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Skill Ontogeny among Tsimane Forager-Horticulturalists

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ABSTRACT

By systematically examining age patterns in reported acquisition, proficiency, and expertise across a broad range of activities including food production, childcare, and other services, we provide the most complete skill development study of a traditional subsistence society to date. Previous studies of forager skill development have often focused on a few abilities (e.g. hunting), and neglected the broad range of skills and services typical of forager economies (e.g. childcare, craft production, music performance, story-telling). Here, we investigate whether age profiles of reported skill development are consistent with predictions derived from life history theory about the timing of productivity and reproduction. Our results show that: (1) most essential skills are acquired prior to first reproduction, then developed further so that their productive returns meet the increasing demands of dependent offspring during adulthood; (2) as post-reproductive adults age beyond earlier years of peak performance, they report developing additional conceptual and procedural proficiency, and despite greater physical frailty than younger adults, are consensually regarded as the most expert (especially in music and storytelling), consistent with their roles as providers and educators. We find that adults have accurate understandings of their skillsets and skill levels –an important awareness for social exchange, comparison, learning, and pedagogy. These findings extend our understanding of the evolved human life history by illustrating how changes in embodied capital and the needs of dependent offspring predict the development of complementary skills and services in a forager economy.

Humans are unique among primates due to their encephalized brain, complex feeding strategies, extensive multi-generational cooperation, and slow life history (Bogin and Smith, 1996; Hawkes et al., 1998; Kaplan et al., 2000). The Embodied Capital Model (ECM) of human life history evolution hypothesizes that this *Human Adaptive Complex* may be an evolved response to the skills-intensive, socio-ecological niche occupied by humans (Kaplan and Robson, 2002; Robson and Kaplan, 2003; Kaplan et al., 2010). It proposes that the co-evolution of slow growth with reduced mortality has facilitated the unique characteristics of the evolved human life history: the long pre-reproductive life-stage during which critical skills are learned by juveniles and adolescents, the reproductive life-stage during which large surpluses are produced and transferred to dependent kin, and a post-reproductive life-stage during which older adults continue to make downward transfers while also complementing the contributions of others in their extended networks. While ECM was developed to explain unique features of human life history, the model has also been tested across a variety of social species (Schuppli et al. 2012), suggesting its robustness for explaining the co-evolution of long lifespan, delayed growth, and productivity.

Evolutionary models of the human life course, such as ECM, the Grandmother Hypothesis (GH) (Hawkes et al., 1998; Hawkes, 2003), and the model proposed by Lee (2003), emphasize the fundamental role of downward transfers from older to younger kin in fostering the evolution of long lifespan. The impacts on fitness that donors make at different ages determine the value of their survival at those ages. These fitness impacts extend the standard Hamiltonian formulation of the "force of selection" that is determined by the age schedule of direct, but not indirect, reproduction (Baudisch, 2005; Bourke, 2007). While Fisher's reproductive value declines to zero by the age of menopause, one's "productive value" (a net measure of inclusive fitness contributions) has the potential to decline more slowly (for data on Ache hunter-gatherers, see Kaplan and Robson, 2002). Gurven et al. (2012) also showed that Tsimane adults remain in a positive net production phase (where mean daily consumption < production) for up to three decades past the age of menopause (around age 45),[1] enabling the support of remaining dependent offspring until age of self-sufficiency (age 20). That study also presented preliminary evidence suggesting that older Tsimane adults contributed to kin not only by producing food but also with complementary services, such as by mediating conflicts, helping during sickness, and providing ecologically relevant information. These formal studies of skill development, production, and transfers have greater contributed to our understanding of the human life course.

In spite of their strengths, previous studies have largely ignored the communication of information, pedagogy, socialization, leadership, and other non-material transfers, despite anecdotal reports that these are important for improving fitness (but see Aunger, 2000; Henrich & Henrich, 2010; Henrich & Broesch 2011). There are currently no systematic studies of knowledge, performance, and skill development for the broad range of essential skills in a traditional subsistence society, despite much discussion of its importance for understanding the evolved human life history (MacDonald, 2007; Scalise Sugiyama, 2011). Existing studies have instead focused on one skill set or limited sets of subsistence skills (e.g., Bock, 2002; Walker et al., 2002; Gurven et al., 2006; Reyes-Garcia et al., 2009, Hooper, 2011; Henrich & Broesch, 2011; Demps, 2012; but see Kline et al., 2012).

To fill this gap, this paper examines the acquisition, proficiency, and expertise of a broad range of skills among Tsimane forager-horticulturalists of the Bolivian Amazon. Following others, we examine skills essential for food production (e.g., gardening, fishing, hunting), but also examine childrearing and a wide variety of complementary skills (e.g., craft production, household chores, social activity, musical performance, story-telling). We test whether age profiles of skill development are consistent with predictions derived from ECM about the timing of productivity and reproduction. For each skill they possessed, informants reported ages of "acquisition" (i.e., when they achieved basic ability to self-sufficiently perform the skill)[2] and "proficiency" (i.e., a high level of conceptual and procedural knowledge needed to perform the skill well). Informants also nominated others whom they judged to be "expert" at the skill.

Our overarching hypothesis is that the time-path of skill development corresponds with the functional "life goals" specific to each of three stages of the human life course. In the *pre-reproductive life stage* the goals are to: (1) acquire basic competence with a skillset to support one's self; and (2) attract and secure a mate, which often involves demonstrating the first goal. In a natural fertility ecology, the goals of the *reproductive life stage* are to (3) reproduce and produce, optimally developing and using skills to support reproduction, such that (4) offspring are successfully raised to be able to accomplish pre-reproductive and reproductive goals 1, 2, 3, and 4. After reproduction ceases with menopause, an additional 10-20 years of life are needed for the last-born offspring to fully achieve goals 1, 2, 3, and 4. During transition to the *post-reproductive life stage,* adults (5) continue making direct and indirect contributions towards fulfilling kin's goals 1, 2, 3, and 4, despite age-related senescence.

PREDICTIONS

Below we derive several predictions concerning skill development across the life course.

Pre-reproductive life stage

The pre-reproductive life stage includes gestation, infancy, childhood, and adolescence, and ends at the age of first reproduction (approximately age 18 for females and 20 for males among Tsimane; Winking, 2005; Winking et al., 2007). During this period young adults are supported by the surplus production supplied by older adults (Kaplan, 1994; Kaplan et al., 2000), are protected (Blurton Jones et al. 1994), and remain relatively free of responsibilities that require great exertion or risk (Draper 1976; Blurton Jones et al. 1989). Classic life history theory relies on Charnov's (1991, 1993) 'production function' to model the transition from physical growth to reproduction. At the transition to age of first reproduction, the organism reallocates energy away from growth and towards reproduction. We extend this model, recognizing that in humans, the ability to be economically self-sufficient and support dependents is achieved later than sexual maturity. The ECM proposes that the extensive provisioning during the pre-reproductive period supports learning, skill acquisition and on-the-job training. These costs are offset by greater surplus returns over the long reproductive and post-reproductive life span (Kaplan et al., 2000; Robson and Kaplan, 2003). Marriage usually occurs close to when individuals are capable of producing the energy needed to support reproduction and the provisioning of offspring, which requires that most food production, craft production, and childrearing skills have been "acquired", and that a stage of practical learning-through-doing has begun. Many skills require substantial learning, practice and physical ability before they can provide returns on investments (e.g., Pereira and Fairbanks, 2002). Social learning of conceptual elements and procedures is well underway during childhood (Ruddle & Chesterfield, 1977; Hewlett et al., 2011; Kline et al., 2013; Stieglitz et al., 2013). However, the necessary strength and size needed for coping with dangers, independent performance, and dedicated practice are not developed until after the adolescent growth spurt,[3] when adult stature is nearly attained and most skills are mastered (e.g., see Ruddle & Chesterfield, 1977; Hewlett & Cavalli-Sforza, 1986; Ohmagari & Berkes, 1997).

