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Cultural transmission of ethnobotanical knowledge and skills: an empirical analysis from an Amerindian society☆

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Abstract

The modeling of cultural transmission is of great importance for understanding the maintenance, erosion, and spread of cultural traits and innovations. Researchers have hypothesized that, unlike biological transmission, cultural transmission occurs through at least three different, non-mutually exclusive paths: (1) from parents (vertical); (2) from age peers (horizontal); and (3) from older generations (oblique). We used data from 270 adults in a society in the Bolivian Amazon to estimate the association between a person's knowledge and skills and the knowledge and skills of the (1) same-sex parent, (2) age peers (or individuals born in the same village as the subject within ±4 years of the subject's year of birth), and (3) parental cohort (excluding parents). We found a statistically significant association between personal and parental and old cohort knowledge. The magnitude of the association is larger for old cohort knowledge than for parental knowledge, suggesting that, for the studied population, the transmission of ethnobotanical knowledge and skills is mostly oblique.

Keywords: Ethnobotanical knowledge; Transmission of knowledge; Tsimane'; Bolivia; Oblique transmission

1. Introduction

Cultural transmission refers to the process of social reproduction in which a culture's technology, knowledge, behaviors, language, and beliefs are communicated and acquired (Cavalli-Sforza & Feldman, 1981; Hewlett & Cavalli-Sforza, 1986). Researchers have hypothesized that, unlike biological traits, which are largely transmitted by a vertical path through genes, cultural traits can be transmitted through at least three distinct but not mutually exclusive paths: (1) from parent to child (vertical transmission); (2) between any two individuals of the

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same generation (horizontal transmission); and (3) from non-parental individuals of the parental generation to members of the filial generation (oblique transmission) (Cavalli-Sforza & Feldman, 1981).

The modeling of cultural transmission is of great importance for understanding the maintenance, erosion, and spread of cultural traits and innovations. Quantitative data on the mechanisms of transmission of cultural traits could be useful in predicting within-group variability, stability of cultural traits over time and space, and the evolution of culture (Boyd & Richerson, 1985; Cavalli-Sforza & Feldman, 1981; Richerson & Boyd, 2005). For example, as Cavalli-Sforza and Feldman discussed, vertical transmission is highly conservative, may maintain individual variation, and would be associated with slower rates of diffusion in a population as compared with horizontal and oblique transmissions. Innovations would spread slowly in a society where transmission of knowledge is done mainly through vertical transmission. By contrast, horizontal transmission might lead to fast diffusion of new cultural traits if contact with transmitters is frequent. Horizontal and oblique transmissions involving many transmitters to one receiver tend to generate the highest uniformity within a social group while allowing for generational cultural change (cf. Cavalli-Sforza & Feldman, 1981, for a discussion on the effects of different ways of transmission on the spread of cultural traits). Since these pathways are not mutually exclusive, the interaction between these pathways and their relative role in the transmission of a trait are also important. For example, if vertical transmission is relatively weak, coupling it with oblique transmission might prevent traits being eliminated from a population more than if it is coupled with horizontal transmission. However, the opposite is true if vertical transmission is strong (Cavalli-Sforza & Feldman, 1981, page 351).

Recent modeling work has shown that different pathways of transmission are favored under different conditions. When the environment is stable, the selection is strong, or the transmission refers to cultural traits affecting fertility, vertical transmission would be favored over oblique transmission. However, when environments are variable, the selection is relatively weak, or the transmission refers to cultural traits affecting survival to adulthood, oblique transmission would be favored over vertical transmission (McElreath & Strimling, 2008). Because cultural transmission can occur through different mechanisms that are likely to be relatively more or less important depending on the context and because the mechanisms through which cultural transmission occurs affect the stability of cultural traits over time and space, it is important to assess the relative weight of each mechanism.

In this study, we estimated the relative weight of vertical, horizontal, and oblique transmissions of an important technology in a small-scale society—ethnobotanical competence, defined as ethnobotanical knowledge and skills. To do this, we estimated the association between (1) a person's ethnobotanical competence and (2) the ethnobotanical competence of (a) the person's same-sex parent (vertical transmission), (b) the person's age peers (horizontal transmission), and (c) individuals from the parental cohort other than the parents (oblique transmission). We focused on ethnobotanical competence because researchers have outlined that ethnobotanical knowledge and skills confer many benefits to people in small-scale societies (Johns, 1996; Leonard, Tanner, & Huanca, 2007; McDade, Reyes-García, Leonard, Tanner, & Huanca, 2007; Reyes-García, Molina, et al., 2008; Reyes-García, Vadez, et al., 2008). We used same-sex parent knowledge and not average parental knowledge because the division of labor among the Tsimane' follows sex lines. For the empirical analysis, we drew upon a unique body of primary data collected from adults (≥16 years old) in 13 villages of a gatherer–horticulturalist society in the Bolivian Amazon (Tsimane'). Data include individual-level information on ethnobotanical knowledge and skills for a sample of adults related by both kinship (parents and their offspring) and spatial and temporal proximity (birth date and village of residency during childhood).

2. Previous studies on the transmission of folk biological knowledge

We reviewed the literature on the transmission of folk biological knowledge, focusing on (1) the acquisition of folk biological knowledge in indigenous and rural societies and (2) the empirical evidence for horizontal, vertical, and oblique transmissions of folk biological knowledge.

