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Cultural transmission vectors of essential knowledge and skills among Tsimane forager-farmers

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ABSTRACT

Humans transmit cultural information to others in a variety of ways that can affect productivity, cultural success, and ultimately fitness. Not all potential transmitters are expected to be equally preferred by learners or equally willing to influence their culture acquisition. Across socioeconomic opportunities and ages in the human life course, costs and benefits to both learners and potential transmitters are expected to vary, affecting rates of culture transmission from different vectors. Here we examine reported patterns of culture transmission contributing to 92 essential skills among a sample of 421 Tsimane forager-farmers native to Bolivia. Consistent with the expectation that the costly provision of support and cultural information typically flows from older to younger generations in a subsistence society, we find that the development of essential knowledge and skills is primarily influenced by older same-sex relatives, especially parents. Grandparents are more often reported as transmitters for low-strength/high-difficulty skills that they have comparative advantage in, such as storytelling and musical performance. Though less frequent, same generation peers are more likely to provide discouragement in the learning process and to transmit modern, market-oriented skills. Our findings suggest that kinship, gender, generational seniority, and skill type together explain the vectors and styles of influence responsible for essential culture transmission. The multigenerational pedagogy documented here helps facilitate successful economic and social production in a complex skills niche dependent on multigenerational cooperation, such as observed in human hunter-gatherers and other subsistence populations.

1. Introduction

Culture is interpersonally transmitted information that is essential for human survival; it contains behavioral solutions for successful living that we could not likely discover on our own (Boyd & Richerson, 1985). Humans depend on culture to solve problems critical to survival, including how to acquire food, make and use tools, weapons, fire, cooking, clothing, and housing (Aiello & Wheeler, 1995; Holloway, 1981; Laland & Brown, 2006; Wrangham, 2009). Once received and developed, our embodied cultural knowledge and skills provide us opportunity: the more culturally competent can transmit their accumulated information and skill to less competent others in need. Before the advent of written language, mass printing, and electronic broadcast, the rudiments of cumulative culture in human societies were largely transmitted interpersonally from culturally competent influencers and then, along with trial-and-error learning, were practiced, mastered, and further developed by recipients (Thornton & Raihani, 2008; Tomasello, Kruger, & Ratner, 1993).

Interpersonal cultural transmission occurs through a variety of vectors and styles of influence. Culture is transmitted within or between generations—upwards from younger to older or downwards from older to younger. It is also transmitted based on gender, and kin relations, and can be described along three vectors: (1) horizontally (e.g. from same generation peers), (2) vertically (downward from parents to children), and (3) obliquely (e.g. downwards from non-parental older generation individuals) (Cavalli-Sforza & Feldman, 1981). Parents, older kin, and peers use instruction, correction, example, encouragement, and discouragement to influence the transmission of cultural information that recipients acquire through direct experiences, observations, and social interactions.

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To impart knowledge on novice learners, expert transmitters may need to pay costs and forgo productive opportunities. Costs are paid with efforts to direct a pupil's attention to relevant information, locations, and examples. Costs are also involved with efforts to provide direct instruction with coaching and evaluate feedback, and efforts to delegate tasks and provide play, on-the-job practice, and interaction opportunities for learners (Kline, 2015; Rendell et al., 2011; Stieglitz, Gurven, Kaplan, & Hooper, 2013). For the learner, there are also the opportunity costs of time spent listening, observing, and practicing newly learned skills.

The embodied capital theory of human life history evolution focuses specifically on those costs and on the benefits of skill and knowledge acquisition over the life course (Kaplan, 1996; Kaplan, Hill, Hurtado, & Lancaster, 2001; Kaplan, Hill, Lancaster, & Hurtado, 2000; Kaplan, Lancaster, & Robson, 2003; Kaplan & Robson, 2002; Robson & Kaplan, 2003a). Embodied capital can be thought of as a stock of somatic capital, including muscle, fat, and immune cells, as well as skill and knowledge programmed in the brain and housed throughout the soma. The theory models both investment in own embodied capital, and also investments in descendants' capital in terms of a 'dynastic' (i.e. multi-generational) fitness function. However, most models of cultural transmission and evolution do not consider variation in costs and benefits to both learners and transmitters. A principal goal of this paper is to integrate embodied capital theory with cultural evolutionary theory by exploring who transmits the many diverse essential skills and types of knowledge among Tsimane Native South Americans in Bolivia. The Tsimane practice a mixed forager-farmer economy and are undergoing socioeconomic change towards greater market integration. This mix requires that Tsimane acquire and develop the traditional skillset associated with foraging, horticulture, food processing, childcare and reproduction, crafts and chores, music and oral tradition, as well as some new skills associated with market involvement.

Our overarching hypothesis is that the benefits and costs of learning and transmitting information will shape the principle vectors of transmission among the Tsimane, and more generally, in most societies. From the benefit side, we consider who will be the most effective transmitters and from the cost side, we consider who will be most willing to bear those costs and for whom will transmission influence be least costly. The application of this logic to the set of skills and knowledge that Tsimane acquire generates three predictions that we test below.

The paper proceeds as follows. We first review background literature on transmission vectors and cultural influence, both theoretical and empirical, and then link those findings to skill development, intergenerational transmission of food energy among the Tsimane, and embodied capital theory. We then present the hypothesis and three predictions to be tested, followed by the empirical analysis of transmission vectors and their patterning. We conclude with a discussion of the implications of our findings and directions for future research.

2. Background

2.1. Transmission vectors and cultural influences

Unlike genetic transmission which exclusively occurs from parent to offspring, cultural transmission allows the exchange of important information between a variety of human relations. In contrast to the short-lived horizontal transmission more commonly seen among other mammals (Fragaszy & Perry, 2003), humans transmit complex information across generations and to a great degree downwards, from older to younger, via vertical and oblique vectors (Cavalli-Sforza & Feldman, 1981; Garfield, Garfield, & Hewlett, 2016; Lozada, Ladio, & Weigandt, 2006; MacDonald, 2007; Ohmagari & Berkes, 1997; Reyes-García et al., 2009; Ruddle & Chesterfield, 1977). Additionally, as a result of opportunities made available by gender-divided skill and knowledge domains, transmitters and receivers across cultures are most often same-sex (Borgerhoff Mulder et al., 2019; Hewlett & Cavalli-Sforza, 1986; Reyes-García et al., 2009; Schniter, Wilcox, Beheim, Kaplan, & Gurven, 2018). While inclusive fitness benefits can favor teaching related learners (Cavalli-Sforza & Feldman, 1981), the settings provided by a particular group's subsistence system have great impact on the socio-ecology of interaction opportunities where culture can be transmitted (Hewlett, 2016; Lew-Levy et al., 2022; Whiting & Whiting, 1975). For example and in contrast to forager societies where families provide childcare and traditional education, consider the high frequency with which costly childcare and education is provided for fee by non-parental sources in wealthy industrialized societies.