Prediction 1. *Age of acquisition for food production, child-rearing, and craft production skills will be during adolescence and prior to adulthood.*

To evaluate our first prediction about the timing of skill acquisition, we investigated 31 food production skills (including 3 tool use skills, 11 hunting skills, 6 fishing skills, 5 gardening and husbandry skills, and 6 food processing skills), 10 childrearing skills (including healthcare, childcare, birth, and family planning skills), 28 household chore and craft production skills, 9 social skills, and 13 cultural skills (music, stories, and dreams).

Reproductive life stage

The reproductive stage for females spans from the onset of reproduction to its cessation prior to menopause (approximately age 37-45 for foragers, Kaplan et al., 2010). During this stage, a primary goal is maintaining sufficient food production to track the waxing and waning demands of a family of dependents accumulated under a natural fertility schedule. On average, Tsimane women become mothers by age 18, and have an interbirth interval of 2.6 years. Survivorship to age 15 is 75%; thus, the average number of dependents surviving to their teens is just under 7 (McAllister et al., 2012). Offspring consume more than they produce until about age 20, and a last-born offspring will remain dependent until its mother is in her sixties (Gurven et al., 2012). The average fertility schedule of a Tsimane man is tied to that of a long-term female mate only a few years younger (Kaplan et al., 2010).

As the number and caloric demands of dependents increase in a family, parents and grandparents are faced with greater provisioning and caregiving demands. Gurven and Walker (2006) showed that forager adults relying primarily on hunting and gathering are at their most productive “when caloric demand of dependents is highest” (p.839). Performance with reproduction, childcare, and food production skills is most needed by the time offspring’s demands for provisioning and caretaking are greatest. Physical strength that contributes to this performance peaks earlier in adulthood, while returns from “cognitive capital” (accumulation and communication of knowledge and experience) may increase or show stability with age until the final decade of life (Salthouse, 1993; Schaie, 1994; Park et al., 2002). Thus, even after the expected age of peak production (timed to meet dependents’ needs), conceptual and procedural learning continues and the accumulated knowledge should contribute to greater confidence over one’s proficiency and pedagogical capability.

Prediction 2. *While performance for childrearing and food production skills should peak around the time of peak offspring dependency, informants’ self-ratings of proficiency (reflecting self-recognition of accumulated conceptual and procedural knowledge and confidence) can peak concurrently or later.*

During the reproductive life stage, an adult’s reputation for expertise with a childrearing skill may continually improve over time with competent demonstrations to others that garner recognition and with achievement of greater skill proficiency. However, as mobility becomes limited by physical senescence, the ability to demonstrate skills requiring strength and to garner recognition for them may be increasingly compromised. For these reasons, the likelihood of being publicly identified as an "expert" with different food production skills should change with age.

Prediction 3. *During the reproductive life stage, the likelihood of being nominated as an expert in food production skills requiring strength will be higher than for those with minimal strength requirements (P3.1). During this time, the frequency of expertise nominations for food production skills requiring minimal strength will increase at a faster rate than those requiring strength (P3.2).*

Post-reproductive life stage

Strength declines in adulthood with the onset of sarcopenia (the monotonic loss of skeletal muscle contributing to declines with advancing age and leading to increasing disability and frailty: Roubenhoff, 2000), with an average 11% decrease in muscle performance every decade after age 45 among Tsimane (Kaplan et al., 2010). By the seventh decade of life when all children have reached economic self-sufficiency, caloric production among Tsimane and other foragers declines (Amoss and Harrell, 1981; Walker and Hill, 2003; Gurven and Kaplan, 2006; Gurven et al., 2012), functional disability increases (Kaplan et al., 2010; Stieglitz et al., 2014) and food transfers to kin declines (Kaplan et al., 2000; Hooper, 2011). Despite these deficits, older adults often can use their respect and prestige[4] to assist with the transmission of culture (e.g. with musical performance and storytelling) and to make other contributions through craft production, household chores, social activity, and forms of knowledge transfer.

The opportunity costs of developing pedagogical, oratory, and musical skills for instructing and socializing offspring during the childrearing years may be high due to the heavy burden of provisioning multiple children. The efficiency of high-strength food production skills suffers most among older adults, and so low-strength skills, such as craft production, household chores, social activity, musical performance, ritual leadership and story-telling become prime candidates for time investment. In co-resident extended families with cooperative divisions of labor, reproductive-aged adults can depend on older parents and other kin for these contributions. Under these conditions there is increased utility for grandparents, older kin, and older non-kin neighbors to specialize in non-substitutable activities that are low-strength, and in some cases most-difficult. Indeed, heterogeneity in physical (Maddox and Clark, 1992; Nelson and Dannefer, 1992) and mental abilities (Christensen et al., 1999; Ardila, 2007) increases at late ages, reinforcing greater specialization in the post-reproductive life stage, with older adults increasingly focusing on skills best suited to their abilities and contribution opportunities.

Prediction 4. *The highest levels of "very proficient" self-evaluations (P4.1) and others' recognition of expertise (P4.2) in low-strength skills unrelated to food production, should be delayed until after offspring provisioning demand is greatest (after ~age 40).*

Prediction 5. *In late adulthood, the reported skill sets of post-reproductive adults will increasingly be composed of most-difficult skills and skills requiring only minimal strength.*

Despite physical aging and compromised skill performance at later ages, conceptual and procedural knowledge of how to proficiently perform a skill is sufficient for the pedagogical purposes of transferring skill “know-how” to younger kin. As older adults increasingly take advantage of opportunities to transfer accumulated knowledge to younger kin, reputational information about their expertise spreads across social networks, leading to a growth in consensual recognition of their expertise over time. Dispersed networks may cause time lags in reputational information flow leading to a “delayed” public recognition of expertise.

Prediction 6. *Peak ages of consensually recognized expertise will coincide with or be older than peak ages of conceptual and procedural knowledge proficiency for those skills.*

Older adults often co-reside in extended family clusters with many less experienced dependent kin in close proximity, thereby facilitating information transmission from one-to-many. Among Tsimane, traditional pedagogy with respect to learning the behavior of animals and fish, and of morality and proper social behavior, is accomplished through oral broadcast of a rich repertoire of songs and stories (Huanca, 2006). This form of delayed productivity, extending beyond peak ages of caloric productivity and of importance to youngsters, is consistent with ECM expectations.

Prediction 7. *Expertise in pedagogical skills (music and storytelling) will be most recognized at relatively older ages in the post-reproductive life stage.*

METHODS

Study population

The Tsimane` (population ~ 15,000) are forager-horticulturalists inhabiting the lowland forests and savannas east of the Andes in the Beni department of Bolivia. The Tsimane` reside in 90+ kin-based villages that range in size from 50-500 people, and that vary in river and road access, wild game, and access to market goods.

