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Research article

Evolutionary aspects that guide the cultural transmission pathways in a local medical system in Northeast Brazil

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ABSTRACT

Most of the studies with a focus on pathways and biases of cultural transmission in different domains show that vertical transmission predominates over horizontal and oblique transmission, especially in traits linked to traditions and survival skills, such as local medicine. However, overestimation of the importance of vertical transmission has been an object of methodological criticism. Therefore, a statistical analysis with diachronic perspective may obtain more accurate results. The present study uses an eight-year time frame, as well as synchronous analysis, to study evolutionary aspects that guide the transmission pathways of a local medical system in northeast Brazil. We find that even with vertical transmission being predominant in the learning of information in this cultural domain, the evolutionary implications of this predominance may not be the same as that expected by the theory of cultural evolution. There is a substantial updating of knowledge through horizontal and oblique routes, guided primarily by a model-based bias on prestige and success, which is quite adaptive. Moreover, even when the information is passed vertically, the transmission is much more diffusive than conservative. Indeed, there is a small set of information that remains over time, known as a "structural core," but new information is aggregated continuously, preparing the system to adapt to new events. By analyzing the transmission routes of knowledge about medicinal plants, this study presents a new perspective on the evolutionary implications of cultural transmission.

1. Introduction

Cultural transmission is the easiest way through which humans learn about a wide range of beliefs and behaviors about the environment and culture they live in, and add to their knowledge (Henrich and Gil-White, 2001). In seeking from whom to learn new information, people weigh, consciously or unconsciously, the potential gains in copying from a specific person (their model) against the costs of accessing that person (Henrich and Gil-White, 2001). Indeed, learning from parents – vertical transmission – can be adaptive in the first years of an individual's life (Ohmagari and Berkes, 1997; Zarger and Stepp, 2004; Reyes-Garcia et al., 2009; Srithi et al., 2009; Tehrani and Collard, 2009; Hewlett et al., 2011) when all knowledge is new and there is little to gain from more specialized models. Also, access to parents is the least expensive. Throughout their development, people can update the information learned vertically by searching for other models, using horizontal (from people of the same generation) and oblique (from people of the parental generation) pathways (Henrich and Broesh, 2011).

Such models may be preferred due to the success they have in a particular cultural domain, their gender, age, and similarity with the learner, among other characteristics that may bias the copy of information. Some studies have shown that success and prestige are the main cues that people use to copy adaptive information, followed by other parameters, when the person's success is not so obvious (Henrich and Broesh, 2011; McElreath et al., 2008).

According to theoretical studies, in cultural domains in which vertical transmission is the prevalent route, the evolutionary response to disturbances will be slower than that with oblique and horizontal pathways (Hewlett and Cavali-Sforza, 1986; Cavalli-Sforza and Feldman, 1981). Dealing with a medical domain, slower responses could be highly

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disadvantageous in an environment in which new diseases may appear anytime. Furthermore, in this scenario, we would expect low acceptance for innovations and high knowledge variation among people from the same population (Hewlett and Cavali-Sforza, 1986; Cavalli-Sforza and Feldman, 1981).

Although some studies have shown that the transmission route of knowledge about medicinal plants is mainly vertical (Lozada et al., 2006; Eyssartier et al., 2008; Hewlett and Cavali-Sforza, 1986; Soldati et al., 2015), the methodology of these studies, based on the informants' self-reports about people from who they learned such information, has been object of criticism (Aunger, 2000; McElreath and Strimling, 2008). It is argued that people tend to overvalue the role of parents in the learning process when asked from whom they learned any knowledge, overestimating vertical routes (Aunger, 2000; McElreath and Strimling, 2008). In other cultural domains, the few studies that do not apply the methodology of self-reports found a greater importance of horizontal and oblique pathways (Reyes-García et al., 2009; Henrich and Broesh, 2011). We proposes that, in medicinal plants domain, horizontal and oblique pathways have greater influence than reported by literature, providing faster evolutionary responses and making knowledge more homogeneous in local populations. We can check the replacement of vertical pathways by horizontal and oblique ones by verifying the decrease in similarity between parents and children and increase in similarity between people and their favorite models over time. Knowing the patterns of transmission of medicinal knowledge will allow us to infer the cultural bias that guide the evolutionary path, and, above all, the speed of evolutionary responses of a local medical system.

Sharing a deeper perspective on vertical versus horizontal and oblique transmission and its evolutionary implications, some authors argue that transmission through a similar pathway can hide other phenomena. For example, Aunger (2000) suggests that "*children may not learn what their parents learned when they were young (from grandparents), but instead what the parent more recently heard from someone outside the family.*" If this happens, vertical transmission would not be as conservative as expected by mathematical models and could result in a more homogeneous cultural system. Based mainly on this argument of Aunger (2000), Soldati and Albuquerque (2016) propose that vertical transmission has conservative events, but it also has diffusive events, which occur when a cultural trait that is transmitted from parents to children has an origin in non-parental pairs.