2.1. Learning

The literature on how people learn the everyday skills and tasks that shape their interactions with the environment has reached three main conclusions: (1) cultural learning occurs through a temporal sequence that spans from childhood to adulthood; (2) people learn from others, but knowledge acquisition is faster if people can put the knowledge in practice on their own; and (3) people need to come in direct contact with nature to accumulate folk biological knowledge.

First, previous research suggests that people learn most about folk biology during childhood. Children in subsistence societies master great quantities of empirical knowledge about their natural environment and subsistence-related skills before they are 12 years old (Stross, 1973; Zarger, 2002). Simple skills, such as the ability to identify and prepare medicinal plants, are mastered before adolescence. For instance, primary school children in rural and indigenous societies have been shown to self-medicate with local herbs (Geissler et al., 2002; Sternberg et al., 2001). By the time children reach adolescence, their ability to name plants and describe their uses peaks and remains largely unchanged for the rest of their life (Hunn, 2002; Stross, 1973; Zarger & Stepp, 2004). However, complex skills, such as hunting and craft production, may require years of experience to be done well and may not be mastered until adulthood (Gurven, Kaplan, & Gutierrez, 2006).

Second, learning in small-scale societies is typically experimental and unlikely to occur in schools (Atran & Sperber 1991). Qualitative studies on children's acquisition of folk biological knowledge suggest that children acquire most of their folk biological knowledge through hands-on experience, play, and direct observations (Zarger, 2002), rather than through organized and verbal instruction. Furthermore, parents and other elders do not see their duty toward children as primarily one of instruction, although interactions with parents, siblings, and other adults matter in the transmission of folk biological knowledge (Ruddle & Chesterfield, 1977; Zarger, 2002). Research studies also suggest that children must practice tasks to learn folk biological knowledge (Chipeniuk, 1998; Ohmagari & Berkes, 1997). For example, Ruddle and Chesterfield examined the traditional system of knowledge transmission on Guara Island in the Orinoco Delta of Venezuela. They concluded that learning occurs through repeated practice over time, rather than through simple observation of adults' performance.

Third, research studies suggest that contact with nature is of pivotal importance for the acquisition of folk biological knowledge (Atran, Medin, & Ross, 2004; Chipeniuk, 1995; Nabhan & St Antoine, 1993; Wolff, Medin, & Pankratz, 1999; Zent, 1999). For example, in a cross-cultural study, Ross, Medin, Coley, and Atran (2003) administered the same task to groups of rural and urban children from the United States. They found that urban children generalized less in terms of biological affinity than even the youngest rural children due to their impoverished experience with nature. Recent theoretical work have also pointed out that learners first engage in "critical social learning" and then switch to individual learning and experimentation when social learning does not fulfill their expected performance threshold (Enquist, Eriksson, & Ghirlanda, 2007; Enquist & Ghirlanda, 2007).

2.2. Paths for the transmission of folk biological knowledge

Genetic and cultural factors likely affect the acquisition of cultural knowledge. Genetic inheritance might be involved not in the specific knowledge acquired (i.e., there is no gene for knowing that plant X does Y), but genes might underlie learning capacity, or speed of learning, which would influence the acquisition of cultural knowledge. However, since the goal of our study was to estimate the relative weight of paths for cultural transmission, in this section, we focus on quantitative research related to the cultural, not genetic, transmission paths.

2.2.1. Vertical transmission

Anthropologists have stated that folk biological knowledge is mainly transmitted from one generation to the next by parents to offspring (Hewlett, De Silvestri, & Guglielmino, 2002; Lancy, 1999). The intuition that folk biological knowledge is transmitted directly from parents can be theoretically explained (Cronk, 1991; McElreath & Strimling, 2008) and finds support in several empirical studies (Hewlett & Cavalli-Sforza, 1986; Lozada, Ladio, & Weigandt, 2006; Ohmagari & Berkes, 1997). For example, in a study of a rural population in Argentina, Lozada et al. analyzed the transmission of knowledge of medicinal and edible plants. They concluded that family members (especially mothers) were the most important source for the acquisition of knowledge, followed by experienced non-familial traditional healers.

The results of another study on the transmission of cultural traits suggest that vertical dominance might not be preferential but is contextual to the type of knowledge being transmitted. In a study on the transmission of cultural traits and skills among Aka in the tropical forest of Africa, Hewlett and Cavalli-Sforza (1986) found that parents were singled out as the transmitters of 81% of the studied skills, followed by "watching others" (10%) and grandparents (4%). However, data suggest that vertical transmission was dominant only for highly shared knowledge and that new knowledge was mostly diffused through horizontal and oblique paths.

2.2.2. Oblique transmission

Some anthropologists, sociologists, and development psychologists have argued that parent–child transmission might not be the dominant mode of cultural learning (Henrich & Gil-White, 2001), at least when a person's total life span is considered (Aunger, 2000). Vertical transmission is based on two models, whereas oblique and horizontal transmissions are based on a larger sample size. A larger sample size might provide more accurate (less biased) information (Henrich & Boyd, 1998).

Oblique transmission can take the form of (1) *one to many*, when one person (e.g., a teacher) transmits information to many people of a younger generation, or that of (b) *many to one*, when a person learns from older adults other than the parents (Cavalli-Sforza & Feldman, 1981). Quantitative studies on oblique transmission of ethnobotanical knowledge are scarce and focus on the transmission of knowledge from one to many. For example, Lozada et al. (2006) found that experienced traditional healers outside the family are important in the transmission of ethnobotanical knowledge. Hewlett and Cavalli-Sforza (1986) found that non-parental older family members contributed only 1.4% to the transmission of bush skills among the Aka in the tropical forest of Africa.