Tsimane are semi-sedentary: men and women tend to move throughout their lives. Although exposed to Jesuit missionaries in the late 17th century, Tsimane have lived and continue to live autonomously and remain relatively isolated from Bolivian society at large (see Huanca, 2006; Iamele, 2001 for general ethnography).

Tsimane Skills Survey

We developed a *Skills Survey* to investigate Tsimane self-evaluations of skill proficiency, and to identify consensus judgments about others' expertise in a variety of skills that have the potential to impact biological fitness of self, spouses or kin. Skills were identified from twenty-two semi-structured interviews with Tsimane men and women aged 20-72 years (mean age 35 years). These resulted in 101 specific skills from across 12 skill categories, which were then reviewed by a panel of six Tsimane researchers and their spouses who unanimously agreed on a refined list of 92 skills to use in the *Skills Survey* (see Online Supplement 1 for complete list of skills). They also categorized skills and rated them on their strength requirements.

Due to a marked sexual division of labor, many Tsimane skills are gender specific. Both female-specific skills (n=11), and male-specific skills (n=30) are considered equally important to both genders, as the end products of these skills are usually of mutual benefit. The 51 most common types of skills apply to both genders. Skills were assigned to five categories: food production, childcare and reproduction, household chores and craft production, social and market, and music and stories. The list of specific skills comprising these categories is detailed in Online Supplement 2. Ethnographic information about skill sets is given in Online Supplement 3. Fifteen skills were omitted from analysis because these only rarely received expert nominations, very few informants claimed to possess these skills, or they were deemed subject to strong cohort effects, making interpretation of age effects particularly unreliable.[5] The final skill set consists of 77 skills (48 for females, 69 for males, and 40 for either gender).

In 2006, the panel of six Tsimane researchers and the lead author interviewed 421 Tsimane (51% male) aged 15-86 from a sample of 8 villages using the *Skills Survey* (complete coverage of all adults present during the study period, 71% of the censused population for those villages)[6]; we index these informants by $i \in \{1,2,...,421\}$. Our sample is composed of 9 individuals in the pre-reproductive life stage age<18), 319 in the reproductive life stage (ages 18 to 44), and 93 in the post-reproductive life stage (ages 45+). The relative proportions of reproductive and post-reproductive aged individuals sampled do not differ significantly from those in the census population. Combining the 421 informants (who could be and frequently were nominated experts) with 176 others they nominated as experts, we have a set of 597 potential expert nominees; we index them by $e \in \{1,2,...,597\}$.[7]

For each appropriate skill, indexed by s, the following questions were asked:

(1) "Are you able to and in the habit of ...?" If informant i answered "yes" for skill s, then $H_i^s = 1$; otherwise $H_i^s = 0$. Older adults who had lost the ability to perform a skill often reported not having the skill and were recorded as not having the skill ($H_i^s = 0$). Those who answered yes ($H_i^s = 1$) to this first question about skill s were also asked the following five questions about that skill (questions 2-6):

(2) "Is ... difficult (to do)?" Informants chose one of three ordered responses to this "performance difficulty" question: We let PD_i^s = 1, 2 or 3 if informant *i* responded "very easy," "not so difficult/not so easy" or "very difficult," respectively, for each skill *s* they possessed. As explained to informants, this measure covers a variety of factors that affect difficulty, including level of detailed complexity, number of sub-tasks involved, muscular and hand-eye coordination, and memory or performance requirements.

(3) "Does it take a long time to learn ...?" Informants chose one of three ordered responses to this "learning difficulty" question: We let LD_i^s = 1, 2 or 3 if informant *i* responded "quickly learned [minutes/hours]," "takes some time [days/weeks]" or "takes a long time [years]," respectively, for each skill *s* they had.

(4) "At what age did you acquire basic competence with ...?" The variable AA_i^s codes this "acquisition age" in years (i.e., when one first acquired capability for basic performance and practical application). In an attempt to anchor ages, we provided informants a set of standardized photographs of known-age Tsimane from outside of the immediate sample.[8]

(5) "Do you know how to ... well?" Informants chose one of three ordered responses to this "proficiency" question: "not so well," "more or less" or "very well." The response "not so well" was rare (<1%), so we let $P_i^s = 1$ when informant *i* responds "very well," $P_i^s = 0$ otherwise, for each skill *s* possessed. We hereafter refer to $P_i^s = 1$ as "very proficient".

(6) "Who do you know to be most expert at …?" We recorded a maximum of three "expert nominations" for each skill *s*. We let $N_{ie}^{s} = 1$ if informant *i* nominated potential expert *e* as expert at skill *s*; otherwise $N_{ie}^{s} = 0$.

The *Skills Survey* combined with census and demographic information enable us to assign ages for all informants *i* (A_i) and potential experts *e* (A_e). For each skill *s*, we compute a measure of skill difficulty, D^s, as the weighted average of performance difficulty PD_i^s and learning difficulty LD_i^s.[9] The median value of D^s across all skills divides the set of skills into two halves, referred to below as the "most difficult" and "least difficult" skill subsets. The Tsimane researchers partitioned skills into categories requiring high or low "strength", defined as muscular strength, endurance, agility, and cardiorespiratory fitness (see Online Supplement 2). We let $M^s = 1$ for skills *s* requiring high strength, $M^s = 0$ otherwise.

Demography, Census, Food Production and Consumption

Between 2002-2006, census data were recorded by researchers of the THLHP, documenting age, sex, kinship, and community membership using methods described in Gurven et al. (2007). Shared nuclear family residential location was mapped using a handheld GPS unit. Adult parents and their co-resident dependents (i.e. offspring and adopted dependents) were classified together as nuclear families. Body weight, height and upper and lower body strength were measured during annual medical exams. Gurven, Kaplan, and Gutierrez (2006) report peak strength among men by age 29, peak height (163 cm) by age 31, and peak weight (63 kg) by age

35. Overall, adults are approximately within 90% of their peak total strength between the ages 20 through 40.

Demographic interviews, described at length in Gurven et al. (2007), were conducted from 2002-2005 with 1,702 individuals in order to identify consanguinal and affinal kinship relations, ascribe ages, and to estimate age profiles of mortality and fertility. Production and sharing interviews were conducted between 2005-2009 roughly twice per week among 245 nuclear families covering 1198 individuals, to estimate daily food production and food transfers by age and sex (see Hooper, 2011; Hooper et al. submitted for details).

Daily food consumption was estimated by distributing total production among individuals according to their basal metabolic rates, as estimated using FAO formulae (Schofield, 1985; FAO, 2001) according to age, sex and body mass. An individual's daily net production was calculated by subtracting their estimated daily consumption from measured gross production rate. The net caloric consumption demands of children specific to parental age was calculated by summing the net caloric production of all children an average parent would have at that age, based on age-specific fertility and mortality schedules.