Based on these issues about the transmission of cultural traits related to health care, and taking advantage of our scenario in a diachronic perspective, this study aims to answer the following questions:

1. Do people learn about medicinal plants mainly through vertical pathways? With this question, we not only want to know if people learn from their parents, but also whether their knowledge is more similar to that of their parents than the rest of the population, reinforcing the view that learning is mainly passed by vertical route.
2. Do people update the information learned vertically through horizontal and oblique pathways throughout their development? We also wants to verify whether the similarity of knowledge between parents and offspring decreases or remains constant while that between each person and his/her respective model increases over time.
3. Does success or prestige-based model bias excel over other model biases in the transmission of information about medicinal plants? We expect to find that the models most indicated as preferred by the population are those perceived as prestigious people in the community. We also expect to find that the people indicated as models have greater knowledge of medicinal plants than the rest of the population.
4. Is vertical transmission of cultural traits purely conservative? We aim to find whether the transmission frequency of cultural traits related to medicinal plants of diffusive origin (when a cultural trait that is transmitted from parents to children has an origin in non-parental pairs) is equal to or greater than the frequency of cultural traits of conservative origin (parental origin cross generations).

2. Material and methods

2.1. The local medical system

This study investigates the local medical system of the rural community of Carão, located in the municipality of Altinho (geographical coordinates are 8° 29′ 32″ South, 36° 03′ 03″ West), in the mesoregion Agreste of Pernambuco, Brazil. The region is covered with arboreal hypoxerophytic vegetation of deciduous and semi-deciduous type, which qualifies it as a Caatinga ecosystem. The climate is semi-arid, according to Caruaru's weather station (60 km away from Altinho) and the average annual temperature is 23 °C (Lamepe/Imepe, 2011).

The local population is small, with about 100 inhabitants, according to information provided by the locals themselves and the health center. Some of the local youth has migrated to the bigger cities of Brazil, such as São Paulo, and they regularly visit their families in Carão. Farming of corn, beans, and cassava is the main subsistence activity and is performed equally by men and women, without division of labor. Most of the adult population has had no more than 5 years of formal education or is illiterate. There is an elementary school in Carão, while older children go to Altinho's downtown for higher education. Altinho's downtown is 16km away from Carão and is accessed via a one-way dirt road on a truck that belongs to a local family, who offers transportation daily at 7h – from the community to Altinho's downtown – and at 12h – from Altinho's downtown back to the community.

The community of Carão has been the focus of many ethnobiological studies since 2007, involving the knowledge and use of plants for wood harvesting, as food, and as medicine (Araujo, Alencar, Amorim, and Albuquerque, 2008; Melo et al., 2010; Alencar et al., 2010; Ferreira Junior, Ladio, and Albuquerque, 2011; Alencar et al., 2014). All these studies recognized its medical system as being primarily based on medicinal plants and oral transmission of knowledge. Carão also has a health center that gets weekly visits from a nurse who is a resident of the community. The center uses and recommends medicinal plants as well as industrial drugs for treatment.

2.2. Data collection

In accordance with current Brazilian legislation (Resolution no. 466 from December 12, 2012, by Conselho Nacional de Saúde – Brazil National Health Council), all people who agreed to take part in the research were asked to sign a Termo de Consentimento Livre e Esclarecido (TCLE) – Informed Consent Form – authorizing the collection, use, and publishing of the data obtained from this study. The research was also approved by the ethical committee of Universidade de Pernambuco (UPE) – Comitê de Ética em Pesquisa envolvendo Seres Humanos (Plataforma Brasil) – registered at no. CAAE:64811715.3.0000.5207.

This study was conducted in two different periods: the first one was between January and June of 2007 (period 1), and the second was from June, 2015 to February 2016 (period 2). The data collected in period 1 belongs to the database of Laboratory of Ecology and Evolution of Social-Ecological Systems (LEA-UFPE) and has free access to the student's lab. The researchers who collected the data in period 1 were contacted before the start of data collection in period 2, so that the same methodological procedures could be adopted. The strong bond that the research group of LEA-UFPE created with the community of Carão in 2007 cleared the way for our research group in 2015. Some researchers from 2007 also accompanied us during our first visits to Carão.

The study included all people older than 18 in the two periods (census): 104 people including 68 women and 36 men aged 18 to 90 in period 1 (Alencar et al., 2014), and 99 people including 51 women and 48 men aged 19 to 88 in period 2; a total of 63 people participated in the two periods.