2.2.3. Horizontal transmission

Several researchers have argued that there are also social and evolutionary reasons to expect intragenerational transmission of some types of cultural knowledge beyond the parent–offspring dyad (Boyd & Richerson, 1985; Harris, 1999). Observational studies suggest that, in some domains, children learn a considerable amount from age peers (Lancy, 1999; Zarger, 2002). For example, children regularly teach one another tasks and skills during the course of their daily play (Lancy, 1999). Zarger showed that siblings pass along extensive information to one another about plants, including where to find them, their uses, and how to harvest or cultivate them. Research also suggests that, later in life, young adults turn to age peers rather than to parents for information. In non-stable environments, age peers are the individuals most likely to have tracked changes and should provide the best information to update the information previously acquired from parents (Aunger, 2000; Cavalli-Sforza & Feldman, 1981). Furthermore, asking age peers is less socially questionable than asking parents because, at certain ages, parents might reproach offspring for their inability in certain skills.

The importance of age peers in the transmission of cultural knowledge has only been sparsely tested in relation to ethnobotanical competence but dovetails with studies in developmental psychology and cultural anthropology. Studies in developmental psychology stress the importance of age peers in the acquisition of knowledge and socialization, even in school (Shaeffer, 1996; Vygostky, 1978). Cultural anthropologists have conducted time allocation studies with children to show that children spend large portions of time with siblings and age peers (Weisner & Gallimore, 1977; Whiting & Whiting, 1975). Time spent together gives children the opportunity to share knowledge. It also allows for staggered learning because it allows children to learn from someone who knows just a little more than themselves and is not necessarily an expert. It might be easier to learn from these individuals than it would be to learn from an adult because adults might be less accessible, might move quickly over things because of their expertise, and be less willing to deal with the naive learner.

In sum, previous anthropological empirical research had outlined the importance of the vertical path in the transmission of ethnobotanical knowledge. Theoretical models and empirical evidence from fields other than anthropology suggest that the importance of vertical transmission may be overstated (Aunger, 2000) and that neither a vertical nor an oblique mode of transmission should be expected to dominate across all domains (McElreath & Strimling, 2008).

3. Tsimane': social organization and acquisition of ethnobotanical competence

The Tsimane' are composed of ~8000 individuals and live in the rainforests and savannahs at the foothills of the Andes, mostly in the Bolivia Department of Beni. Relatively isolated until the mid-20th century, they started to engage in more frequent and prolonged contact with Westerners after the arrival of Protestant missionaries in the late 1940s and early 1950s (Daillant, 2003; Huanca, 2008). Like many native Amazonians, the Tsimane' practice a mix of slash-and-burn farming, hunting, fishing, and plant gathering (Vadez et al., 2004).

Ethnographic observations suggest that, as in other gatherer–horticulturalist societies, among Tsimane', cultural knowledge is transmitted orally and through informal means. The Tsimane' have been exposed to schooling since the 1950s, but despite nearly five decades of exposure to schools, Tsimane' adults have little formal schooling (Godoy et al., 2007). Given the limited levels of literacy among the Tsimane', it is accurate to say that cultural transmission requires personal interaction, either through oral communication or imitation of observed behaviors.

In previous publications, we provided ethnographic details of the Tsimane', including descriptions of Tsimane' ethnobotanical knowledge (Huanca, 2008; Reyes-García, Huanca, Vadez, Leonard, & Wilkie, 2006; Godoy et al., in press). Here, we focus on describing the Tsimane' social organization and the learning process for the acquisition of ethnobotanical competencies. We focus on social organization because it might be central to understanding the potential paths for the transmission of cultural traits.

3.1. Tsimane' social organization

Until recently, the Tsimane' were a highly autarkic and egalitarian society (Ellis, 1996). Polygynous in the past, most Tsimane' presently practice monogamy and live in nuclear households run jointly by a wife and a husband. Each household contains an average of 6.23 people (S.D.=2.85), including 2.66 adults (S.D.=1.10) and 3.59 children (S.D.=2.31), defined as individuals younger than 16 years. Although nowadays most Tsimane' households are nucleated, households related by kin are usually organized in village clusters and situated at a short distance from one another. The villages included in this study contain an average of 24 nuclear households (S.D.=10.88).

The Tsimane' kinship system is Dravidian and functions as a social organization (Daillant, 2003). The Tsimane' practice cross-cousin marriage, meaning that a man weds the daughter of his mother's brother or that of his father's sister. This preferential system of marriage generates a thick network of relations and multiple alliances (Daillant, 2003). The Tsimane' call one another *chatidye* (relative), and they apply the term liberally to any Tsimane'.

The Tsimane' visit one another frequently. Social visits within the village occur on a daily basis; visits to family and friends in other villages are also frequent, sometimes lasting several weeks and even months. Ethnographers have stressed the importance of visiting for the transmission of cultural knowledge among the Tsimane' (Ellis, 1996).

3.2. The learning process

In previous research, we found that, like other indigenous groups, the Tsimane' acquire most of their ethnobotanical knowledge during childhood. The increase in ethnobotanical knowledge is slow after adolescence and more important for the acquisition of skills than for the acquisition of theoretical knowledge (Godoy et al., 2007; Reyes-García et al., 2007).