Theoretical work shows that different transmission vectors are favored under different conditions and that no single transmission vector should be expected to dominate over others for all knowledge and skill domains (McElreath & Strimling, 2008). For example, concerning solutions to new problems, we might expect a preference for culture transmitted from individuals other than parents and older kin (Aunger, 2000; Henrich & Gil-White, 2001; Hewlett, 2016). Transmission vector variation can affect the spread and conservation of cultural traits over time and space. For example, stylistic similarity of Conambo pottery bowls between female potters in the Ecuadorian Amazon changes for potters at different ages, suggesting life-stage changes in stylistic influences due to status and social-network composition (Bowser & Patton, 2008). Given the importance of cultural conservation and development efforts, there is great interest to develop predictive models explaining variability in transmission contributions. Debate has ensued concerning which vectors are most influential for the transmission of traditional culture in foraging societies and how we can best study their influences on cultural transmission (Harris, 1998; Hewlett & Cavalli-Sforza, 1986a; Kline, 2015).

Compared to the passive role of transmitters in animal cultures, humans are more actively involved in information transfer and pedagogy to facilitate culture transmission and enhance the speed of skill acquisition (Csibra & Gergely, 2006, 2011; Gurven, Davison, & Kraft, 2020; Strauss & Ziv, 2012; Thornton & Raihani, 2008). Among subsistence populations, various forms of helpful teaching have been identified, including instruction, example, encouragement, and negative feedback (Boyette & Hewlett, 2017; Hewlett, Fouts, Boyette, & Hewlett, 2011; Hewlett & Roulette, 2016; Kline, Boyd, & Henrich, 2013). Pedagogy is not without its costs, however, which may explain why ethnographic reports of active teaching among foragers are rare (Blurton Jones & Konner, 1976; Gould, 1969; Premack & Premack, 1998). Pedagogy can be costly for the teacher when behavior is explicitly modified in the presence of the pupil to make its procedures more safe or salient, when the teacher requires extra time and effort to reference things, or when the teacher needs to model the limits and constraints of the pupil so as to provide them appropriate examples and tests of understanding or awareness (Caro & Hauser, 1992; Kline, 2015). Despite its rarity, costly pedagogy requiring communication is more expected for skills requiring greater investment to accurately transmit, acquire, and develop, and when teacher opportunity costs are low or can be recouped once the learner improves their skills (Csibra & Gergely, 2011; Fogarty, Strimling, & Laland, 2011; Gurven et al., 2020; Hoppitt et al., 2008; Montrey & Shultz, 2020). Consistent with these predictions, Dira and Hewlett's (2016) study of Ethiopian Chabu foragers and Lew-Levy et al.'s (2022) study of BaYaka foragers from Republic of the Congo both show that costly teaching such as verbal instruction are important elements of adolescents' spear hunting skill acquisition.

Age and sex determine a number of interpersonal asymmetries between culture transmitters and learners in skill proficiency, knowledge, strength, dexterity, economic productivity, and kinship connections that further affect pedagogical opportunities. For example, stocks of embodied capital in the form of strength, dexterity, and knowledge change throughout adulthood resulting in mid to late-adult peaks in many forms of productivity (Gurven, Kaplan, & Gutierrez, 2006). Additionally, adults' pedagogical availability tends to increase with later ages: not only do patterns of social exposure broaden to include

more variety of interactions in adulthood, kinship connections within the local community often increase with age affecting opportunities for investment in shared fitness interests (Koster et al., 2019). These changes affect production opportunities (Gurven et al., 2020; Stieglitz et al., 2013), cultural competence, and transmission opportunities (Schniter et al., 2018; Schniter et al., 2021; Schniter, Gurven, Kaplan, Wilcox, & Hooper, 2015), generating differential costs and benefits of providing and receiving caloric and cultural resources for potential interaction partners.

A variety of ethnographic examples highlight differential opportunities for influence that can lead to cultural transmission patterns other than parent-to-offspring. In one common pattern reported, when not in the company of adults, children may learn and develop subsistence skills with the help of same generation peers (Boyette & Hewlett, 2017; Crittenden, 2016; Lew-Levy, Reckin, Lavi, Cristóbal-Azkarate, & Ellis-Davies, 2017). Among Central Kalahari San foragers older children transmit tool manufacture skills to younger children through both example and correction (Imamura & Akiyama, 2016). Among Q'eqchi' Maya subsistence farmers in Belize children learn important subsistence skills concerning identification and use of garden plants from older siblings and age peers (Zarger, 2002). Among Kpelle subsistence farmers in Liberia children regularly teach one another subsistence skills during the course of their daily play (Lancy, 1996). Martu forager children learn how to hunt lizards without adults and with older children playing key roles in those learning experiences (Bird & Bliege Bird, 2017). Another common pattern reported is for children to learn subsistence skills from non-parental older relatives. Among Chabu hunter-gatherers oblique transmission is more common than vertical or horizontal transmission for adolescents learning to spear hunt (Dira & Hewlett, 2016). Among the Tsimane forager-farmers, transmission of ethnobotanical knowledge and skills is mostly oblique (Reyes-García et al., 2009), as is transmission of traditional stories (Schniter et al., 2018). As several have suggested, these oblique patterns may apply to more difficult and complex skills acquired later in life being while the horizontal patterns apply to simple skills acquired early (Aunger, 2000; Henrich & Broesch, 2011; Hewlett et al., 2011; Reyes-García, Gallois, & Demps, 2016).

The information exchanged by various vectors can be facilitated and influenced in a variety of ways, such as by instruction, correction, discouragement, encouragement, and example. Instruction (Guglielmino, Viganotti, Hewlett, & Cavalli-Sforza, 1995; Pinker & Jackendoff, 2005; Tomasello et al., 1993), whether verbal or demonstrative, is a form of deliberate pedagogy that involves intentional ostentation, reference, and transmission of generalizable knowledge (Csibra & Gergely, 2006, 2011; Scalise Sugiyama, 2021; Thornton & Raihani, 2008). Correction or interactive coaching involves monitoring learners' efforts and interacting with the learner to assess their knowledge level and comprehension (Tomasello et al., 1993). Helpful correction and coaching require sophisticated attribution of knowledge to the learner and appropriate responses that provide evaluative and corrective feedback (Pearson, 2016; Premack, 1984; Premack & Premack, 1998). Instruction, correction, and coaching are often scaffolded by encouragement and discouragement through verbal feedback and approval or disapproval (Barnett, 1977; Castro & Toro, 2004; Pinker & Jackendoff, 2005; Thornton & Raihani, 2008). Helpful discouragement of inefficient or harmful behaviors may be useful for avoiding dangers, costly errors, and guiding the healthy learning and productive skill development of novices. Competitors may also rely on forms of discouragement, but for different reasons. Among both non-human and human primates, unrelated peers seeking to gain competitive advantage may discourage or aggressively punish others to inhibit skills acquisition and proficiency development among competitors (Barnett, 1977; Castro & Toro, 2004; Thornton & Raihani, 2008). Finally, cultural information is often a leaky good that broadcasts beyond intended recipients who can observe skill performance or the resulting products (Morris & Schniter, 2018). As such, less complex knowledge and skills could also be efficiently transmitted by example – providing opportunities for those who are more frequently encountered to influence information transmission. Among most animals, the transmission of information that facilitates reproduction and survival does not involve instruction and correction but rather depends on observation of conspecifics' examples (Galef, 2012).