Local knowledge of medicinal plants was gathered through semi-structured interviews (Albuquerque et al., 2014), which began with the free list technique (see Albuquerque et al., 2014): that is, informants were

asked to list the medicinal plants they were familiar with. In the interviews, the informants were asked about what illnesses each medicinal plant cited in the free list can treat. In period 2, we also asked them to name the source from whom they learned about each plant and who they would ask for help if they had to treat an unknown illness or if they wanted to learn about medicinal plants, and why. This latter question aimed to access their preferred model to search for information about health care and the reason behind it, thus revealing the influence of age, success, and prestige of the model. According to Henrich and Broesh (2011), asking the informants whom they would go to for cultural information, given what they currently know, avoids memory biases presented in other methods, such as recalling past learning.

In this study, we used the local classification of plants and diseases. Therefore, we took some time to standardize the local terminology of these variables. We sought help from three local specialists in order to confirm the names considered synonyms within the community, such as "imburana açu" and "imburana de cheiro."

2.3. Data analysis

To protect the privacy of respondents, we named each informant with a number that corresponds to the order in which they were interviewed (informant 1, informant 2...), as shown in Table 1. With their answers to the question "from whom they learned about each plant cited," we classified the transmission pathways according to their own perspective on which routes they used to learn about medicinal plants. Thus, we classified the pathway as vertical when they reported to have learned from their parents; horizontal when had learned from other people of the same generation in the community; and oblique when they had learned from older but nonparental people in the community.

With their answers to "who they would look for to treat a disease or learn about medicinal plants," we were able to list the main models consciously chosen to copy and the reason for that choice. After repeated qualitative analysis, models were classified as based on: age, when people choose to copy other people because of their age (for example, people "linked to older time"); familiarity, if the reason for the choice was look for a very close person or one from the same family (with answers such as "I have confidence in this person" or "it's my sister who lives nearby"); success and prestige, when people indicate that the other person has greater knowledge of medicinal plants (like "this person is more experienced with plants") or a high prestige in the community (like "this person has general knowledge"), regardless the prestige is related to his/her knowledge of medicinal plants. This included healers, midwives or those working at health center. We could not separate the prestige and success bias because we noticed that people often indicated a model for having great prestige, but did not mention their knowledge about medicinal plants, although it seemed clear that their prestige was because of great knowledge in the subject of medicinal plants (especially when they were local specialists).

With data from the free list, we organized matrices of the presence and absence of medicinal plants citation for each informant in the two periods. To quantify the similarity among people in the community, we used these matrices to obtain the similarity index with Jaccard coefficient in the two periods (Jaccard package - Chung et al., 2018). We compared the similarity value between people and their parents (n = 23, limited to those people who had parents in the community) with the average similarity value between the same people and other members of the community using the t-test to verify if people learn about medicinal plants mainly through vertical route. We did this analysis with data from period 2, because there was a greater number of parent-child pairs presented in the sample during this period. In addition, we quantified the transmission pathways according to their own perspective on which routes they used to learn about medicinal plants in period 2. We then compared the number of each transmission route with chi-square test.

To verify if the similarity between people and their parents decreased over time or remain constant, we used the t-test to compare the value of parents-offspring similarities between the two periods (n = 8, limited to people whose parents were present in the two analysis periods). We followed the same procedure to compare the values of similarities between people and their favorite models, which showed that transmission of knowledge is guided by model-based context bias. For this analysis, n was 42 (limited to those people who chose a model and were present in the two periods of analysis). However, we also performed this test only with the 8 people considered in the parents-offspring analysis.

To verify whether the model-based bias guided by success or prestige excels over other model-based biases in the transmission of information about medicinal plants, we quantified the number of times people indicated having a model and why they choose that model based on our classification (age, familiarity, and success or prestige). We assumed that the locals' subjective evaluations about prestige and success are accurate (Hill and Kintigh, 2009). We also verified the number of units of information (the binomial plants-disease) cited by the chosen models as being indicative of their success in the cultural domain of medicinal plants. We assume that if a person cited a large number of binomials, this would be an indication that this person would be a successful person in the cultural domain of medicinal plants. If these people had been chosen as a model by most people, possibly people would be choosing their models because of the success they have (seen by the amount of knowledge, i.e. the quantity of binomials).

To check if the vertical transmission is conservative or diffusive, we first checked whether information about medicinal plants referred to as learned from parents was also cited by parents. For this, n was 21 (limited to people who reported having learned information from parents and whose parents were present in the community). Among the medicinal plants that were actually cited by parents and offspring, we verified whether parents also reported that they had learned this plant from their own parents. We then used a chi-square text to compare the number of times parents reported they had learned from their own parents, indicating a conservative vertical transmission, with the number of times they reported they had learned through horizontal or oblique transmission, indicating a diffusive vertical transmission.

All analyses were carried out using software R, version 3.5.1 (R Core Team, 2018).