From ethnographic work, we also know that Tsimane' learning is based on observation and direct experience. Children are free to play, explore, and interact with the natural world with little or no restriction or supervision. Children older than 5 years usually spend a good portion of each day solely in the company of their brothers, sisters, cousins, and friends carrying out daily activities, such as household chores, babysitting, playing, bathing, and looking for snack foods. As in other subsistence societies (Lancy, 1999; Zarger, 2002), Tsimane' play and work activities are frequently intertwined. For example, boys organize and go on fishing expeditions by themselves. Girls are expected to perform household tasks and accompany mothers and older siblings to agricultural fields, where they often play with and take care of younger siblings.

The early acquisition of ethnobotanical competence is important for Tsimane' youngsters. The skills of young unmarried Tsimane' boys and girls seeking partners are typically evaluated by their potential in-laws as well as by their own parents, who worry about their children's ability to meet their expected duties in their future homes. The Tsimane' stress the need to acquire competence in sex-specific tasks before marriage, and many of these tasks require a certain domain of folk biological knowledge. For example, boys must know how to hunt and fish. Every boy needs to go on a hunting expedition alone and hunt with his bow and arrow before being able to form a new household. Similarly, girls must know how to prepare fermented beverages, farm, and weave. Excelling in subsistence-related activities (some of them highly dependent on ethnobotanical competence) is a source of social status for the Tsimane' (Reyes-García, Molina, et al., 2008; Reyes-García, Vadez, et al., 2008).

4. Estimation strategy

4.1. Assumptions and biases

The goal of this study was to estimate the relative weight of parents, age peers, and parental cohort in the transmission of ethnobotanical competence, but the statistical analysis of the transmission of cultural knowledge is a difficult problem with no straightforward method. Our estimations suffered from several biases, which we discuss in the next paragraphs. By acknowledging assumptions and potential biases in our estimations, we hope to contribute to move forward future quantitative empirical analysis of the transmission of knowledge.

Our empirical estimations assess the association between (1) the two outcome variables of ethnobotanical knowledge and ethnobotanical skills and (2) the ethnobotanical knowledge and skills of the (a) same-sex parent, (b) age peers, and (c) parental cohort. We assumed that an association between personal and the same-sex parent's ethnobotanical competence implies vertical transmission of cultural knowledge, that an association between personal and age peers' ethnobotanical competence implies horizontal transmission of knowledge, and that an association between personal and the parental cohort's ethnobotanical competence implies oblique transmission of knowledge. However, any conclusion on the paths for the transmission of knowledge from these estimations is based on four strong assumptions.

First, we assumed that all the information being analyzed had been transmitted through social learning—that is, we disregarded the possibility that any correlation between the knowledge of two individuals is due to one or both individuals in the comparison having acquired their knowledge through individual rather than social learning. Second, to imply transmission of knowledge from the associations in our model, we needed to assume endogenous effects, or that individual ethnobotanical competence varies with group ethnobotanical competence. However, our data suffered from what is known as the reflection problem (Manski, 1993), so individual ethnobotanical competence could also vary with the distribution of background characteristics of the group (contextual effects) or just be associated to group ethnobotanical competence because both the individual and the group face a similar environment (correlated effects). Third, to imply transmission of knowledge from the associations in our model, we also needed to assume that causality runs from the explanatory variable to the outcome variable. This is a strong assumption given that children can transmit knowledge to parents (Harris, 1999). Lastly, we assumed that a contemporaneous association illustrates past transmission of knowledge.

Potential biases in our estimations relate to (1) random measurement error, (2) omitted variables, and (3) redundant predictors. First, we might have measurement error in our proxy measures of ethnobotanical competence. For example, the test for skills is based on self-reports where we asked informants to recall whether they have ever crafted an item from a plant. So, our measure of ethnobotanical skills might suffer from random measurement error if, for example, some informants have better memory than others. Second, our estimations might be biased by the role of omitted variables. The underlying assumption of the econometric model is that a person acquires cultural knowledge through vertical, horizontal, or oblique transmission only. However, there might be other paths for the transmission of cultural knowledge. For example, people might acquire ethnobotanical knowledge and skills from people outside their own villages. Genetic inheritance might also be confounded with vertical transmission of knowledge. Failure to control for other variables that might influence transmission of knowledge will bias our estimations in an unknown magnitude and direction. Third, our estimates could suffer from having redundant predictors, which raises questions about the assumption of independence of predictors (Manski, 2007). For example, parental ethnobotanical competence might not be independent with respect to parental cohort ethnobotanical competence. As we explain below, parental cohort competence is calculated as the average of a group. For each observation, the number of values averaged changes according to the age of the person and the identity of the parents. However, this variation might not be enough to ensure independence of the two predictors.

4.2. The estimation strategy

Keeping those assumptions and caveats in mind, we used the following expression to model the association between ethnobotanical competence (Y) and covariates:

$$\mathrm{OK}_{ijv} = \alpha + \beta \mathrm{PK}_{ijv} + \gamma \mathrm{SK}_{ijv} + \theta \mathrm{CK}_{ijv} + \varphi \mathrm{D}_{ijv} + \varphi' \mathrm{V}_v + \varepsilon_{ijv} \quad (1)$$

OK_{ijv} refers to a person's ethnobotanical knowledge, where i is the participant, j is the household, and v is the village. We used ethnobotanical knowledge for ease of exposition, but the expression also applies to ethnobotanical skills. We differentiated between ethnobotanical knowledge and ethnobotanical skills because the two dimensions of ethnobotanical competence might be transmitted through different paths. PK_{ijv} captures the ethnobotanical competence of the same-sex parent. SK_{ijv} captures the average ethnobotanical competence of the subject's age peers (excluding the subject's own competence). We defined age peers as individuals who were born within ±4 years of the subject's year of birth and who reported spending their childhood in the same village as the subject. Because we do not have kinship data, we were not able to conduct a separate analysis for siblings. The measure of same age peers might include some, but not all, of the subject's siblings. CK_{ijv} captures the average ethnobotanical competence of the parental cohort, defined as individuals who were born between 20 and 40 years before the subject and who lived in the subject's village during the subject's childhood (excluding the parents). D_{ijv} is a vector of variables that captures the demographic attributes of the participant (e.g., age, sex, school attainment). V_{v} is a vector of dummy variables to control for the subject's village of residency, and ε_{ijv} is a random error term with standard properties.