What is less clear from the growing human social learning literature is whether variation in identified cultural transmission vectors across populations is due to ecological and sociocultural variation, or due to research method. Prior research has been limited by its narrow foci (e.g. few types of cultural influence investigated, few types of knowledge or skill investigated, multiple responses not allowed and recorded, limited observations), social desirability and demand effects stemming from a reliance on self-reports and nominations (e.g. strong norms of filial piety might encourage reporting parents and grandparents as transmitters), and narrow participant sampling (e.g. children or adults only, when preferred transmission vector may vary with age).

2.2. Skill development, intergenerational transmission of food energy among the Tsimane, and embodied capital theory

While social learning is well underway during childhood, skill acquisition and mastery is often strength-dependent, cognitively difficult, and time-intensive (Bock, 2005; Gurven et al., 2006; Kaplan et al., 2000; Liebenberg, 1990). Many important skills cannot be mastered until the necessary strength and size needed for coping with dangers, independent performance, and dedicated practice have been developed. Often, this does not occur until after the adolescent growth spurt, when adult stature is nearly attained (e.g., see Hewlett & Cavalli-Sforza, 1986; Ohmagari & Berkes, 1997; Ruddle & Chesterfield, 1977). As such, older kin are particularly well situated to fill supporting roles for children, providing needed resources and masterful guidance (Gurven et al., 2020; Schniter, 2014; Schniter et al., 2018).

For example, among Tsimane forager-farmers, juveniles are relatively unskilled at food production, craft production, and providing themselves the care they need. With little ability to provide themselves food, Tsimane youngsters consume more than they are able to produce for themselves during their first two decades of life (Gurven, Stieglitz, Hooper, Gomes, & Kaplan, 2012). The majority of caloric food transfers that support these dependent young are made across three generations within extended families (Hooper, Gurven, & Kaplan, 2014; Hooper, Gurven, Winking, & Kaplan, 2015). Of the calories transferred to feed an average offspring's demands (beyond what they can provide for themselves), approximately 69% are flowing downward from older kin within families (Hooper et al., 2014).

The Embodied Capital Model (ECM) proposes that several unique features of the human life course are adapted responses to a skills-intensive socio-ecological niche (Kaplan & Robson, 2002; Kaplan, Gurven, Winking, Hooper, & Stieglitz, 2010). The ECM hypothesizes that human's extensive provisioning of both material resources and cultural competence to pre-reproductive dependents is a strategy to support their learning and on-the-job training (Gurven et al., 2020; Schniter et al., 2015). These support costs paid by parents and older kin are later offset by offspring's increasing surplus returns over the long reproductive and post-reproductive life span (Kaplan et al., 2000; Robson & Kaplan, 2003b). The ECM also hypothesizes that the life course of skill performance is shaped by characteristics of specific tasks (i.e., their difficulty, strength, motor dexterity, and knowledge requirements) and the changing needs of the family budget (Bock, 2005; Crittenden, 2016; Gurven & Kaplan, 2006; Schniter et al., 2015). During child-rearing years, parents' productivity increases to meet the growing needs of dependent children such that parents maintain peak levels of productive output from roughly the ages of 35 to 45 when net caloric demands of dependents are highest (Gurven & Kaplan, 2006; Gurven & Walker, 2006). Due to the opportunity costs associated with pedagogy, parents experiencing high productivity tend to delegate more tasks to others in the household (Stieglitz et al., 2013), encouraging a division of labor

which might also involve non-parental relatives influencing the skill acquisition of youngsters. As adults become grandparents and age into their post-reproductive years, declines in a number of physical attributes such as strength and endurance reduce the profitability of performing strength-intensive production skills. In response to these declines, older adults shift their efforts towards low-strength yet knowledge-intensive skills where they may develop comparative advantage. Schniter et al. (2015) show that, consistent with self-reports, older Tsimane adults are regarded by their peers as experts in low-strength but knowledge-intensive skills. In particular, the oral tradition (storytelling, musical performance, dream interpretation) provides a specialized late-life pedagogical niche for Tsimane adults who have accumulated important experience and knowledge relevant to foraging and sociality but have lost comparative advantage in other productive domains (Schniter et al., 2018). According to this ECM perspective, the life course of skill transmission contributions is likely shaped by changes in transmitter and receiver embodied capital, characteristics of the specific tasks transmitted, and the tradeoffs between opportunities for interpersonal transmission and productivity.

3. Hypotheses and predictions

We test predictions based on hypotheses highlighting the ways kinship, sex, seniority, and skill type affect the costs and benefits for different styles of culture transmission influence (instruction, correction, example, encouragement, discouragement) for different transmission vectors (vertical, oblique, grandparental, horizontal).

3.1. Effects of kinship, sex, seniority, and skill type on transmission vector and influence

Our over-arching hypothesis is that transmitter and skill characteristics affect the costs and benefits of different styles of culture transmission influence, which in turn affects the frequency that informants report different vectors and relationships in our study. Ceteris paribus, closer kin should provide reliable cultural information –they have locally relevant knowledge, share common interests, and have little incentive to provide dishonest information—and should be more willing to endure pedagogical costs due to shared genetic interests. In gender-divided socioecologies, same-sex others have the greatest opportunities for influencing cultural transmission due to more time shared in same-sex settings and greater experience with sex-appropriate knowledge and skills. Beyond time shared in same-sex settings, we expect cross-sex transmission where shared time allows opportunity for cross-sex learning, such as when males learn childcare skills from their primary female care givers. Transmitters from older generations than the informants' generation should have greater accumulated knowledge and experience with traditional skills and greater availability due to fewer opportunity costs with strength-intensive production alternatives. As such, transmitters' kinship, same-sex, and seniority to informants should explain the likelihood of being reported as a transmitter. Beyond these general expectations, we consider how opportunities for influencing the transmission of specific types of skill (i.e., modern and market, traditional, oral tradition and vanishing) might change the specific transmission vectors and styles of influence that informants report for those skills, leading to nuanced deviations from the general pattern of same-sex, older generation, kin-based transmission.

