[3]	OLS regression using logarithm of the number of eggs as dependent variable	Ethnomedical knowledge	−0.718*
		Biomedical knowledge	0.024
[4]	Clustering by household	Ethnomedical knowledge	0.848
		Biomedical knowledge	1.016
[5]	Only for children 10 years of age of younger	Ethnomedical knowledge	0.826*
		Biomedical knowledge	1.027
[6]	For girls	Ethnomedical knowledge	0.933
		Biomedical knowledge	1.124
[7]	For boys	Ethnomedical knowledge	0.763**
		Biomedical knowledge	0.922

Note: For definition of variables see Table 2. * and ** significant at the 10% and 5% level. Regressions are identical to those of Table 4, except for the changes noted in the column called "Changes".

In a final analysis, we examined the importance of household hygiene behavior. Results relying on the index of risky and preventive hygienic behaviors in a household did not allow one to assess which behaviors were particularly associated with the explanatory variables. So, in analysis not shown, we ran a regression model similar to the one presented in Table 4, but replacing the two indices with the eight variables used in their construction. We found that the presence of pigs among household domestic animals was the risky behavior most associated with a child suffering from hookworm infections. Depending on the model, the presence of pigs in the house multiplies the odds of a child having hookworm infection by 3.1–3.9 ($p < 0.001$). Having a table in the kitchen and the cleanliness around the house compound were the two preventive factors most consistently associated with reduced risk of child hookworm infection. The presence of a table in the kitchen multiplied the odds of a child infection by about 0.53–0.64 ($p < 0.04$), whereas each step in the index of house cleanliness multiplied the odds of a child infection by about 0.56–0.70 ($p < 0.10$). We also tested the interaction effects of the eight variables used to construct our indices of risky and preventive in their association with the probability of a child having hookworm infection. We found that those variables have an interaction effect on the outcome ($F = 118$; $p > F = 0.0001$ when using mother's attributes and $F = 59.8$; $p > F = 0.0001$ when using father's attributes), suggesting that those variables might in fact stand for a larger socio-economic construct.

Discussion and conclusions

Similar to many rural and indigenous populations, Tsimane' rely on a mix of ethnomedical and biomedical knowledge and treatments to manage common infectious disease such as helminth parasites. Social science has long appreciated the importance of local behavior and beliefs in shaping the burden of disease (Helman, 2007) and, in this study we investigate the association between local systems of medicinal knowledge, household risky and preventive hygienic behavior, and the occurrence of helminth infections in children and adolescents. Our discussion centers on two important findings. First, indices that capture a household's relative state of risky and preventive hygienic behavior are associated with a child's risk of hookworm infection. Second, we found that mother's, but not father's, ethnomedical knowledge has a negative association with a child's probability of being positive for hookworm infection. This effect of mother's knowledge was larger for young children and boys that for adolescents or girls.

Our first finding is that household risky and preventive hygienic behaviors are the most important factors in our model explaining the probability of a child suffering from hookworm infection. The two indices bear the expected signs and the results remain robust when controlling for the different proxies of mother's and father's medicinal knowledge. This finding is consistent with research in other resource-poor locations. For example, in Panama, Holland et al. (1988) found that the lower the household sanitation levels, the higher the probabilities of people in the household suffering from helminth infections. Similarly, in Kenya, Olsen et al. (2001) found hookworm infection to be associated with the absence of a latrine or the absence of soap for hand washing.

Although the association between household hygiene indices and hookworm risk are strong and robust, these results should be interpreted as indicating a general effect of household sanitation levels, rather than pointing to the value of specific behaviors. The indices of household hygiene used in this study include several behaviors not directly involved in the hookworm transmission cycle. For example, while wearing shoes does decrease skin contact with potentially infective soil, we measured shoe ownership because shoe use is highly irregular. People may wear shoes around the household for specific occasions (a festival, playing soccer, or going to school), but not during other activities like fishing or household chores. The presence of a kitchen table (protective behavior) would not directly interfere in the transmission of hookworm species, which most commonly require direct skin contact with soil contaminated by human fecal material. In contrast, domestic pigs have been found to be a factor in disseminating human hookworm eggs if they have the opportunity to ingest them, serving as a transport host (Steenhard et al., 2000). Therefore, finding a significant association between child infection and household hygiene suggests that general household environment can have a significant impact on overall infection patterns, especially in areas where helminth infections are endemic.

Our second important finding is that, from all the types of medical knowledge analyzed, only maternal ethnomedical knowledge showed a protective effect against child hookworm infection. Although the effect of maternal ethnomedical knowledge on child hookworm infection is low in real terms, the finding remained weakly significant after controlling for household hygiene behavior in all of our robustness analysis. These findings are consistent with previous research demonstrating a significant protective effect of maternal ethnobotanical knowledge on several measures of child health and nutritional status (McDade et al., 2007; Reyes-García, McDade et al., 2008).

The association between maternal knowledge and child health is also consistent with results from another body of research: research documenting the importance of maternal education to child health (Caldwell, 1994). Among Tsimane', women are primarily responsible for childcare and it is reasonable to expect that maternal attributes might have a greater impact on child health than paternal attributes. There are several possible pathways that might explain this link. For example, to prevent or cure infections mothers with greater knowledge may be more likely to effectively administer plant-based treatments to their children. Another possibility is that mothers with higher knowledge may be more likely to maintain plants believed to treat parasites in their gardens and treat their children if they suspect infection. Although we have not assessed the effectiveness of plants against helminths in this area, there is a large body of literature documenting botanical treatments for helminths in diverse cultures (Lewis & Elvin-Lewis, 2003).

Our last finding suggests that the effect of maternal ethnomedical knowledge is greater for young children and boys than for adolescents and girls. We can think of two possible reasons why the relation may be stronger at younger ages. First, children first come into contact with the infectious stages of helminth parasites as they begin to walk and explore the household compound and other close spaces. It is possible that, at younger ages, mothers are better able to monitor and treat their children at the first signs of poor health and thereby could quickly act to eliminate or reduce infections. Secondly it is possible that, in older children, child's knowledge mediates the importance of maternal knowledge by engaging in self-medication without discussing the illness with their parents. For example, we have observed older children using plants for medicinal purposes and, especially at older ages, seeking drugs. For older children, it is possible that own ethnomedical or biomedical knowledge may be more relevant to the presence of parasitic infections than parental knowledge. Unfortunately, we did not collect knowledge data for children and adolescents, so we cannot further test these ideas.

Finally, it is important to note the limitations of this study. Of greatest concern is omitted variable bias. The variables we have selected are likely correlated with other unmeasured attributes of children, parents, or the household. For example, it is possible that the hygiene indices or parental knowledge scores are part of a larger, and more significant, socio-economic construct. We have attempted to account for this problem by including variables related to the child, parent, and community as controls in all models, but we cannot rule out that other variables omitted from the analysis bias our results. Secondly, in this project we are unable to investigate the pathways linking household hygiene or maternal ethnomedical knowledge to child infection levels. Additional research including more refined data collection techniques (longer term observation, more nuanced knowledge interviews) would be needed to uncover the links of ethnomedical knowledge to either prevention or effective helminth treatment.

In conclusion, integration into markets and national societies is likely to affect local medical systems by increasing the reliance and use of biomedicine as formal education and biomedical interventions prioritize biomedical over ethnomedical knowledge. Our key findings point to the value of taking culture and local knowledge seriously when studying child health, especially among rural indigenous populations. There is no question that providing medication is critical, but this study demonstrates that poverty is not synonymous with either poor hygiene or the lack of valuable ethnomedicinal knowledge.

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