Data Analysis: Age-specific Response Likelihoods

We examine the likelihood that informants report high (vs. low) skill proficiency (the response $P_i^s = 1$) and the likelihood that informants nominate any particular person as expert (the response $N_{ie}^s = 1$). Binary response variables like these can be analyzed by means of a "generalized linear model" (McCullagh and Nelder, 1989). The proficiency reports P_i^s are the simpler case so we describe that approach here (see Online Supplement 4 for discussion of the expert nominations model). Our primary interest lies with the dependence of the response likelihood on the age of informants. The purpose of the model is to statistically remove the influence of other factors that could be correlated with age, or are likely sources of appreciable variance, and to smoothly characterize the response likelihood with an age polynomial. We view the probability Π_i^s of a "very proficient" response from informant *i* on skill *s* as $Prob(P_i^s = 1|A_i, AA_i^s, X_i, Z^s)$. As indicated by the four symbols in the conditioning list, we view this probability as depending on four factors:

(1) informant *i*'s current age A_i;

(2) informant *i*'s age AA_i^s when she initially acquired the skill;

(3) other characteristics of informant *i*, captured by a vector of informant characteristics X_i (informants' sex, village and interviewer); and

(4) other characteristics of skill *s*, captured by a vector of skill characteristics Z^s (skill category, skill difficulty D^s and strength requirement M^s).

Generalized linear models write the probability Π of a response such as $P_i^s = 1$ as a function of a "linear predictor" η, a real-valued variable linearly composed of the conditioning variables, each weighted by estimable parameters in a vector θ. The linear predictor is then transformed into a probability by means of a suitable function such as the logistic response function $\Pi = [1 + exp(-\eta)]^{-1}$ we use in our models.

The essence of our linear predictor of "very proficient" ($P_i^s = 1$) responses is *linear predictor* = *polynomial in age* A_i + *other factors governing the proficiency response*, or

$$\eta_i^s = a_1(A_i - 35) + a_2(A_i - 35)^2 + a_3(A_i - 35)^3 + a_4(A_i - 35)^4 + g(AA_i^s, X_i, Z^s, \theta).$$

The function g is the expected value of the linear predictor for an informant of age $A_i = 35$ (the mean age of the informants in our sample), given the acquisition age AA_i^s and other characteristics X_i of informant *i* and characteristics Z^s of skill *s*; and $\Pi = [1 + exp(-g(AA_i^s, X_i, Z^s, \theta))]^{-1}$ is the model probability that informant *i* says she is very proficient at skill *s* if she happens to be the average age 35 of all informants. The inverse of the logistic response function is the "log odds ratio" $ln[\Pi/(1-\Pi)] = \eta$. Therefore, we have

$$ln[\Pi_i^s/(1-\Pi_i^s)] = a_1(A_i - 35) + a_2(A_i - 35)^2 + a_3(A_i - 35)^3 + a_4(A_i - 35)^4 + g(AA_i^s, X_i, Z^s, \theta).$$

Many of the figures in our results below are graphs of the age polynomial portion of this expression for the log odds ratio favoring some response by our informants, given our estimates of the parameters in this expression (the polynomial coefficients *a* and other coefficients and effects θ). The estimated value of the function g is removed, so that these graphs are to be interpreted as changes in the log odds ratio with age, relative to an age 35 informant with otherwise identical characteristics AA_i^s and X_i. Statistical analysis of the estimated polynomial coefficients a_i allows us to derive confidence intervals for ages at which skill proficiency reports reach their peak,[10] as well as allowing statistical comparisons of these "age-proficiency profiles" across different skills sets (see Online Supplement 4).

RESULTS

Pre-reproductive life stage

P1: *Are productivity-related skills acquired before adulthood? Yes.*

Figure 1 shows cumulative distribution functions (CDFs) for self-reported ages of skill acquisition in five categories of skills for men and women. Table 1 reports distributions of gender-specific mean acquisition ages for each skill category.

Almost everyone possesses one or more skills in each of the categories, except for music and storytelling in which about only half possess them (228 of the 421 subjects have one or more of these latter skills). Median ages of skill acquisition range from 13-16 for females, and 14-17 for males (Table 1). Food production skills are generally acquired earliest, followed by chores and craft skills, social and market skills, childcare and reproductive skills, and music and story-telling skills as the final skill set (Fig. 1). The differences between the within-informant median timing of food production skill and Music & Storytelling skill acquisition is around three years (39 months for males, n=152, and 32 months for females, n= 71, both $p < 0.0001$).[11] Males acquire skills later than females (11 months for food production and 22 months for chores & crafts; $p < 0.01$ in all five categories by a Satterthwaite t-test with unequal variances). Male acquisition ages are also significantly more variable than those of females ($p < 0.01$ in all five categories by a folded F-test).

By age 20, the CDFs of all skills are above 95% and 90% in women and men, respectively. Thus, differences in the proportion of skills held by adult age cohorts should be due mostly to secular changes over the past several decades, such as integration into the cash economy and greater schooling, rather than delayed learning. We examine the relative size of skill portfolios held by informants across age cohorts and found that younger age cohorts report fewer skills than older cohorts, and a difference in size of male and female skill portfolios for the 21-30 year old age cohort (Fig. 2).[12] A two-way unbalanced ANOVA (with gender and age categories as factors), using $ln[\overline{H}_i/(1-\overline{H}_i)]$ as the dependent variable, shows a highly significant main effect of age cohort ($F_{3,361}$= 32.21, $p < 0.0001$). A comparison of acquisition rates across age cohorts for each surveyed skill shows evidence of cohort effects, with younger age cohorts reporting a smaller proportion of more skills (Online Supplement 5). The list of suspected "vanishing" traditional skills from Online Supplement 2 show greater effects of age cohort on skill acquisition. The five skills most frequently lost among younger cohorts are woven hat production, ceramic vessel production, wheel barrow making, getting and processing bark cloth, and knowing the old stories and myths.

Reproductive life stage

P2: *Does skill proficiency in child rearing (food production, childcare and reproduction) peak at same time or after peaks in offspring demand? Yes.*

Figure 3 plots gross food production, net production, and net caloric demand of children under 20 by parental age. The peak ages of gross and net production range from 39-51. Figure 4 shows that the age profile of gross caloric food production overlaps substantially with the age profiles of skill proficiency ($P_i^s = 1$) for food production skills alone and for food production combined with childrearing skills. Peak ages of "very proficient" self-ratings are 44-56 for combined childrearing and food production, and 46-62 for food production skills. The ages of peak reported skill proficiency and caloric production occur during and after (but not before) the ages of peak caloric demand of children (ages 30-40) (Fig. 3).

***P3**: Do strength requirements of food production skills affect likelihood of expertise nominations, and rates of increase in expertise nominations with age? Yes.*

We compare the relationship between consensus expertise for high-strength production skills (e.g. hunting, clearing new fields) and consensus for low-strength production skills (e.g. hook-and-line fishing, horticultural tasks like planting). Among reproductive ages, the likelihood of being nominated an expert for these high strength skills exceeds that of the low strength production skills for both men and women (Fig. 5). Expertise for high strength tasks peaks in the reproductive period for women and in the post-reproductive period for men, with declines for both genders in the post-reproductive period (Fig. 5). We also find that the rate of increase in expertise nominations is greater for low-strength productive tasks than for high-strength production tasks (Fig. 5). With advancing age, the likelihood of being nominated an expert decreases for high-strength food production skills while it increases for food production skills requiring only minimal strength (Fig. 5).

Post-reproductive life stage

P4: *Do peak levels of proficiency and consensus-based expertise for low-strength skills unrelated to food production occur after ages of peak offspring caloric demand? Yes.*

Whereas peak caloric demands of children occur from ages 30-40 (Fig. 3), peak ages of consensus expertise for skills unrelated to food production are almost entirely in the post-reproductive period, as are peak ages for "very-proficient" self-ratings with these skills (Fig. 6).