By including the ethnobotanical competence of parents, age peers, and parental cohort in the same equation, we can compare the coefficients and significance of the three variables. If transmission of ethnobotanical competence occurs mainly from parents to offspring, then the knowledge of parents and offspring should be highly correlated, and the coefficient β should be positive and larger than γ and θ. If the three paths of transmission have a similar weight, then the three coefficients, γ, β, and θ, should be positive, statistically significant, and of similar magnitude.

To estimate the parameters, we used ordinary least-squares regressions with robust standard errors. We ran regressions with clustering of individuals by households (at the time of the interview) because individuals are nested in households and because individuals from a household are more likely to be similar in their ethnobotanical competence than individuals from different households. We included a full set of dummies for village of residency to control for village-level attributes that are of pivotal importance in explaining the pathways for the transmission of ethnobotanical knowledge and skills. For example, it is possible that the transmission of ethnobotanical knowledge and skills in a village is affected by its given ecological context or by the presence of a charismatic or knowledgeable person who lives (or lived) in the village and from whom all the people learned. By including village dummies, we can partially control for these unmeasured phenomena.

5. Methods

Data came from a survey that took place during June–September 2005 among the Tsimane'. Four experienced interviewers and translators, who have been working with the Tsimane' since 1999, did the survey. The study protocol was approved by the Northwestern University and Brandeis University review boards for research involving human subjects. The Grand Tsimane' Council approved the study, and individual consent was obtained before enrollment.

5.1. Sample

We collected data among nearly all households (n=252) in 13 Tsimane' villages straddling the Maniqui River. The villages surveyed differed in their proximity to the market town of San Borja (population of ∼19,000) (mean=25.96 km; S.D.=16.70). Our initial sample included every person older than 16 years (or younger if they headed a household) willing to participate (n=642). During interviews, we asked informants to provide their father's and mother's names and their village of residency. We interviewed parents who were part of the studied villages but did not attempt to find parents who resided in villages outside our sample. From the 642 adults who answered the survey, only 270 (123 men and 147 women) from 163 households had the same-sex parent in the sample.

5.2. Personal ethnobotanical knowledge

To measure ethnobotanical knowledge, we mentioned to informants the Tsimane' name of 15 local plants selected at random from a list of 92 plants developed in an earlier study (Reyes-García et al., 2006). We asked participants whether they knew each plant and recorded positive answers as one and negative answers as zero. Responses show a high intercorrelation with a Cronbach's α of 0.78, so we used them to construct an individual summary measure of ethnobotanical knowledge by adding the answers to the 15 questions. We transformed knowledge scores to natural logarithms to ease the reading of the coefficients from regression analysis.

5.3. Personal ethnobotanical skills

To measure ethnobotanical skills, we asked subjects whether they had ever used 12 plants for a specific purpose [e.g., “Have you ever used coyoj (*Zantedeschia* spp.) for medicine?”]. None of the questions was purposefully false. If participants reported having used the plant, we coded the answer as one; otherwise, we coded the answer as zero. Responses were intercorrelated with a Cronbach’s α of 0.75, so we used them to construct a summary measure of ethnobotanical skills by adding the answers to the 12 questions to obtain a total score for ethnobotanical skills for each participant. Twenty-two people (14 women and 8 men) or 8% of the sample had a score of zero in the test of ethnobotanical skills, so we added one point to subjects’ scores before transforming data to logarithms.

5.4. Same-sex parent ethnobotanical competence

We used the same test to measure subjects’ and parents’ ethnobotanical knowledge and skills. Using pairwise Pearson correlations, we found that fathers’ and sons’ ethnobotanical knowledge scores were correlated (r=0.225, p=.003), whereas their ethnobotanical skills were not (r=0.03, p=.6). Mothers’ and daugthers’ ethnobotanical knowledge (r=0.505, p<.001) and skills (r=0.443, p<.001) were positively correlated.

Correlations of scores do not indicate an actual match in responses. Two persons with the same score might have correctly answered totally different sets of questions. To measure actual match in ethnobotanical knowledge and skills between a subject and his or her same-sex parent, we generated two new variables. We compared the responses of parents and offspring to each of the questions in our tests and added one point to the new variable each time both parent and offspring had a correct answer in the test.

The pairwise Pearson correlation coefficient between the variable that measures parent–offspring matches in the ethnobotanical knowledge and the ethnobotanical skills tests was relatively high and statistically significant (r=0.553, p<.0001). To avoid collinearity between outcome (personal knowledge) and explanatory (number of positive matches between parent and offspring in the knowledge test) variables, in regression analyses we used the variable that measures positive matches in ethnobotanical skills as the explanatory variable in the model with ethnobotanical knowledge as outcome and vice versa.