3. Results

The community recognized about 150 diseases, including many with recent onset, recognized in the last 5 years, such as Chikungunya, Zika, and some types of cancer. All these diseases have some form of treatment with medicinal plants, according to local citations. People mentioned 233 medicinal plants in period 1 and 190 in period 2 (162 were mentioned in the two periods). There were 908 citations of plants learned by vertical pathways and 733 by horizontal or oblique pathways; for 300 citations of plants, people could not remember from whom they had learned (Tables 1 and 2). Among the plants learned by the horizontal and oblique pathways, those learned from doctors and nurses are included. There was also mention of learning through a book (7 mentions) television (11), internet (1), radio (1) and magazine (3 mentions), all classified as horizontal or oblique pathways. There were 37 citations characterized as innovations, when people said they discovered about the use of a certain plant by themselves. Thus, the number of self-reported citations points out at a significantly higher number of vertical transmissions (X^2 = 18.662, p = 1.56e-05).

We verified that the similarity of knowledge between parents-offspring is greater than the average similarity between each offspring and other members of the community using a t-test (n = 23; t = -3.2253; p = 0.003893). The average similarity between parents-offspring was 0.204174 with SD = 0.099409 and the average similarity between offspring-other members was 0.1402154 with SD = 0.04228383, reinforcing the view that vertical pathway can be the main source of learning of medicinal plants.

Table 1. Informants in two different periods, the number of diseases for each plant (D), the number of medicinal plants mentioned (MP), the number of information units cited (IU), and their age.

Informants period 1	D	MP	IU	Age	Informants period 2	D	MP	IU	Age
Informant 1	7	9	8	53					
					Informant 105	5	8	9	22
Informant 2	7	8	9	19					
Informant 3	7	8	10	26					
Informant 4	11	9	12	34	Informant 4	14	22	39	42
					Informant 106	9	11	26	18
					Informant 107	6	5	7	23
Informant 5	5	5	5	33	Informant 5	6	7	10	41
Informant 6	19	34	43	20	Informant 6	43	70	109	28
					Informant 108	3	4	4	26
Informant 7	13	17	18	20	Informant 7	16	15	24	28
Informant 8	7	17	18	72	Informant 8	17	17	25	46
					Informant 109	3	4	4	58
					Informant 110	14	14	36	42
Informant 9	12	11	15	64	Informant 9	7	13	13	73
Informant 10	7	11	13	49	Informant 10	25	35	48	58
Informant 11	17	19	21	55	Informant 11	10	9	12	64
Informant 12	11	18	21	83					
Informant 13	2	5	5	43	Informant 13	12	15	23	53
Informant 14	35	48	63	71					
Informant 15	11	19	21	44	Informant 15	12	14	17	54
				31	Informant 111	5	5	6	25
					Informant 112	9	10	12	78
Informant 16	2	3	3	24	Informant 16	7	11	11	33
Informant 17	13	15	16	58	Informant 17	9	10	11	67
Informant 18	8	10	11	48	Informant 18	6	8	9	58
Informant 19	16	13	21	25	Informant 19	5	8	5	35
					Informant 113	6	10	10	25
Informant 20	3	5	6	18	Informant 20	4	5	6	44
Informant 21	12	11	15	35					
Informant 22 (resident B)	42	38	80	48	Informant 22 (resident B)	40	48	92	57
Informant 23	9	12	15	19					
Informant 24	1	3	2	24					
Informant 25	8	11	12	46	Informant 25	8	13	18	56
Informant 26	0	1	0	26					
Informant 27	10	8	14	19					
Informant 28	10	9	13	57	Informant 28	8	12	14	66
					Informant 114	12	13	24	34
Informant 29	10	17	16	67	Informant 29	22	36	42	75
Informant 30	6	6	9	43	Informant 30	4	9	10	52
Informant 31	18	25	33	46	Informant 31	11	13	23	54
Informant 32	13	20	25	59					
Informant 33	6	9	10	27	Informant 33	8	13	15	37
					Informant 115	6	7	8	30
Informant 34	26	24	34	75	Informant 34	13	14	26	84
					Informant 116	5	5	7	21
					Informant 117	2	3	3	24
Informant 35	17	17	26	48	Informant 35	10	10	14	58
					Informant 118	2	7	7	19
Informant 36	12	18	10	63					
					Informant 119	13	11	19	69
Informant 37	12	15	15	46	Informant 37	13	20	23	56
Informant 38	20	23	26	37	Informant 38	5	6	8	46
Informant 39	15	13	18	32	Informant 39	7	7	9	44
Informant 40	12	17	17	73					
Informant 41	12	13	16	68					
Informant 42	14	18	25	74					
Informant 43	8	12	14	65	Informant 43	6	8	11	75

(*continued on next page*)

Table 1 (*continued*)