3.2. Predicted reports of vertical transmission

(P1) Over all traditional skills (i.e., skills not categorized as "modern" and "market activity") and influence types, parents, because they are closer kin with more shared interests and have greater experience than the younger generation, should be reported more as transmitters than other categories of kin.

3.3. Predicted reports of oblique transmission

(P2.1) The proportion of kin from older generations reported as transmitters for low-strength/high-difficulty traditional skills will be greatest for those skills compared to all other skills because older adults have comparative advantage with those skills. **(P2.2)** Likewise, because of their comparative advantage with low-strength/high-difficulty "oral tradition" and traditional skills suspected to be "vanishing", the share of grandparent transmitter reports will be highest for those skills compared to all other skills.

3.4. Predicted reports of horizontal transmission

(**P3.1**) We predict a greater share of reported horizontal transmission for skills related to modern aspects of the socio-economy (i.e., skills categorized by Schniter et al. (2015) as "modern" and "market activity"), than for the traditional skills that have changed little in generations because horizontal transmitters are more likely to provide solutions to new problems than transmitters from older generations. (**P3.2**) Reports of discouragement should be higher for non-family peers who are more likely than family to have competing interests and to use discouragement in an effort to inhibit skills acquisition and proficiency development among competitors.

4. Methods

4.1. Study population

Our study was conducted among the Tsimane, forager-farmers inhabiting the southern reaches of the Amazon Basin in central Bolivia. Tsimane assume semi-sedentary residence in 90+ kin-based villages (most between 50 and 250 people) that vary in river access, surrounding game densities, recent local deforestation, and access to market goods. Ninety-two percent of the Tsimane diet derives from nonmarket sources (Kraft et al., 2018): foods from family-maintained fields including rice, plantains, corn, and sweet manioc, hunted game, fish and foraged fruits, nuts and honey. To meet their subsistence challenges, Tsimane pass on a rich body of knowledge that informs youngsters who eventually will master the necessary production, extraction, and processing techniques after years of practice. Over the life course Tsimane also transmit and develop knowledge and skills in the domains of childcare and reproduction, household chores and craft production, social and market skills, music performance, and storytelling. This wide variety of essential knowledge and skills for Tsimane living is described in Schniter et al. (2015). In this study we focus on the reported transmission of that skill set.

Opportunities for cultural transmission occur wherever Tsimane interact with or observe one another: at home, while working in fields or in the forest, at play, and while socializing. Tsimane show a clear division of productive labor, with men and women spending about equal amounts of time in complementary but specialized activities and with roughly half of all work activities highly segregated by sex (Gurven, Winking, Kaplan, von Rueden, & McAllister, 2009). Tsimane children spend more time engaged in play with same-generation peers (e.g. siblings, nonfamily friends) than in productive activities with family members (Stieglitz, 2009). Socializing occurs primarily among families and extended kin networks, but also by visiting neighbors, nearby towns, and by maintaining relationships with merchants, ranchers, and loggers (Miner, Gurven, Kaplan, & Gaulin, 2014). At large gatherings, older adults often perform music and tell stories (Ellis, 1997; Schniter,

2014).

4.2. Sample and Survey

Using the *Skills Survey* reported by Schniter et al. (2015), 421 participants (51% male) aged 15–86 from 8 villages were interviewed at their homes by the lead author with assistance of Tsimane research assistants. Participants and their family units were identified from Tsimane Health and Life History Project demographic information. Our interviews identified vectors and types of influence responsible for the transmission of 92 skills. The *Skills Survey* inquired about sex-appropriate knowledge and skills deemed important by Tsimane focus groups: a total of 81 skills for males and 62 skills for females; of which 30 skills were specifically "male-only" and 11 "female-only", with the remaining 51 appropriate for both-sexes. For each skill we consider a number of skill attributes previously determined by Schniter et al. (2015): whether it requires high strength requirement or not, its difficulty score (based on informants' learning and performance difficulty evaluations), and associated skill category ("modern and market", "traditional", "oral tradition" and "vanishing", "childcare and reproduction") (see Table A.1 for details). Most (86/92) of the knowledge and skills studied are "traditional". Six modern and market skills are not traditional and include getting to San Borja (the regional market and government center), collecting government subsidies, organizing community members, finding work with traders, loggers, and ranchers, using a machine to harvest crops, and selling products. Thirteen oral tradition skills include making various musical instruments, playing music and singing, knowing and telling stories, and interpreting dreams. A minority (11/86) of the traditional knowledge and skills are suspected to be vanishing (no longer being learned and acquired) with younger generations. These vanishing skills include identifying medicinal plants and handmaking traditional clothes, tools, and musical instruments that are now more readily acquired via market sources. Ten childcare and reproduction skills include various kinds of knowledge and experience with sex and reproduction as well as various skills involving feeding and caring for babies and children.

For each skill in the interview that the participant indicated having, the following five transmission questions were asked in Tsimane or Spanish (filling in missing detail with reference to the skill inquired about) (1) "Who taught you to…?", (2) "Who corrected you while you were learning to…?", (3) "Who did you watch while learning to…?", (4) "Who motivated or encouraged you while learning to…?", and (5) "Who discouraged you while learning to…?". For each of these questions, up to three responses were recorded by noting the reported transmitter's relationship type. For each relationship type we have determined the transmitters' corresponding transmission vector (up or down, and vertical, oblique, or horizontal) as defined by Cavalli-Sforza and Feldman (1981), their seniority (horizontal vectors are considered same generation, downward vertical and oblique vectors are considered older generation and senior), and their sex. Close kinship among consanguineal relatives is assessed by the coefficient of genetic relatedness (r) (Wright, 1922) between transmitter and informant. Affinal relatives include spouses, stepparents, and kin from the spouse's perspective (as with in-law relations) or the stepparent's perspective (as with step-relations) (see Table A.2).

4.3. Consent, permitting, and data availability

Verbal consent was attained on three levels: the Tsimane governing council, village-level approval by leaders and community members, and from each participant individually. Internal review board approval was granted by the University of California, Santa Barbara. The data and code for statistical analyses are available at https://doi.org/10.5281/zenodo.6687745.