5.5. Age peers' ethnobotanical competence

We asked informants to report their birth date, or estimated age in years, and their village of residency during childhood. We used the reported age and village of residency during childhood to group subjects into cohorts. For each individual in the sample, we generated a group of age peers, defined as individuals who spent childhood in the same village as the subject and who were born within ±4 years of the subject’s year of birth. The composition of age-peer cohorts changed for each individual in the sample. We did not calculate actual matches between an individual and his or her cohort and simply used as explanatory variable the average knowledge of the cohort, excluding the individual’s knowledge. We followed the same procedure to calculate age peers’ ethnobotanical skills.

5.6. Parental cohort ethnobotanical competence

To define parental cohort, we first estimated the average difference in age between subjects and their parents. The average difference in age between a woman and her mother was 31.5 years (S.D.=12.5). The average difference in age between a man and his father was 35.4 years (S.D.=12.4). We defined parental cohort as individuals who were born between 20 and 40 years before the subject and who lived in the village where the subject spent childhood. As with age-peer cohorts, to calculate parental cohort ethnobotanical knowledge, we averaged the measured ethnobotanical knowledge scores of informants in each group, excluding the ethnobotanical knowledge of the subject’s parents. We followed a similar procedure to calculate parental cohort ethnobotanical skills.

5.7. Controls

Controls for the regression analysis included age, schooling, and a full set of dummies for village of residency.

6. Results

Table 1 contains a definition and summary statistics of the variables used in the regression analysis.

Table 2 contains the regression results for ethnobotanical knowledge and ethnobotanical skills. In column 1, we included only men (n=123); in column 2, only women (n=147); and in column 3, the full sample (N=270).

6.1. Ethnobotanical knowledge

The analysis of the possible transmission of ethnobotanical knowledge among men (column 1) suggests that a man’s ethnobotanical knowledge is associated with his father’s ethnobotanical skills and with the knowledge of the parental cohort but not with the knowledge of his age peers. A 1% increase in the measure of the father’s skills is associated with a 0.02% increase in the ethnobotanical knowledge of the man (p=.04), and a 1% increase in the ethnobotanical knowledge of the parental cohort is associated with a 0.62% increase in the ethnobotanical knowledge of the man (p=.008).

The analysis of the paths for the possible transmission of ethnobotanical knowledge among women (column 2) suggests a similar pattern. A woman’s ethnobotanical

Table 1
Definition and descriptive statistics of variables used in regression analysis (N=270)

Variable	Definition	Mean	S.D.
Outcome variables			
Ethnobotanical knowledge	Score in test of plant knowledge; subjects were asked if they knew names of 15 wild and semi-domesticated plants; in regression, this was entered in natural logarithms	11.61	2.78
Ethnobotanical skills	Reported use of 12 wild and semi-domesticated plants; in regression, this was entered in natural logarithms	4.39	2.68
Explanatory variables			
Same-sex parent ethnobotanical knowledge	Number of matches in responses to the ethnobotanical knowledge test between a person and his or her same-sex parent	3.13	2.15
Age peers' ethnobotanical knowledge	Average ethnobotanical knowledge score of individuals who were born in the same year as or within ±4 years of the subject's year of birth and who lived in the same village during childhood (excluding subject's knowledge)	12.15	2.04
Parental cohort ethnobotanical knowledge	Average ethnobotanical knowledge score of individuals who were born between 20 and 40 years before the subject and who lived in the subject's village of childhood, excluding parental knowledge	13.08	1.61
Same-sex parent ethnobotanical skills	Number of matches in responses to the ethnobotanical skills test between a person and his or her same-sex parent	4.39	2.68
Age peers' ethnobotanical skills	Average ethnobotanical skills score of individuals who were born in the same year as or within ±4 years of the subject's year of birth and who lived in the same village during childhood (excluding subject's knowledge)	4.59	1.42
Parental cohort ethnobotanical skills	Average ethnobotanical knowledge score of individuals who were born between 20 and 40 years before the subject and who lived in the subject's village of childhood, excluding parental knowledge	6.04	1.57
Control			
Male	Sex of the subject, male=1	0.44	0.49
Age	Age in years	27.31	11.15
Schooling	Maximum school grade achieved by subject	2.62	2.10

knowledge bears a positive and statistically significant association with the measure of her mother's skills and a low association with the ethnobotanical knowledge of her parental cohort. As for a man's ethnobotanical knowledge, a woman's ethnobotanical knowledge is not associated to the ethnobotanical knowledge of her age peers. A 1% increase in the measure of the mother's ethnobotanical skills is associated with a 0.023% increase in the ethnobotanical knowledge of the woman (p=.01). A 1% increase in the average ethnobotanical knowledge of the parental cohort is associated with a 0.37% increase in the ethnobotanical knowledge of the woman (p=.10).