P5: *Do older adults concentrate on the most difficult skills and those requiring less strength? Yes*

We find that with increasing age, the skill sets of older adult women and men are increasingly composed of the more difficult skills (Fig. 7b,d) and those requiring only minimal strength (Fig. 7a,c). We also find that proficiency peaks of post reproductive adults between the ages of 41 and 62 are higher for most difficult skills (Fig. 8b) and after age 69, older adults' "very proficient" self-ratings for skills requiring strength decrease at a faster rate than for skills not requiring strength (Fig. 8a)

P6: *Do peak ages of consensus-based experts coincide with and lag behind peak ages of self-reported proficiency? Yes.*

We find that peak ages of consensus expertise for skills (49-77 for females and 59-73 for males) are concurrent with or later than peak ages for "very-proficient" self-ratings (ages 45-60) (Fig. 9).

P7: *Is expertise in pedagogical skills more concentrated at older ages than other skill categories? Yes*

We consider songs and storytelling as two fundamental forms of traditional pedagogy in Tsimane culture (see Online Supplement 3). We find that peak consensus expertise for the "music and stories" category begins at a later age than other skill categories (65 for females and 66 for males) (Fig. 10). The gains in consensus expertise with age are also largest for this late maturing category of skills relative to other skill types (Fig. 10).

DISCUSSION

Accurate mental representations of life course stages, knowledge of one's own skills and those of others, may not only be required for social comparison, but also for social learning and pedagogy. Such knowledge may also be important when seeking reliable social partners for cooperation and exchange. We found that Tsimane not only have a keen sense of life stages and how their own skill development progresses through these, but they also make accurate assessments of others' abilities. Tsimane use their own terminology to describe the different phases of physical and social development: unweaned infants who cannot speak, and do not walk (approximately 0-2 years) are called *joijnó;* children (approximately 2-14 years) who speak and walk but do not seriously engage in adult production activities are called *miquity*, adolescents and young adults (approximately 14-25 years) are called *nanaty;* middle-aged adults (approximately 30-40 years) are called *furety*, and "older" adults (over the age of 40) are called *isho' muntyi* (with finer distinctions among these older people: *Aty isho'* refers to those "getting older", *isho'* refers to those who are "older", and *anic isho'* to the "very old"). By using emic and etic perspectives on the factors determining age-specific performance and recognition of expertise in essential skills of all types common to preindustrial humans, we can better understand the timing of functional and perceived adulthood, the potential fitness contributions made by adults across the lifespan, and the evolution of multi-generational sociality.

By systematically surveying informants about the timing of skill acquisition, level of skill proficiency, and their perceptions of expertise for essential food production (e.g., gardening, fishing, hunting), childrearing, and complementary skills, we have shown that: (1) most essential skills are acquired by late adolescence prior to the initiation of reproduction, they are further developed over adulthood in conjunction with the increases in net caloric demand of children; (2) socially recognized “expertise” crucial to downward transmission of skill information occurs primarily in the post-reproductive life stage; (3) gross and net caloric production rates peak during peak offspring demand near the end of the reproductive life stage, but it is not until the post-reproductive life stage that older adults reach peak self-perceived proficiency and consensus-based expertise for most skills, especially low-strength but high-skill activities complementary to food production; and (4) the patterns of skill development across the life course depend on their strength and knowledge requirements, and are similar in both men and women.

The ECM predicts that the extended developmental period during which production at young ages remains low is compensated by productive surplus at later ages, and that delays in production are due to interactions between skills-based learning, on-the-job training and physical development. Net production is maximized in adulthood during periods of high offspring demand, and declines at late ages as a consequence of physical senescence.

Our results show that from the age at which informants report basic "acquisition" (the marginal proficiency required for learning-through-doing), there are substantial delays in reported peak proficiency and recognized expertise for a broad range of skills in men and women, not just high-prestige skills like hunting and leadership (Gurven et al. 2006). Due to the gains of joint investment in descendants with marriage and the sexual division of labor, the ECM predicts learning-based delays in productivity for both men and women. Skills perceived as difficult to learn and perform, such as obtaining honey (#15), healing sick children (#14), making canoes (#4), houses (#17), household crafts (e.g. #5, 8, 12, 13, 16), and musical instruments (e.g. #6, 9, 11, 16), all show marked delays in proficiency and expertise that exceed the ages of peak physical condition in early adulthood by at least a decade. Even when advancing through the later-life ages of declining caloric productivity, consensus expertise increases for many skills in the household chores and craft production, and music and stories categories.

Consistent with their roles as recognized experts, older (same sex) kin (e.g., grandparents)[13] often serve as the archetypical models for vertical knowledge transmission and exemplar performance. Older kin (i.e. parents, parents-in-law, aunts and uncles, grandparents) account for 69% of identified contributors to early-life skill acquisition, as teachers, active modifiers of behavior, observed exemplars, or as encouraging motivators by informants of this study (Schniter, 2009). The majority of older kin identified by informants as contributors to early-life skill acquisition are same-sex, including grandparents. Females report having learned more skills from maternal grandmothers, and males more from paternal grandfathers (ibid).

While the lifespan of most animals does not extend past the reproductive period (Williams, 1957; Hamilton, 1966; Levitus & Lackey, 2011), the human lifespan features a uniquely long post-reproductive period of skill maturation and generativity. In numerous human societies, it is documented that post-reproductive adults are not only the most proficient in a variety of skills, but they also are the most effective instructors and communicators (Simmons, 1945; Amoss & Harrell, 1981). Older adults might be revered as experts when their activities are easily observable (Davis and Wagner, 2003), if they effectively communicate their experience (Mergler et al., 1984; Adams et al., 2002; Paupathi et al., 2002), if their information is reliable and useful (Castro and Toro, 2004; Birdsell, 1979) or if they are deemed imitation-worthy due to prestige (Henrich and Gil-White, 2001). Indeed, it is frequently mentioned that older Tsimane adults "know how to think (about work and what needs to be done)" (*chij dyiji'jiyequi*). Furthermore, because they are unique in their ability to "think", they are especially skilled in planning tasks and executing them with efficiency and accuracy, and in orchestrating the schedules of other family members –contributing to their roles as instructors, exemplars, and encouragers of skill development in younger kin.

Our results support the notion that with advancing age, post-reproductive adults accommodate their changing positions in family and society and gradually compensate for the effects of their declining physical strength by cultivating their accumulated knowledge and prestige. We find evidence for two distinct views of how skills might develop throughout adulthood before reaching the unusually late age of peak competence: (1) the "life-long learning" account associated with the ECM suggests that the monotonic rise of procedural and declarative knowledge (Anderson, 1983) contributes to slow gradual development of more difficult knowledge-intensive skills; and (2) the "career change" and "compensation" accounts (Salthouse, 1990) where individuals compensate for declining muscle mass and productivity by cultivating and specializing in skillsets that they can perform well and which are not easily substitutable by others. Indeed, our results support the life-long learning account, indicating that more difficult skills are increasingly represented in the skillsets of older adults and that the peaks in proficiency for the most difficult skills extend more than a decade later than for the least difficult skills. We also saw support for the notion of career changes, with proficiency for food production and childrearing skills peaking around the end of the reproductive career, then proficiency and expertise in household chores and craft production, and music and stories categories – peaking at later ages. These findings are also consistent with a documented shift in male time allocation within productive tasks from strength-intensive hunting to horticultural production in later middle age (Hooper, 2011). Consistent with the notion of late-life specialization, older adults specialize in the last-to-be-acquired skill set: musical and oral traditions. By capitalizing on their high prestige and the attention of co-resident novice kin, older adults use songs and stories to engage in the one-to-many downward vertical transmission (i.e. "teaching") of their knowledge.