Informants period 1	D	MP	IU	Age	Informants period 2	D	MP	IU	Age
					Informant 120	5	7	9	42
					Informant 121	3	3	4	20
Informant 44	9	16	11	66	Informant 44	1	6	6	77
Informant 45	15	24	27	68					
Informant 46	10	10	11	37	Informant 46	5	8	9	47
					Informant 122	2	6	6	24
					Informant123	10	12	17	60
Informant 47	11	16	18	26	Informant 47	11	11	16	36
Informant 48	12	16	21	79	Informant 48	8	10	15	87
Informant 49	21	34	38	59	Informant 49	15	22	41	67
Informant 50	16	19	24	54	Informant 50	14	29	35	63
Informant 51	10	10	13	32	Informant 51	8	10	10	40
Informant 52	13	13	16	70					
Informant 53	7	12	15	54	Informant 53	4	7	8	64
					Informant 124	13	13	15	73
Informant 54	25	31	40	44	Informant 54	17	16	31	53
					Informant 125	3	3	3	22
Informant 55	6	12	12	73	Informant 55	7	14	16	83
					Informant 126	1	1	1	20
Informant 56 (resident C)	75	97	170	59	Informant 56 (resident C)	30	36	48	67
Informant 57	10	12	14	37	Informant 57	18	23	42	46
Informant 58	15	16	21	83					
Informant 59	20	31	39	55	Informant 59	9	13	15	65
Informant 60	9	16	18	20					
Informant 61	2	2	2	19					
Informant 62	14	15	21	47	Informant 62	17	25	35	55
Informant 63	13	18	18	70					
					Informant 127	7	8	10	40
					Informant 128	10	14	17	82
Informant 64	28	40	50	63	Informant 64	8	25	27	
Informant 65	5	5	5	55	Informant 65	17	15	26	63
Informant 66	9	14	19	36					
Informant 67	13	21	22	78					
Informant 68	8	9	9	45	Informant 68	6	5	7	54
Informant 69	16	26	34	58	Informant 69	16	25	43	67
Informant 70	7	11	10	90					
Informant 71	6	12	14	53	Informant 71	7	10	16	62
Informant 72	4	5	3	27	Informant 72	6	7	8	35
					Informant 129	20	25	28	29
Informant 73	9	9	12	43	Informant 73	10	8	18	53
Informant 74	7	8	9	53					
Informant 75	23	21	28	48	Informant 75	14	20	28	57
Informant 76	17	15	22	87					
Informant 77	6	14	15	83					
Informant 78	10	13	18	37					
Informant 79	4	6	7	86					
Informant 80	5	8	8	28					
Informant 81	20	36	43	58	Informant 81	22	35	45	67
Informant 82	16	12	15	25					
Informant 83	13	18	20	61	Informant 83	12	13	20	69
Informant 84	11	8	13	45	Informant 84	20	16	32	54
Informant 85	9	16	17	40	Informant 85	6	6	8	48
Informant 86	9	11	14	55	Informant 86	10	12	12	57
Informant 87	9	20	23	68	Informant 87	13	19	31	77
					Informant 130	10	9	15	26
Informant 88	2	18	19	45	Informant 88	10	13	13	54
Informant 89	22	25	30	63	Informant 89	18	21	27	72
Informant 90	28	27	40	69	Informant 90	14	16	21	77
Informant 91	6	7	7	66					

(*continued on next page*)

Table 1 (*continued*)

Informants period 1	D	MP	IU	Age	Informants period 2	D	MP	IU	Age
Informant 92	13	17	19	41	Informant 92	8	8	11	50
Informant 93	10	9	14	38	Informant 93	2	6	7	47
Informant 94	13	19	17	77					
Informant 95 (resident A)	45	60	81	69	Informant 95 (resident A)	34	29	58	77
Informant 96	8	9	9	71	Informant 96	5	6	7	81
Informant 97	4	5	5	18					
					Informant 131	10	9	13	58
					Informant 132	22	20	32	39
Informant 98	16	24	28	31	Informant 98	15	25	27	41
Informant 99	10	18	19	43	Informant 99	9	13	14	52
Informant 100	21	28	36	67	Informant 100	10	13	16	75
Informant 101	12	9	15	35					
Informant 102	9	15	15	78	Informant 102	6	6	8	88
Informant 103	19	24	25	64	Informant 103	20	28	28	74
					Informant 133	11	9	17	74
Informant 104	7	8	8	24					
					Informant 134	6	6	8	28
					Informant 135	2	4	4	57

When verifying whether the similarity between people and their parents decreases over time, we did not find significant results ($t = -0.01038$; p-value $= 0.9919$), showing that the similarity between parents-offspring is maintained over time, and does not diminishes gradually. The average similarity between parents-offspring in period 1 was 0.20825, with SD = 0.06812122, and that in period 2 was 0.208625, with SD = 0.0713409. We also verified that the similarity between people and their preferred models was greater in period 2 than in period 1 ($t = -2.2644$; $p = 0.0262$), showing that people's knowledge becomes more similar to their models over time. The average similarity between people-models in period 1 was 0.1547143, with SD = 0.06876588, and that in period 2 was 0.1900238, with SD = 0.07405057; that is, people learn from their favorite models over time, but also retain what they have learned from their parents.