In column 3, we present results from the pooled sample. We found that the strongest association in real terms was between the ethnobotanical knowledge of an individual and that of the individual's parental cohort. Doubling the average knowledge of the person's parental cohort would be associated with a 37% increase in the person's ethnobotanical knowledge (p=.01), whereas doubling the number of matches with the same-sex parent in the skills test would be

Table 2
Regression results: paths of the transmission of ethnobotanical knowledge and skills among Tsimane' adults

Dependent variables							
Ethnobotanical knowledge (log)				Ethnobotanical skills (log)			
	Male	Female	Pool		Male	Female	Pool
Explanatory variables							
Same-sex parent skills (log)	.025**	.023**	.022***	Same-sex parent knowledge (log)	−.010	.073***	.038**
Age peers' knowledge (log)	−.314	.235	−.074	Age peers' skills (log)	−.186	−.121	−.198
Parental cohort knowledge (log)	.618***	.372*	.373**	Parental cohort skills (log)	.460*	−.160	−.008
Control variables							
Male	–	–	.078***		–	–	.146**
Schooling	−.009	−.021	−.015*		−.054***	−.051	−.055***
Age	.008***	−.004**	.006**		.013**	.003	.009**
Constant	1.154	0.653	1.44***		1.083	1.514	1.442**
R^2	0.58	0.55	0.54		0.38	0.40	0.33
n	123	147	270		123	147	269

Regressions are ordinary least squares and contain a full set of dummy variables for village of residency (not shown). Robust standard errors were used when the probability of exceeding the χ^2 value in the Breusch–Pagan test was <5%. Variables were intentionally left out in the columns marked by a dash. For a definition of variables, see Table 1.

* Significant at ≤10%.

** Significant at ≤5%.

*** Significant at ≤1%.

associated with only a 2% increase in the person's knowledge ($p<.0001$).

6.2. Ethnobotanical skills

Results for the paths of transmission of ethnobotanical skills differ from those for the transmission of ethnobotanical knowledge. We found that a man's ethnobotanical skills were weakly associated with the average skills of the parental cohort but not associated with his father's knowledge or with the skills of his age peers. A 1% increase in the average skills of the parental cohort would be associated with a 0.46% increase in a man's ethnobotanical skills (p=.09). A woman's ethnobotanical skills were associated with her mother's ethnobotanical knowledge. A 1% increase in the number of matches between a woman and her mother would be associated with a 0.07% increase in the woman's knowledge (p=.003).

Results from the transmission of ethnobotanical skills with the pooled sample (Table 2, column 3 under Ethnobotanical Skills) suggest a low association between the skills of an individual and the ethnobotanical knowledge of the person's same-sex parent. A 1% increase in the number of matches between a person and the same-sex parent in the ethnobotanical knowledge test would be associated with a 0.038% increase in the person's knowledge (p=.01).

In sum, we generally found that (1) the ethnobotanical competence of the same-sex parent is generally associated with a person's ethnobotanical competence, (2) parental cohort knowledge is associated to a person's ethnobotanical knowledge (the association is stronger for men than for women), and (3) age peers' ethnobotanical competence is not associated in a statistically significant way with personal ethnobotanical competence.

6.3. Robustness

In Table 3, we present results from a series of sensitivity analyses to assess how well the results of Table 2 hold up. The first column in Table 3 contains a description of the changes made to the core model.

In Model 2, we ran regressions similar to those presented in Table 2 but changed age peers' and parental cohort knowledge to age peers' and parental cohort skills as explanatory variables for personal ethnobotanical knowledge (under the Ethnobotanical knowledge part). Under the Ethnobotanical skills part, we include age peers' and parental cohort ethnobotanical knowledge as explanatory variables for personal ethnobotanical skills. We found results similar to the core model with one exception. Age peers' ethnobotanical knowledge was associated with a man's ethnobotanical skills. A 1% increase in age peers' ethnobotanical knowledge would be associated with a 0.87% increase in a man's ethnobotanical skills (p=.06).

In Model 3, we include decade of birth dummies to separate the collinearity between the cohort and age effects (Borjas, 2005). In Model 4, we ran the same regression, substituting the set of dummy variables for current village of residency by a set of village dummy variables for a subject's village of residency during childhood. Dummies for village of residency during childhood allowed us to control for fixed effects related with intragroup correlation during an important time for the transmission of knowledge—childhood. Results from Models 3 and 4 closely resemble those presented in Model 1.

Table 3
Robustness

	Dependent variables							
	Ethnobotanical knowledge (log)				Ethnobotanical skills (log)			
		Male	Female	Pool		Male	Female	Pool
1. Core model, as in Table 2	Same-sex parent skills	.025**	.023**	.022***	Same-sex parent knowledge	−.010	.073***	.038**
	Age peers' knowledge	−.314	.235	−.074	Age peers' skills	−.186	−.121	−.198
	Parental cohort knowledge	.618***	.372*	.373**	Parental cohort skills	.460*	−.160	−.008
2. Skill as explanatory variable for knowledge and vice versa	Same-sex parent skills	.022*	.023**	.023***	Same-sex parent knowledge	−.001	.072***	.037**
	Age peers' skills	−.072	.092	.061	Age peers' knowledge	.871*	−.189	.628
	Parental cohort skills	.210**	−.044	.082	Parental cohort knowledge	.463	−.374	−.181
3. With decade of birth dummies	Same-sex parent skills	.021*	.023**	.021***	Same-sex parent knowledge	−.014	.074***	.038**
	Age peers' knowledge	−.441*	.074	−.215	Age peers' skills	−.385	−.145	−.258
	Parental cohort knowledge	.605**	.436*	.382***	Parental cohort skills	.309	−.221	−.062
4. With dummies for the village where the person grew up	Same-sex parent skills	.027**	.025**	.023***	Same-sex parent knowledge	−.026	.075***	.039**
	Age peers' knowledge	−.365	.220	−.123	Age peers' skills	−.175	−.158	−.191
	Parental cohort knowledge	.835***	.271	.335	Parental cohort skills	1.042***	−.185	.188

Regressions are as those in Table 2, with changes indicated in the first column. See the legend to Table 2.
* Significant at ≤10%.
** Significant at ≤5%.
*** Significant at ≤1%.