Limitations and Future Prospects

We discuss possible limitations to our study method and results. Our methods are based on self-reports of skill level and third-party reports on expertise, rather than direct observation of task or skill performance. While direct observation may be most reliable, the yardstick for assessing task performance is not transparent for many skills, nor do experiments provide a convenient solution. Our reliance on interviews for assessing skill level is supported by a recent study which showed that informant interviews may be as or more reliable than behavioral data for detecting moderate differences in individual ability in productive tasks where returns are variable or subject to noise (Hill & Kintigh, 2009). Nonetheless, several of our findings lend confidence to our interview methods. First, ages at which people report high proficiency for their own skills corresponded to ages at which people are nominated as experts (Figs. 6, 9). Second, the age profile of self-reported proficiency in food production skills (Fig. 5) is similar to the age profile of gross caloric production rates that derive from separate methods (Fig. 3), showing only a five year lag between point estimates of peak caloric production and of food production proficiency.[14]

While the set of skills included in this study is extensive and exceeds that of any other study to date, key skills are missing (e.g. household and food processing skills like cleaning, processing manioc root, making manioc beer) and several sub-categories contain only few skills (e.g. tool use, chores). While we attempted to survey skills important to males and females, our final skill set is not representative of the complete skillsets utilized by each gender. We have not accounted for how much females engage in what are classified as exclusively male skills, and how often males engage in what are classified as exclusively female skills though evidence of such performance was suggested over the course of our investigations. Some informants candidly explained to us that they practiced skills otherwise associated exclusively with their opposite gender while other informants remarked that a “gender-appropriate” skill which we asked them about was inappropriate for their gender.[15] Indeed, we expect that different perspectives are capable of yielding different categorizations of skills perceived to be gender appropriate, and further investigation is encouraged to address the issue of gender normativity. This should not be a major concern for our conclusions however, as the majority of investigated skills were appropriate to both genders and we see few meaningful differences between genders in our results. Where we do see interesting differences between genders is with strength-intensive skills that also contribute disproportionately to the differences between male and female skillset composition. In a separate study that quantified time spent in over 90 activities, Tsimane men overwhelmingly specialized in activities that were deemed high strength and incompatible with childcare (Gurven et al., 2009).

As reported in Methods, we omitted several skills from expertise analyses because they did not reliably elicit nominations from informants. We are unable to assess the confidence of our informants' judgments about expertise and consider that informants may face challenges identifying the "best" individuals at certain skills whose "product" may be difficult to observe. For this reason, residential proximity and relatedness (see Online Supplement 4) may be as important, or more, as predictors of expertise nominations than pure ability. Future studies on expertise judgments should consider collecting measurements of informant confidence about their expertise nominations. A measure of informant confidence might prove useful for calibrating consensus expertise nomination measures.

Lastly, we acknowledge that skill development would be best captured with longitudinal data on the same individuals, but our study design instead uses a cross-section of adults in eight villages, relying on recall for estimating ages of skill acquisition. Using cross-sectional data can be problematic if age-related differences in skills are instead due to secular changes affecting Tsimane lifestyles (see Reyes-Garcia et al., 2013). We found evidence that younger cohorts (especially in men aged 21-29) were less likely to acquire certain skills that were revealed in focus groups as most "vanishing" (Online Supplement 2, 5; Fig. 2). Young men in that age range are more involved in wage labor than older men, and women at any age (Gurven et al., 2009). Due to the evident effect of culture loss among younger generations, we focused on age-specific changes to shares of particular kinds of skills (e.g. easy versus difficult skills and skills requiring versus not requiring strength) across adult ages, rather than the absolute number of skills reported in specific categories.

Conclusion

Studies of forager skill development and resource transfers have largely neglected complementary skills and generative services, precluding a more complete understanding of the knowledge base and course of essential skill development in a traditional subsistence society. This research extends representations of "production" utilized in classical life history theory (Charnov, 1991, 1993) to now include a wider range of skill development, alongside growth, reproduction, and food production trajectories. Our results highlight the role of complementary (non-food) production, which matures late in life among post-reproductive adults and contributes toward downward transfers that benefit genetic descendants. The pattern of skill ontogeny described here is directly consistent with the Embodied Capital Model of human life history evolution, where long life evolves in the context of a relatively difficult feeding niche and a multi-generational extended family structure with net resource flows from older to younger kin.

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Footnotes

[1] A Tsimane adult who is alive from age 45 to 65 is expected to produce a total of 37.4 million calories and consume a total of 18.2 million calories, yielding a net production of about 19.2 million calories. During the approximately 20 years of dependency, a child consumes 13.7 million calories and produces 6.9 million calories, yielding a net consumption of about 6.8 million calories. On average, an adult between the ages of 45 and 65 is capable of supporting their own consumption, and the caloric demands of a total of 2.83 offspring raised from birth to self-sufficiency.

[2] The age of "acquisition" that we refer to in this paper is not to be confused with the initial age of guided or delegated skill performance. Before reaching the age of "acquisition", when a skill is mastered and can be performed independently and competently, younger novices will be delegated or elect to perform and practice skills, though often under guidance or recourse to aid.

[3] The onset of the growth spurt is at approximately age 10 for females and 12 for males (Bogin & Smith 1996).

[4] When kin and non-kin villagers refer to older Tsimane publicly, they often confer honorary titles like *jayej* (grandmother) or *via'* (grandfather). Tsimane elders are also consulted and respected for their reliable knowledge of traditional stories and myths, ethics for living in accordance with (and not angering) the spirit-world, animal and plant knowledge, locations of hunting grounds and sacred locations, and superior knowledge of family lineage histories and past events (Iamele, 2001).

[5] Skills 1, 3, 7, 10, 39, 41, 44, 45, 61, 68, 72, 73, 80, 85, and 92 in Online Supplement 1.

[6] We control for interviewer effects in all multivariate analyses reported here. We do find statistically significant interviewer effects on reports of having skills, proficiency at skills and expert nominations (see Online Supplement 4 for details). We parameterize our multivariate statistical models so that results discussed below are for "the average interviewer."

[7] All experts nominated in this study were from the same 8 villages that the judges were from. Furthermore, of the 22,170 nominations made, 99% were of adults (mean age 44, SD 14) living within the same village as the judge. Because all nomination "targets" are from within the sample of 8 villages, for the purpose of all analyses in this paper, we consider the set of potential expert nomination targets, for dual-gender skills, to include the 421 judges plus an additional 176 nominated experts from the 8 villages sampled.

[8] When possible, informants were asked to identify years of age, however some informants preferred using an indigenous system of age-grades that had been systematically identified in pilot interviews and was used in conjunction with a series of photographs of known-age male and female Tsimane who were from outside the study sample. Informants who responded with Tsimane terms for age-grades were asked to further refine their answers by choosing a photograph that was most likely representative of the age they had in mind within that age-grade.