People reported choosing their models based on prestige or success 64 times, age 28 times, and familiarity 20 times. Some people indicated more than one model with different justifications, and others said they did not trust any person (see Table 2). There was no self-reported justification of the model chosen according to sex, gender, ethnicity, or educational level.

Among the 37 cited models (in 134 citations), the most were of informant 22 (57 years) and informant 95 (77 years), who were cited 25 and 23 times and knew a total of 92 and 58 units of information about medicinal plants, respectively (see Tables 1 and 2). They were at 2nd and 3rd place among those who cited more information about plants in period 2. Informant 6 (28 years) was more knowledgeable about medicinal plants in period 2, citing 109 units of information, but was not mentioned by anyone as a model. In period 1, informant 6 knew only 44 units of information, showing little knowledge. We noticed that after the research group's first visit in period 1, he became very involved with the researchers, and sought to broaden his knowledge on the topics covered in our research, especially on medicinal plants. This explains his great increase of knowledge between the two periods. In period 1, informant 22 and 96 knew 80 and 81 units of information, and were at 2nd and 3rd place among those who cited more information about plants, behind only informant 56 (68 years and 170 units of information), who was cited a model only once (Tables 1 and 2). It is important to mention here that locals considered informant 56 a witch and avoided talking to her. If we consider informant 56 as an outlier, due to her recognition as a "witch", our results show that the choice for the model is adaptive, since the more cited models showed to be most knowledgeable about medicinal plants.

Among people who had parents in the community, there were 160 self-reported citations of plant use learned vertically, and among these 160 citations only 86 were cited by their parents. Out of these 86, in only 49 citations did parents report having also learned from their parents, evidencing the conservative vertical pathway. In 37 citations, parents reported having learned from other sources, by horizontal or oblique pathways, evidencing the vertical diffusive route. We did not observe a significant difference between the number of purely conservative citations and the information coming from diffusive routes ($X^2 = 1.6744$, $p = 0.1957$). The 49 citations of purely conservative vertical information involved only 20 plants (see Table 3) and 14 of them were among the 20 most shared (most popular) medicinal plants in the two periods of analysis (see Table 3). All these plants are among the 50 most popular (of a total of 235 and 191 plants in each period).

4. Discussion

As per people's own perception, they mostly learn by vertical transmission. However, Aunger (2000) argues that there are biases in the self-reporting of transmission pathways that are overwhelmed by parental influence, especially if parents are normative authority figures in the cultural domain. In our case study, it did not seem like a norm that medicinal plant knowledge should be acquired specifically from parents. However, we complemented the self-reported data with statistical analysis of cultural similarity and saw that even if there is an overvaluation of parents' role in the self-reported learning route, people knowledge about plants is even more similar to that of their parents than the rest of the community. These two combined results allow us to corroborate the findings of previous studies on self-reporting about transmission routes (Lozada et al., 2006; Eyssartier et al., 2008; Hewlett and Cavali-Sforza, 1986; Soldati et al., 2015); that is, the transmission about medicinal plants occurs mainly by the vertical route.

Vertical transmission can result in a situation that inhibits the diffusion of innovations and diversification of knowledge within a group, making cultural evolution quite conservative (McElreath and Strimling, 2008). Conservative cultural evolution is favorable in stable environments (Cavalli-Sforza and Feldman, 1981), but it would negatively affect a medical system with slow responses to new diseases. However, our case study does not present Carão as a conservative medical system in a stable environment, with slow responses to disturbances. People of Carão already know how to treat relatively new diseases, such as Zika and Chikungunya, with medicinal plants. Furthermore, according to Henrich and Henrich (2010), if the cultural system is at equilibrium in stable environments, learners would not update the information learned from

Table 2. Models cited as preferred, the types of model-based biases according to justifications of each informant, and number of citations of each model for each type of bias.