4.4. Statistical analyses

We use multilevel binary logistic regression analysis to model the reported parental, oblique, grandparental, and horizontal transmitters of Tsimane skills using variation in skill characteristics (strength requirement, difficulty), and skill categories (traditional, oral tradition and vanishing, modern and market). Each informant may provide multiple reports and informant age may affect reporting, so we nest the outcome variable at the level of the individual informant and control for age. We assess four classes of models of cultural transmission vectors, predicting: (1) parents reported as transmitters for traditional skills, (2) non-parental older generations kin reported as transmitters of low-strength/high-difficulty traditional skills, especially oral tradition and vanishing skills, (3) grandparents reported as transmitters of low-strength/high-difficulty traditional skills, especially oral tradition and vanishing skills, and (4) same generation peers reported as transmitters of modern and market activity skills. All models presented in this study can be replicated using the statistical and data files presented as electronic supplementary materials. All analyses were performed using IBM SPSS Version 24.

5. Results

We first review whether evidence supports our overarching hypothesis: that same sex older generation close kin are most likely to be reported influencing knowledge and skill acquisition. Next, we review evidence relevant to each of our transmission vector predictions.

5.1. Do same sex, closer kin, of older generations have the most reported influence on the acquisition of essential Tsimane knowledge and skills? Yes

94.8% of all culture transmission reported by participants is within families: 87.3% from consanguineal kin, 7.5% from affinal kin, and 75% from older kin (see Fig. 1). Female informants report 69% transmitters of the same sex and male informants report that 76% transmitters are the same sex. The five family members most frequently reported as transmitters by female informants are mother (35%), followed by father (18%), aunt (10%), grandmother (7%), and sister (7%) (see Fig. 2a). The five family members most frequently reported as transmitter by male informants are father (31%), followed by mother (14%), uncle (14%), brother (9%), and brother-in-law (5%) (see Fig. 2b).

We summarize the characteristics of transmitters reported by male and female informants (Table 1): For both females and males, the average transmitter tends to be close kin, same sex, and from an older generation.

5.2. Is vertical transmission from parents reported more than transmission from other kin categories over all traditional skills and influence types (P1)? Yes

We evaluated whether parents are the most reported transmitters among all kin over all 92 skills as well as over a subset of 86 traditional skills. As detailed in Table 2, vertical transmission reports (i.e., of parent transmitters) were the most reported vector across all skill categories. We also inspected these reports by response order (Table A.3) and found that the most reported transmission vector among first responses (comprising 51% of all responses) was vertical, the same vector most reported among all latter responses. Among traditional skills, parents were the most reported (49%)—more than other older generation kin (26%), same generation kin (20%), and younger generation kin (<1%)—over all essential Tsimane skills and abilities. Parents are also

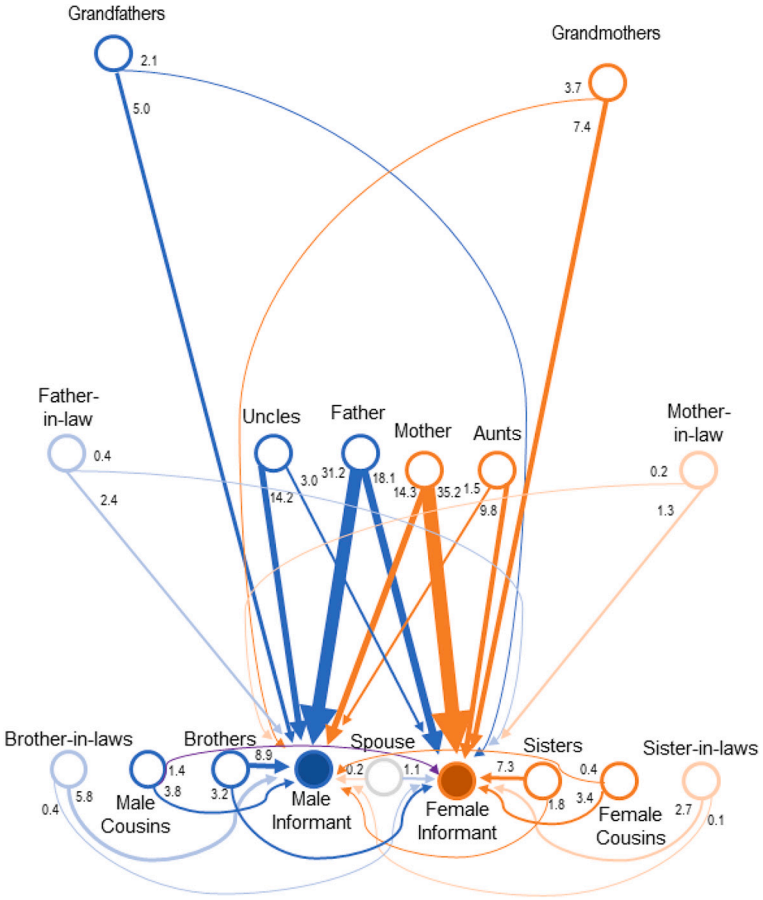


Fig. 1. Proportions of all transmitters reported influencing cultural transmission are shown. Values are percentages of all reported cultural transmission flowing to male and female informants from three generations of kin relations in extended Tsimane families. 94.8% of culture transmission reported is within families (87.3% is consanguineal kin, 7.5% is affinal kin) and 75% is from older kin.

the most reported transmitters of skills in the categories of childcare and reproduction (49%), vanishing skills (41%), and modern and market skills (48%). A logistic regression indicated that parent (vs. nonparent) transmitters were 1.2 times more likely to be reported as transmitters for traditional skills than for modern and market skills ($p < .001$) (Table A.4). Additionally, informant age had a very weak negative effect on vertical transmission reports ($p = .034$, OR = 0.990).