[9] Average values $\overline{PD}^s$ and $\overline{LD}^s$ of informants' ratings of performance difficulty and learning difficulty, respectively, are given in Online Supplement 1. The composite difficulty measure $D^s = -7.97 + 1.54 \cdot \overline{PD}^s + 2.95 \cdot \overline{LD}^s$. This is the first principal component (across skills) of the average performance and learning difficulty measures, scaled to have unit variance.

[10] Most of the time maxima are interior maxima with interior confidence intervals derived from tests on the slope of the polynomial. However, some age profiles increase or decrease over the entire age range, so maxima are observed at corners: In this case, confidence intervals are derived from test on the level of the polynomial.

[11] For both males and females, eight of the ten possible pairwise comparisons of skill categories reject a zero median difference in mean acquisition age at $p < 0.01$.

[12] There is no significant main effect of gender ($F_{1,361}$= 0.07, p = 0.79) but there is a strongly significant interaction between gender and age cohort ($F_{3,361}$= 5.39, p = 0.0012) as suggested by Figure 2's disjoint confidence intervals for male and female proportions in age cohort 21-30. The age effect remains significant when only the two age

cohorts aged > 40 years are compared ($F_{1,120}$= 4.22, p = 0.042): This is the most convincing demonstration of a cohort difference since none of the informants reported any skill acquisition after age 40.

[13] Tsimane grandparents are often primary caretakers when parents divorce or die: Gurven and Schniter (2010) report that "17% of adult Tsimane interviewees had a parent die before age 18, and 19% of these went to live with a grandparent". Grandparents account for 8% of all identified active and passive skill transmission during the early life acquisition process (Gurven & Kaplan, 2008; Schniter, 2009), and are twice as likely to be identified as sources for rare but important skills, such as making pottery, punishing bad behavior, singing traditional songs, and telling old stories and myths.

[14] Psychological constraints in perception and signal detection are expected to deter awareness of change unless minimum thresholds of difference from a prior belief are observed. Attentional blindness to change (decrease) in proficiency may be greater after having experienced a decade of relative stasis (at peak levels). Furthermore, an informant needs to evaluate whether sudden or sustained downward trends in knowledge and performance should be attributed to actual proficiency declines or noise (see Hill & Kintigh, 2009). Temporal self-appraisal theories (Wilson & Ross, 2001) suggest that people tend to perceive their own current abilities as better than in the past. In light of this perceptual bias, it is reasonable that several years of downturn may be necessary for informants to reliably detect and admit their own decline.

[15] For example, a few females considered themselves to have skill #46 "speak in front of a group". Likewise, a few males considered themselves to have skill #34 "make small square mat". These exceptions were few and quantitatively insufficient for meaningful interpretation in terms of acquisition, proficiency, and expertise measures.

Table 1 Percentiles for Mean Acquisition Ages Reported by Informants by Categories.

Females

	Repro & Rearing			Food Production			Chores & Crafts			Social & Market			Music & Stories		
Centile	90	75	50	90	75	50	90	75	50	90	75	50	90	75	50
Point estimate	17.4	15.8	14.6	15.0	14.0	13.2	15.8	14.5	13.6	18.3	16.0	14.0	20.0	18.0	16.0
Upper C.I. 95%	18.3	16.3	15.0	15.7	14.3	13.5	16.6	14.8	13.7	19.8	16.5	14.5	21.0	19.0	17.0

Males

	Repro & Rearing			Food Production			Chores & Crafts			Social & Market			Music & Stories		
Centile	90	75	50	90	75	50	90	75	50	90	75	50	90	75	50
Point estimate	20.0	18.0	16.0	16.4	15.1	14.1	18.3	16.8	15.6	21.0	17.0	15.0	22.5	19.5	17.0
Upper C.I. 95%	20.6	18.2	16.5	17.2	15.4	14.5	19.2	17.0	16.0	24.0	18.0	15.3	25.5	20.3	17.3

Percentile: For example, “75” means “75 percent of informants’ mean acquisition ages are less than or equal to the value shown in the “point estimate” row. The unit of observation reported in the point estimate row is mean acquisition age in a category for all skills reported by each informant. Upper C.I. 95%: This is a distribution-free, rank-based upper confidence limit (at 5% significance, one-tailed) for the point estimated age at each centile.

Fig. 1. Cumulative distribution functions (CDFs) of self-reported acquisition age for skills in five categories: food production, household chores and craft production, social and market activity, childcare and reproduction, music and stories. Few skills are acquired before adolescence (approximately 6% for females and 13% for males), most skills are acquired during adolescence (approximately 84% for females and 78% for males) and the remaining skills (approximately 10% for females and 9% for males) are acquired during early adulthood. During adolescence females acquired 78% of childcare and reproduction, 71% of food production, 78% of household chore and craft production, 74% of social and market, and 70% of music and story-telling skills. During adolescence, males acquired 74% of childcare and reproduction, 64% of food production, 71% of household chore and craft production, 70% of social and market activity, and 75% of music and story-telling skills.

Fig. 2. Proportion of all (gender-appropriate) skills held by informants in each age cohort. For each male informant *i* this is $\overline{H}_i = \sum_s H_i^s/69$; for each female informant this is $\overline{H}_i = \sum_s H_i^s/48$.

Figure 3. Children's yearly total caloric demands by parental age and an average parent's age-specific yearly production (gross) and provisioning rates (production minus consumption). Caloric demands of children peak in the mid-30's and remain high until the fifth decade of life, while peak (gross and net) productivity peaks in the mid-40's.

Fig. 4. "Very proficient" self-ratings: (a) of food production & childrearing skills, and gross caloric production, and (b) of food production skills and gross caloric production. The vertical axis is log odds ratio change (relative to age 35) of "very-proficient" self-ratings for specified skills and the log caloric production change (relative to age 35 log caloric production). We found no significant difference in polynomials between males and females "very proficient" self-reports or gross production and so results are pooled by sex. A proficiency peak for skills essential to childrearing (reproduction, childcare, and food production skills) is seen from age 44 to 56 years for all food production, reproduction, and childcare skills and 46 to 62 for food production skills. The peak ages of caloric productivity are 39-51, substantially overlapping with peak ages of proficiency for specified skills.
]

Fig. 5. Consensus expertise: food production skills of (a) females and (b) males. The vertical axes are log odds ratio change (relative to age 35) of consensus expertise nominations received for food production skills. In both female (a) and male (b) figures the likelihood of being nominated expert for skills requiring strength is higher at younger ages (i.e. ages 17-34 and 36-41 for males, and between 16-27 for females). At younger ages the slopes of high-strength and low-strength skills are different with the likelihood of being nominated an expert in low-strength skills increasing at a faster rate (17-37 for males and 16-31 for females). At older ages (68-75 for males and 60-70 for females) the slopes are again different, creating a difference in height where the likelihood of being nominated expert for low-strength skills is higher (72-85 for males and 66-77 for females). The peak ages of consensus expertise for low-strength skills are late in the post-reproductive stage (57-77 for females and 64-75 for males) whereas the peak ages for consensus expertise for high-strength food production skills are earlier (40-64 for females and 62-70 for males).

Fig. 6. Consensus expertise and "very proficient" self-ratings: non-food production skills, not requiring strength. The vertical axis is log odds ratio change (relative to age 35) of consensus expertise nominations received and "very-proficient" self-ratings for non-food production skills not requiring strength. We found no significant difference in polynomials between males and females for "very proficient" self-ratings of these skills and so plot their pooled results for that measure. The peak ages of consensus expertise (51-77 for females and 45-52 for males) and for "very-proficient" self-ratings (44-61) are almost completely in the post-reproductive stage.