In an additional analysis (not shown), we differentiated between informants 25 years old or younger and informants older than 25 years. We only ran regressions with the pooled sample because we did not have enough observations to perform the analysis separately for men and women. We found that parental skills continue to be associated to personal knowledge for the two groups but that parental knowledge is only associated to personal skills for the younger group. We also found that only the young part of the sample seems to rely on oblique transmission, and only for the transmission of knowledge.

In sum, results from our research suggest that the transmission of ethnobotanical knowledge and skills mostly occurs through vertical and oblique paths for the Tsimane'.

7. Discussion

We organized the discussion around findings from the three paths to explain the transmission of ethnobotanical knowledge and skills analyzed. First, we found that our proxies for same-sex parental ethnobotanical competence are consistently associated to personal ethnobotanical competence with one exception: the father's ethnobotanical knowledge is not associated to a man's skills. The finding of the association between personal and parental knowledge meshes with previous empirical findings on the transmission of ethnobotanical knowledge, thus corroborating that parents play an important role in the transmission of cultural knowledge (Hewlett & Cavalli-Sforza, 1986; Lozada et al., 2006; Ohmagari & Berkes, 1997). However, our findings suggest that the effect of the association is small in real terms. Doubling same-sex parental ethnobotanical competence (an unlikely event) would result in only a 2% increase in offspring ethnobotanical knowledge and a 3% increase in offspring ethnobotanical skills.

Second, we found that knowledge of the parental cohort is generally associated with subjects' ethnobotanical knowledge but that only for the women in the sample are the skills of the parental cohort associated to personal skills. The magnitude of the association for parental cohort ethnobotanical knowledge is larger than the magnitude of the association for same-sex parental ethnobotanical knowledge, suggesting that the real weight of the oblique transmission path is larger than the real weight of the vertical path, at least for ethnobotanical knowledge. A possible explanation for the finding lies in the Tsimane' social organization. As explained before, the Tsimane' social organization provides ample opportunities to interact with older aged kin and friends from a young age. Those interactions facilitate the exchange of information across age groups outside the parent–offspring dyad.

Third, we found that age peers' ethnobotanical competence is not associated in a statistically significant way with personal ethnobotanical competence. Several researchers have argued that there are social and evolutionary reasons to expect intragenerational transmission of cultural knowledge (Boyd & Richerson, 1985; Harris, 1999; Lancy, 1999; Zarger, 2002). We did not find any evidence of horizontal transmission of ethnobotanical knowledge.

Our data also suggest that there might be differences in the transmission of ethnobotanical competencies among men and women, the differences being stronger for the transmission of ethnobotanical skills than for the transmission of ethnobotanical knowledge. The associations are robust for most of the regression models tested, including the model that controls for decade of birth. Why would the paths for the transmission of ethnobotanical knowledge and ethnobotanical skills among Tsimane' men and women differ? And why would ethnobotanical knowledge and skills be transmitted through different paths? Differences in the paths for the transmission of ethnobotanical knowledge and skills among Tsimane' men and women might reflect differences in time allocation and sexual division of labor among the Tsimane'. For example, from a young age, Tsimane' girls are expected to perform household tasks and accompany mothers and other relatives to agricultural fields. Such close interaction could facilitate the transmission of ethnobotanical knowledge and skills from the older to the younger generation. In contrast, Tsimane' men are reluctant to take young children to the forest with them because of the dangers of the forest for young children and because children might make noise, thus spoiling hunting opportunities. This could result in boys having fewer opportunities to directly interact with and learn from their fathers. Thus, it is possible that Tsimane' men's learning from parents is of a more indirect nature than Tsimane' women's learning from mothers. Because men's learning from parents is more indirect, it could be superseded more easily by parental cohort knowledge.

Why would ethnobotanical knowledge and skills be transmitted through different paths? A possible explanation might be related to the different characteristics of ethnobotanical knowledge and skills. Research shows that ethnobotanical knowledge, such as names and traits used for recognition, is easier to acquire than ethnobotanical skills and is mainly acquired during childhood. Knowledge relies on cumulative memory, and individuals can learn quickly and effectively through relatively few interactions; therefore, individuals can acquire ethnobotanical knowledge from many sources. Learning skills might require a higher investment by the learner. Acquiring skills is more costly in time and requires a number of direct observations and repetition within a particular ecological context. Individuals might be more conservative in selecting models for the transmission of skills and place more weight on information acquired from older informants or informants with more expertise than their peers.

We conclude by discussing the potential implications of our findings for cultural evolution in the Tsimane' and suggesting lines of future research. Research suggests that oblique transmission involving many transmitters to one receiver tends to generate the highest uniformity within a social group while allowing for generational cultural change. If, as our data suggest, the Tsimane' favor the oblique path for the transmission of cultural knowledge, then one would expect uniform cultural changes in the Tsimane' society. Furthermore, this increased reliance on oblique transmission would produce more rapid diffusion of innovations in ethnobotanical knowledge than if vertical transmission was favored.

Further empirical research on the transmission of cultural knowledge should address the longitudinal dimension of knowledge acquisition. In the study presented here, we analyzed associations between members of an adult population under the assumption that a present association would reflect past transmission of knowledge, but if ethnobotanical knowledge and skills are acquired across the life span, then different paths of transmission might play different roles through time. Further research should follow children into adulthood to provide a better understanding of how knowledge and behaviors are first acquired and later changed as individuals age and are exposed to other sources of information.

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