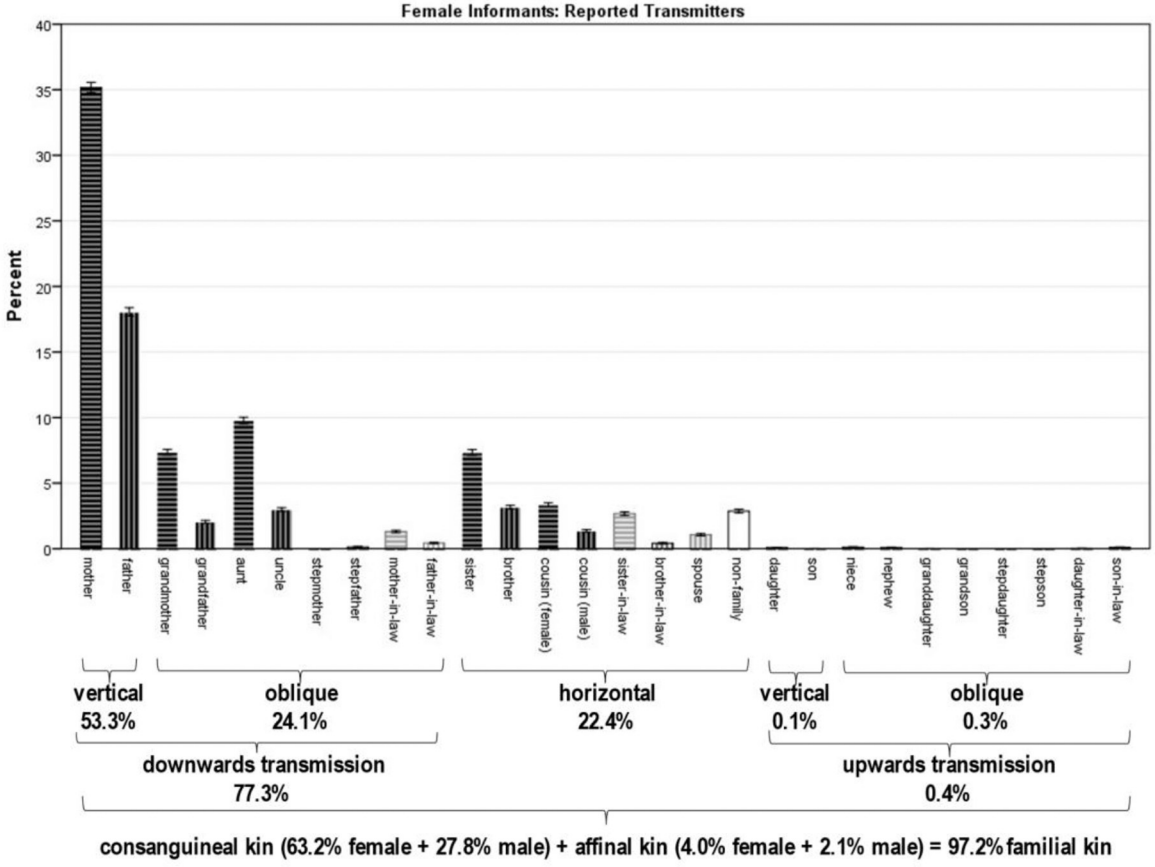
Next, we evaluated transmission vectors reported for each of the five different types of transmission influence studied. Parents were the most reported kin relation among transmitters of traditional skills reported for each of the styles of influence: instruction (58%), correction (49%), example (40%), encouragement (49%), and discouragement (32%) (Table 3). For traditional skills learning among female informants, female consanguineal and affinal kin contributed more instruction, correction, example, and encouragement than did male kin, and among male informants, male consanguineal and affinal kin contributed more of each of these styles of influence than did female kin (Table A.5). And while female consanguineal kin provided more discouragement to female informants than did male consanguineal kin, male affinal kin (79% brother-in-law, 11% son-in-law) provided more discouragement to female informants than did female affinal kin (Table A.5).

We also evaluated how often same-sex transmitters are reported across skill categories. Female informants report a greater share of transmission from female kin rather than male kin for traditional skills (68% vs 29%), oral and vanishing skills (58% vs 38%), and childcare and reproductive skills (70% vs 16%) (Table A.5). Conversely, male informants report a greater share of transmission from male kin rather than female kin for modern skills (72% vs. 16%), traditional skills (71% vs 22%), oral and vanishing skills (78% vs 12%), and childcare and reproductive skills (45% vs 36%). Exceptional to this same-sex trend is that, for transmitters of childcare and reproductive skills, male informants report mothers more than fathers (24% vs 21%) and grandmothers more than grandfathers (3% vs. 2%) (Table A.6).

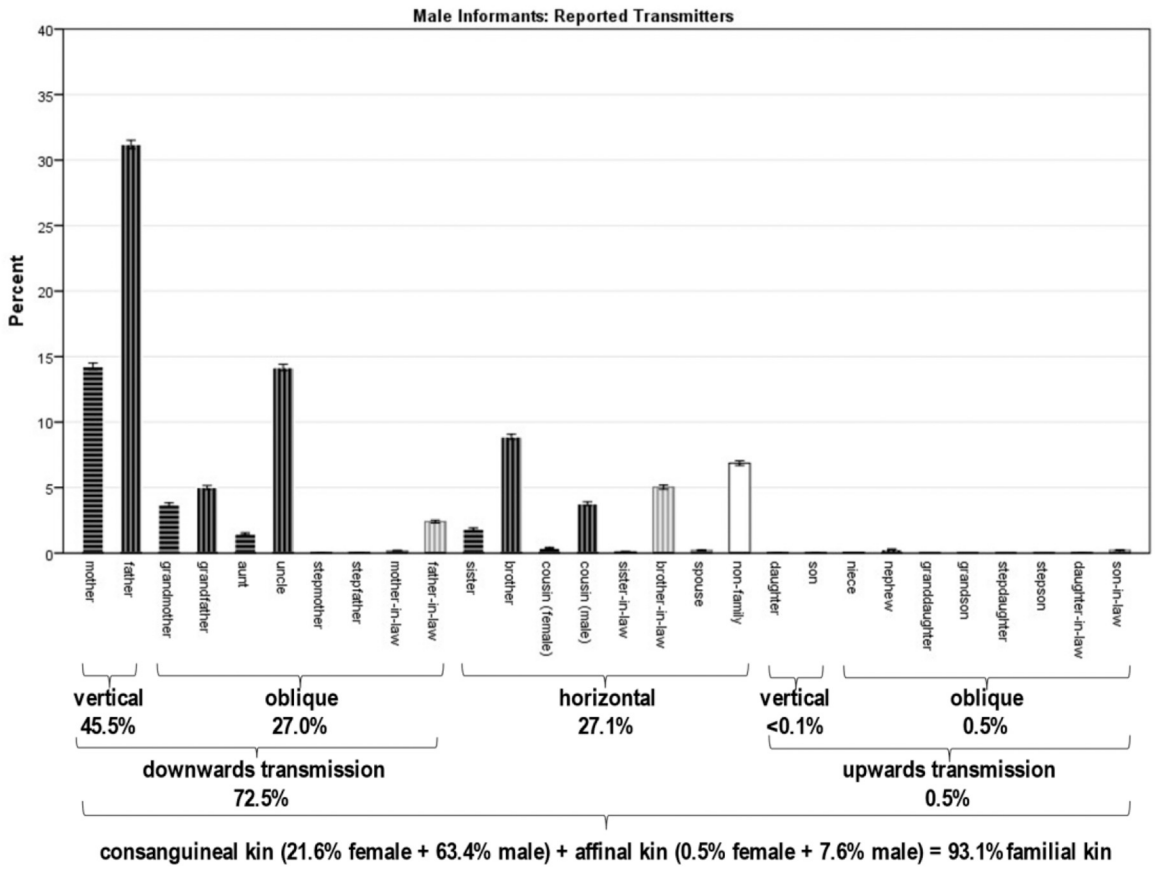
Among oblique transmitters of traditional skills, the most frequently reported transmitters were aunts and uncles (56%), followed by grandparents (36%), in-laws (8%), and stepparents (<1%). While the number of available aunts, uncles, and other relatives varies by participant, there will be fewer close kin ($r \leq 0.5$) than more distant kin available, on average. Considering the risk set of eligible kin to calculate the likelihood that a single individual of that kin category is reported would only exaggerate the effects shown here favoring close over distant kin.