Models	Model-based bias	Citations
Informant 10	success/prestige	4
Informant 15	familiarity	1
Informant 12	age	1
Informant 134	no answer	1
	age	1
	success/prestige	2
Informant 17	familiarity	2
Informant 18	success/prestige	1
Informant 22	no answer	1
	familiarity	2
	success/prestige	22
Drug Store	success/prestige	1
Informant 34	familiarity	1
	age	1
Informant 43	age	1
Informant 47	age	1
Informant 46	familiarity	1
Informant 48	familiarity	1
Informant 49	familiarity	1
Informant 50	age	1
	success/prestige	3
Informant 52	familiarity	1
Informant 53	familiarity	1
Informant 55	age	1
Informant 56	age	1
	success/prestige	2
Informant 62	success/prestige	7
Informant 65	familiarity	1
	age	1
Informant 63	no answer	1
	age	2
	success/prestige	1
Informant 75	familiarity	1
	age	1
Informant 69	age	1
Informant 83	age	3
	success/prestige	1
Informant 135	familiarity	2
Informant 87	age	2
	success/prestige	1
	familiarity	1
Doctors	no answer	1
	por exclusão	2
	success/prestige	3
I don't know	no answer	5
Informant 136	success/prestige	1
Nobody	no answer	4
	age	3
Any person	No answer	1
Informant 92	familiarity	1
Informant 95 (resident A)	familiarity	4
	age	6
	success/prestige	13
Informant 98	familiarity	1
Informant 102	familiarity	1
	age	1
	success/prestige	2

their parents, because parents would know all the information presented in the system and shared by everyone else in the community.

Instead, in our study, we have seen that there is an updating of knowledge throughout an individual's life. Our analysis show that what people learn from their parents remains, since there was no decrease in similarity between parents-offspring, but they also increase their knowledge over time. This finding, although it does not deal with data on childhood, corroborates with the idea that childhood is a critical development stage for learning, and after this stage, knowledge update happens more slowly (Ohmagari and Berkes, 1997; Tehrani and Collard, 2009; Hewlett et al., 2011; Hewlett and Cavali-Sforza, 1986). This idea is proposed in studies of other cultural domains, and we can extend it to the domain of health care.

The knowledge learned during the first stage of life corresponds to basic and elementary information required for the survival of the individual enculturation process (Hewlett and Cavali-Sforza, 1986; Aunger, 2000), and we can call this knowledge the structural core (see Ferreira Junior and Albuquerque, 2015). Knowledge about plants is an important part of the structural core and is transmitted as a priority because it contains the adaptive information necessary for the therapeutic needs of a medical system. This knowledge associated with plants is more conservative (Ferreira Junior and Albuquerque, 2015). These characteristics of the structural core may explain why similarity with parents prevails over time, and does not diminish as people give importance to other models.

However, the degree of reliance on vertical transmission should decrease as the number of alternative sources of cultural information increases (Aunger, 2000). The recognition that some members of the community are great references in the cultural domain of health care leads people to copy information from other models that are not within the family nucleus. Indeed, people in Carão showed themselves closer to the knowledge of their favorite models over time, revealing a copying strategy that is quite adaptive. Thus, despite the majority of knowledge coming from parents, there is a significant updating of this knowledge with information from other models throughout life, and this updating process refines previously acquired knowledge from parents (Henrich and Broesh, 2011).

About this updating process, Henrich and Broesh (2011) propose that success and prestige may be the main cues people use when learning about other cultural domains, but not about medicinal plants, since it is very difficult to quantify the success of a person by the efficiency in the cure of a disease. Nevertheless, they found that believing someone to be among the most knowledgeable about medicinal plants increases their chances of selection as models by 25 times. According to this idea, if it is difficult or impossible to know who the most knowledgeable about medicinal plants is, age will be indicated more often than success as a cue of a good model, and that is exactly what they found.

Our results show that prestige or success with medicinal plants was the main cue that influenced informants when choosing to copy from a specific model, i.e., people choose those people as models who they think to be the most knowledgeable in this domain. However, age has been quite cited in the community, but we consider this an indirect prestige-based model bias, since elders receive deference across many societies and domains (Henrich and Gil-White, 2001). Other works mentioned that higher the age, higher the knowledge about medicinal plants (Hanazaki et al., 2000; Almeida et al., 2012). Therefore, it is adaptive to seek older people who have greater life experience, which includes greater experience in treating diseases and knowledge to discern the best means of treatment.

In addition, independent of the self-reported cue by the informants, those people most indicated as models really are the most knowledgeable about this cultural domain, with only two exceptions. As Henrich and Broesh (2011) mentioned, it is very difficult to quantify the success of a person by the efficiency in the cure of a disease, but it may be an adaptive strategy to seek information from people who have the most knowledge, as one cannot see who has the most efficient treatment. It is important to

Table 3. Medicinal plants (MP) transmitted by conservative vertical route, the number of citations in each period (P1 and P2) and its position among the most cited each period.