While oblique transmitters were reported influencing all types of traditional skill transmission that we investigated (26% of all reports), they are more influential compared to horizontal transmitters with instruction, correction, and example than with encouragement and discouragement (Table 2). In particular, oblique transmitters' most influential contribution to traditional skill transmission is by example

(a)



(b)



(caption on next page)

Fig. 2. Panel (**a**) shows female informants' reports and panel (**b**) shows male informants' reports. Error bars are 95% confidence intervals. Horizontal hashing represents female transmitters, vertical hashing represents male transmitters, dark grey bars represent consanguineal kin, light grey bars represent affinal kin. Most transmitters reported by females are family members (97.2%) and same sex (69.2%); 53% are parents, 24.1% older generation kin, 19.5% same generation kin, and 2.9% non-kin. Most transmitters reported by males are family members (93.1%) and same sex (76.3%); 45.5% are parents, 27.0% other older generation kin, 20.2% same generation kin, and 6.9% non-kin.

(32% of all example reports), nearly as influential as parental example (40% of all example reports) (Table 3). In contrast, horizontal transmitters affecting the acquisition of traditional skills were most likely to use discouragement, more than instruction, correction, example, and encouragement. In particular, non-family horizontal transmitters contributed the greatest share of discouragement (52%) (Table 3).

5.3. Is oblique transmission more likely for low-strength/high-difficulty traditional skills, especially oral tradition and traditional skills suspected to be vanishing (P2)? Yes

Compared to other skill categories, oral tradition skills and vanishing skills showed relatively high proportions of oblique transmission (38%, and 35%, respectively) (Table 2). We evaluated whether non-parental kin from older generations were more likely to be reported as transmitters of traditional skills that Tsimane indicated are difficult to learn and perform (Table A.7). We find that oblique transmitter reports are significantly associated with more difficult skills ($p < .001$) and skill that do not require strength ($p < .001$). Older non-parental kin were 1.5 times more likely to be reported as transmitters for traditional skills than for modern and market skills ($p < .001$), and 1.4 times more likely to be reported if those traditional skills are in the oral tradition or set of vanishing skills ($p < .001$).

In particular, we evaluated how often grandparents contributed to oblique culture transmission. Reports of grandparent transmitters are relatively more common for skills in the oral tradition (17%) and for vanishing skills (16%), than for all traditional skills (9%) childcare and reproduction (6%), or modern and market skills (5%) (Table 2). A logistic regression (Table A.8) indicated grandparents were 2.2 times more likely to be reported as transmitters for traditional skills than for modern and market skills ($p < .001$), and 1.8 times more likely to be reported if those traditional skills are in the oral tradition or set of vanishing skills ($p < .001$). In general, grandparent transmitter reports are significantly associated with more difficult skills ($p < .001$) that do not require strength ($p < .001$).

5.4. Is horizontal transmission more likely to be reported for modern and market skills (P3)? Yes

We evaluated the proportion of horizontal vectors among transmitters of skills that are reported for modern and market skills, compared to traditional skills. Horizontal transmitters are reported more often for modern and market skills (32%) than for traditional skills (25%) (Table 3). A logistic regression analysis (Table A.9) indicated that horizontal transmitters were 1.6 times more likely to be reported for a modern or market skill than for a traditional skill ($p < .001$).

6. Discussion

Effective knowledge and skill transmission among local group members has probably been crucial to the evolution of cumulative culture throughout human history, and continues to be today, despite increasing access to schools, radio, television, and phones throughout the Tsimane territory. All of the skills investigated with our Tsimane *Skills Survey* contain cumulative cultural information relevant to Tsimane productivity and sociality. This essential cultural information travels along a variety of vectors by different influences. The purpose of this study was to gain a better understanding of the cultural transmission vectors that help transfer knowledge and influence the acquisition of 92 essential skills among Tsimane forager-farmers. Our findings show that kinship, gender, generational seniority, and skill type affect the potential opportunities for and benefits of culture transmission.

There are four key findings of the present research. First, the development of essential Tsimane knowledge and skills is primarily

Table 1
Summary of means and standard deviations for number of male and female informants' reports of transmitter influence.

Transmitter characteristics	Informant	Number of reports	M	SD
1. Same Sex Transmitter (=1)	Female	55,644	0.69	0.461
	Male	73,841	0.77	0.462
2. Older Generations Transmitter (=1)	Female	56,873	0.77	0.419
	Male	75,842	0.72	0.447
3. Coefficient of Relatedness to Informant	Female	56,873	0.38	0.171
	Male	75,842	0.35	0.189

Table 2
Transmission Vectors and Grandparent Transmitters Reported for Skills by Skill Categories.

Skill categories	N	Percent of total	Vertical (Down)	Oblique (Down)	Horizontal (Across)	Vertical (Up)	Oblique (Up)	Grandparent
Traditional	124,672	93.9	48.9	26.1	24.6	< 0.1	0.4	9.3
Childcare, Reproduction	17,075	12.9	50.7	24.0	24.9	0.1	0.4	5.6
Oral tradition	5549	4.2	31.0	38.0	30.4	< 0.1%	0.7	16.5
Vanishing	5926	4.5	40.8	34.9	23.8	0	0.4	15.6
Modern, Market	8043	6.1	47.5	19.3	31.9	0.1%	1.3	4.6
Overall	132,715		48.8	25.7	25.0	< 0.1%	0.5	9.0

Note: The percentage of reports classified under different transmission vectors are reported. Vertical transmitters included mother and father, oblique downward transmitters included aunt, uncles, grandparents and relatives of older generations, horizontal transmitters included same generation peers, upwards vertical transmitters included direct offspring (daughters and sons), and upward oblique transmitters included relatives of younger generations. Across rows, cell values from the five columns labeled with either "(down)", "(across)", or (up)" sum to 100%.

Table 3
Proportion of transmission vectors and grandparent transmitters reported for traditional skills by influence type.

Influence type	N	percent of total	Vertical parents (Down)	Oblique older Kin (Down)	Horizontal (across)	Vertical offspring (Up)	Oblique younger Kin (Up)	Horizontal familial Kin	Horizontal non-family	Grandparent
Instruct	32,095	25.7	58.0	22.0	19.6	<0.1	0.3	16.6	3.0	9.0
Correct	30,083	24.1	49.1	26.4	24.2	<0.1	0.3	20.3	3.9	9.2
Example	31,664	25.4	39.8	32.3	27.2	0.2	0.5	20.8	6.4	11.7
Encourage	30,614	24.6	48.5	23.8	27.1	<0.1	0.4	21.1	6.0	7.2
Discourage	216	0.1	31.5	15.7	51.9	0	1.0	15.8	36.1	1.4
Overall	124,672	100	48.9	26.2	24.6	<0.1	0.4	19.7	4.9	9.3

Note: The percentage of reports classified under different transmission vectors are reported by influence types. Vertical transmitters included mother and father, oblique downward transmitters included aunt, uncles, grandparents and relatives of older generations, horizontal transmitters included same generation peers, upwards vertical transmitters included direct offspring (daughters and sons), and upward oblique transmitters included relatives of younger generations. Across rows, cell values from the five columns labeled with either "(down)", "(across)", or (up)" sum to 100%.

influenced by older same-sex relatives. This is despite the greater amount of time spent socially interacting with same-generations peers during childhood when Tsimane acquire most skills. Second, vertical transmission from parents is the most reported vector for acquiring all traditional skills, significantly more than for modern and market skills. Third, oblique transmission is more likely for low-strength/high-difficulty traditional skills. And fourth, same generation horizontal transmitters are more likely to provide discouragement in the learning process and to transmit modern, market-oriented skills..

The dominant pattern of information transmission, reported as coming from older generation (75%), same sex (73%), close kin transmitters (95% family, mostly parents), demonstrates the importance of vertical and oblique transmission vectors. These results are consistent with the expectation that cultural information generally flows from older reliable sources to younger generations (Cavalli-Sforza & Feldman, 1981), that a society's socioeconomic opportunities for interactions affect knowledge and skill transmission within and between sexes (Hewlett, 2016; Lew-Levy, Reckin, et al., 2022) and that parents account for the majority of traditional culture transmission (Guglielmino et al., 1995; Hewlett & Cavalli-Sforza, 1986; Lancy, 1996; Lozada et al., 2006).

We also highlight grandparental influence on the transmission of skills that were considered to be difficult by local Tsimane informants, but that do not require much physical strength. These include skills in the oral tradition and skills that are vanishing such as handmaking traditional clothes, tools, and musical instruments that are now more readily acquired via market sources. Many of these skills are best taught by demonstration and learned by example: the style of transmission influence most reported for grandparents. These grandparental transmission results are consistent with embodied capital model expectations that the life course of skill performance is shaped by characteristics of specific tasks (i.e., their learning and performance difficulty, strength, and knowledge requirements), age-related changes in productivity, and the changing needs of the family budget (Bock, 2005; Cavalli-Sforza & Feldman, 1981; Gurven et al., 2020; Gurven & Kaplan, 2006; Schniter et al., 2015).

While our study of essential Tsimane skills and abilities is by no means exhaustive, the survey we use is perhaps the most extensive traditional skills survey to date, covering a wide range of knowledge and skill domains including chores and crafts, social and market, childcare and reproduction, music and stories, and food production. Furthermore, because so many of these skills depend on knowledge of the local environment and its resources, this study provides important evidence of the dynamics of traditional ecological knowledge and indigenous knowledge transmission –topics receiving increasing attention in the past several decades (Dudgeon & Berkes, 2003; Reyes-García et al., 2014).

To develop a questionnaire approach appropriate for studying local Tsimane culture, we worked with local Tsimane in focus groups and through pilot tests involving Tsimane informants from outside of our study sample. While instruction, correction, example, encouragement, and discouragement are transmission influences well represented in the literature (though sometimes called active teaching, evaluative feedback, and stimulus or local enhancement), there may be more specific forms of cultural influence, such as task delegation (Stieglitz et al., 2013), social tolerance (Kline, 2015), and trust (Hewlett, 2016), not described by our study. Despite ongoing efforts to standardize methods used for the study and description of culture transmission, the use of open-ended questions, focus groups, and pilot testing may continue to be helpful for exploring alternative categories of influence on the culture transmission process and for developing surveys inquiring into locally appropriate behavioral solutions to pedagogy and culture transmission.

Using our Tsimane *Skills Survey,* we conducted a cross-sectional study of culture transmission among the adult population and provide results representative of the population's various perspectives. A sample representative of a wide range of ages is important when generalizing results at the population level because cultural influences may not be uniform across the life span and transmission opportunities among cohorts (Aunger, 2000; McElreath & Strimling, 2008). We previously isolated the set of skills that is expected to be vanishing from the younger generation of informants and looked for evidence of generational cohort differences in this study by controlling for informant age across regression analyses, but found no age effects indicating cohort differences.

A potential limitation concerns the quality of reports identifying transmitters elicited through our survey method. Self-reports may be biased due to problems with recall, with demand characteristics, and with halo effects. Aunger (2000) argued that trends in self-reports of parental influence may reflect a normative reporting bias in favor of authority figures such as parents. We asked participants to name up to three sources for each type of influence if possible and received almost double the responses that would have been collected with a single-response methodology. Across all responses we received reports for transmitters representing each of the vectors studied, and when we compared first responses to latter responses, we found no change in general patterns of reporting: vertical transmitters were the most common vector in both early and later responses. Future research efforts that more closely investigate the identities and characteristics of transmitters reported by our informants will be helpful for further validating the transmission vectors identified by this study. Combining survey methods with observational methods can help resolve some of the limitations of self-reports. Focal follows (Boyette, 2016; Boyette & Hewlett, 2017) and video recordings (Hewlett & Roulette, 2016) of youngsters in natural settings provide high resolution information on behavior. Such methods may feature more play, observational learning, and horizontal transmission than captured by other research methods (Hewlett, 2016).

7. Conclusion

Our research aims to help integrate two lines of research, cultural evolutionary theory and embodied capital theory of human life history evolution. Our findings help extend our understanding of social learning in subsistence societies by illustrating how changes in embodied capital, gender, and relatedness affect the cost-benefit tradeoffs of different types of cultural transmission influence by various vectors in an Amerindian forager-farmer society.

In small-scale subsistence societies, skills continue to develop for decades after they have been acquired such that older adults are social banks of accumulated cultural and practical knowledge. The facilitation of socialization and education by grandparents, parents, and other adult kin requires the styles of influence described here and is preceded by a lifetime of individual practice. Studies of cognitive aging in small-scale societies suggest that over the course of human evolution, selection for a long lifespan may have favored the maintenance of cognitive skills to facilitate retrieval and transmission of important information at late ages (Gurven et al., 2017). Together with evidence of kin-biased net downward intergenerational caloric transfers within extended families (Hooper et al., 2015), the dominant pattern of kin-biased downward cultural transmission presented here is consistent with selection favoring a broad and multi-generational social structure of kin-based exchange.

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Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.evolhumbehav.2022.08.002.

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