MP	Citations P1	Citations P2	Position P1	Position P2
Alfazema de caboclo	3	5	40°	37°
Angico	31	37	14°	8°
Aroeira	81	81	1°	1°
Aloe	40	39	10°	7°
Caju roxo	41	43	9°	5°
Catingueira	45	36	7°	9°
Cidreira	53	50	5°	3°
Colônia	12	12	31°	31°
Eucalyptus	23	12	20°	32°
Large leaf mint	40	34	11°	11°
Small leaf mint	45	35	8°	10°
Imburana açu	62	57	2°	2°
Jatobá	32	26	13°	16°
Juá	58	32	3°	12°
Jucá	56	43	4°	6°
Jurema	17	4	26°	18°
Mulungu	18	14	25°	27°
Pega pinto	11	13	32°	29°
Quixaba	17	27	26°	14°
Velame	27	12	18°	35°

clarify that exceptions to the pattern of seeking information from experts in medicinal plants deserves attention because of these two instances: fewer citations of informant 56 who had greater knowledge about plant treatment in period 1, and the absence of citation of informant 6 who had more knowledge in period 2. With respect to informant 56, we believe that people's perception of her being a witch leads them to avoid obtaining this type of information from her. With regard to informant 6, he probably increased his knowledge about medicinal plants without informing other people in the community. Adding to this the fact that he is young, and the effect of age mentioned above, probably few people knew about his knowledge in the field of medicinal plants.

Therefore, we can say that the medical system is constructed primarily from information that comes from parents, but updating information with successful models is fundamental for adapting the system to new scenarios, such as the appearance of new diseases. However, complementing those results, we found that, even among knowledge exclusively transmitted by parents, only a part of it was conservatively transmitted, i.e., not all the information that the children learned from their parents came directly from the parents of their parents in a process of conservative vertical transmission. Part of the knowledge transmitted by parents to offspring was learned from someone outside the family, through diffusive vertical transmission, thus corroborating the proposals of Aunger (2000) and Soldati and Albuquerque (2016).

Although our data on this issue have major limitations as the data were based only on informants' self-report, we can sparingly discuss the evolutionary consequences of the vertical transmission pathway, which may not be as conservative as expected. If the vertical pathway is diffusive, as our data suggest, it does not inhibit the diffusion of innovations and diversification of knowledge. New information, learned by parents through horizontal or oblique transmission, is passed on to children by vertical transmission, and can reflect new environmental and cultural challenges. Our findings that the medical system of Carão can respond rapidly to disturbances, such as the appearance of new diseases, reinforce this view.

Another curious result of our study is related to the analysis of knowledge about the set of medicinal plants passed through the conservative vertical route. We found that this included knowledge about a small set of plants, which are actually the most popular plants in the medical system. According to the evolutionary implications of cultural transmission, we would expect that vertical transmission would promote heterogeneity in the medical system (Hewlett and Cavali-Sforza, 1986; Cavalli-Sforza and Feldman, 1981; Mesoudi, 2011), once the knowledge of each family remains within the family, not being twisted with other members of the population. Our findings show that conservative transmission (at least in the two generations studied and according to the memory of our informants), is related with the most popular knowledge being transmitted within each family. We can again associate this finding with the structural core. Using the ideas of Nairne and Pandeirada (2008) and Nairne et al. (2008) about adaptive memory, Ferreira Junior and Albuquerque (2015) propose that the plants with the greatest consensus represent a structural core that is responsible for the structure and functioning of the entire medical system. Plants in the structural core should be popularized and learned about by new generations primarily due to their local importance, and therefore they are less susceptible to replacement over time.

5. Limitations of the study

We assume that a study done at two different times with two different teams has limitations. In spite of our best efforts to minimize possible research biases, following the same procedures done by the researchers of period 1, we know that the application of the interviews by different people may lead to a loss of data. Beside that, the analyzes were based on the free listing, but it is known that the free listing method has a limitation associated with memory, since people are not really listing all their knowledge, but what they remember at that time. Nevertheless, as we analyzed the collected data, we observed that the mentions of plants and diseases followed the same patterns, them, in general, there was not a significant loss of information throughout the time.

6. Conclusion

All these results help us understand that there is a conservative structural core, composed of a small set of plants that is passed over several generations and probably remains over time with few variations. However, the medical system is still made up of a lot of new information updated by the parents themselves before they pass it on to their offspring, and their own offspring seek out new information with their

favorite models, based mostly on the prestige they have, a copy strategy which is quite adaptive.

We confirmed with a statistical analysis of similarity the predominance of vertical transmission in the transmission of knowledge about medicinal plants. However, with a deeper analysis over time, we could see that the similarity with parents does not increase during the life of an individual, while new knowledge is acquired through an adaptive model-based bias. Combined with the finding that even what is transmitted vertically is not purely conservative, we can conclude that the medical system analyzed is very flexible and open to innovations, much more than we would expect from a system that has vertical transmission as its main pathway of learning. This is an important case study on the transmission routes of knowledge about medicinal plants and presents a new perspective on the evolutionary implications of cultural transmission.

Declarations

Author contribution statement

U. Albuquerque: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

F. Santoro: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

L.S. Chaves: Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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