Fig. 7. Scatterplots showing informants' shares of reported skills by informant age for the following: (a) females' skills requiring high strength, (b) females' most difficult skills, (c) males' skills requiring high strength, and (d) males' most difficult skills. (a) and (c) show decreases with age in the shares of skills requiring strength; (b) and (d) show increases in shares of most difficult skills from the top half of the difficulty distribution. The difficulty distribution is based on a composite measure combining perceived performance and learning difficulty, for which separate results are virtually identical when examined separately (not shown).

Fig. 8. "Very proficient" self-ratings of skills varying by: (a) strength requirements, (b) difficulty. The vertical axis is log odds ratio change (relative to age 35) of "very-proficient" self-ratings for specified skill of type. For each

type of skill examined, we found no significant difference in polynomials between males and females and so plot their pooled results. “Very proficient” self-evaluations peak among older-adults with ages in the post reproductive stage. Maxima for these “very proficient” self-ratings are from ages 42 to 77 for least difficult, from ages 47 to 63 for most difficult, 45-68 for strength-requiring, and 45-57 for not requiring strength skills. Slopes of “very proficient” age profiles for skills requiring strength and skills not requiring strength are significantly different from ages 69 to 77 and slopes for most difficult and least difficult are significantly different from 65 to 77. Heights of “very proficient” age profiles for most difficult and least difficult skills significantly differ from ages 41 to 62 and at 77.

Fig. 9. Consensus expertise and “very proficient” self-ratings: all skills. The vertical axis is log odds ratio change (relative to age 35) of consensus expertise nominations received and "very-proficient" self-ratings for all skills. We found no significant difference in polynomials between males and females for “very proficient” self-ratings and so plot their pooled results for that measure. The peak ages of consensus expertise (49-77 for females and 59-73 for males) and for "very-proficient" self-ratings (45-60) are in the post-reproductive stage.

Fig. 10. Consensus expertise for categories of skills. The vertical axis is log odds ratio change (relative to age 35) of consensus expertise nominations received for categories of skills. The horizontal axes is age of (a) female, and (b) male informant. In both female and male figures the likelihood of being nominated expert for “social and market” skills is highest at the end of the reproductive life stage (from ages 36 to 43 for females and 40 to 46 for males). Likelihood of consensus expertise nomination for “Reproduction and childcare” is highest from age 45 to 57 for females and 38 to 86 for males. Expertise for “chores and crafts” peaks in the post reproductive life stage (from ages 59 to 77 for females and 55 to 86 for males) as does expertise for “food production” (from ages 36 to 77 for females and 63 to 72 for males). Finally, peak expertise for “music and stories” is first recognized at the relatively latest ages, from ages 65 to 77 for females and 66 to 86 for males. As a general pattern relative to age thirty-five, larger gains in consensus expertise are seen for categories with maxima beginning at later ages.

Cumulative distribution functions (CDFs) of self-reported acquisition age for skills in five categories: food production, household chores and craft production, social and market activity, childcare and reproduction, music and stories.

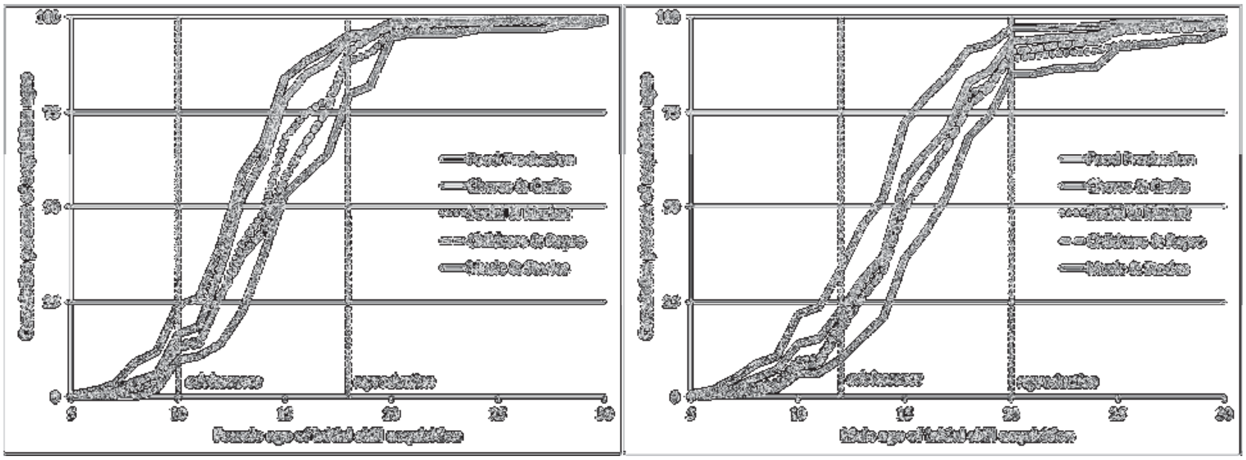

Fig. 1.

Proportion of all (gender-appropriate) skills held by informants in each age cohort.

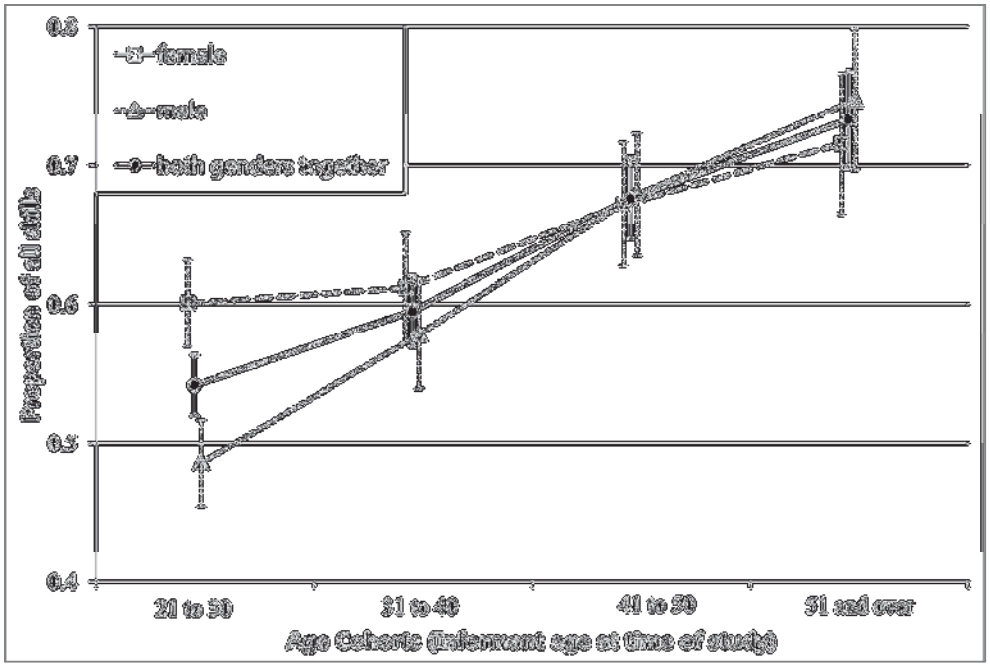

Fig. 2.

Children's yearly total caloric demands by parental age and an average parent's age-specific yearly production (gross) and provisioning rates (production minus consumption).

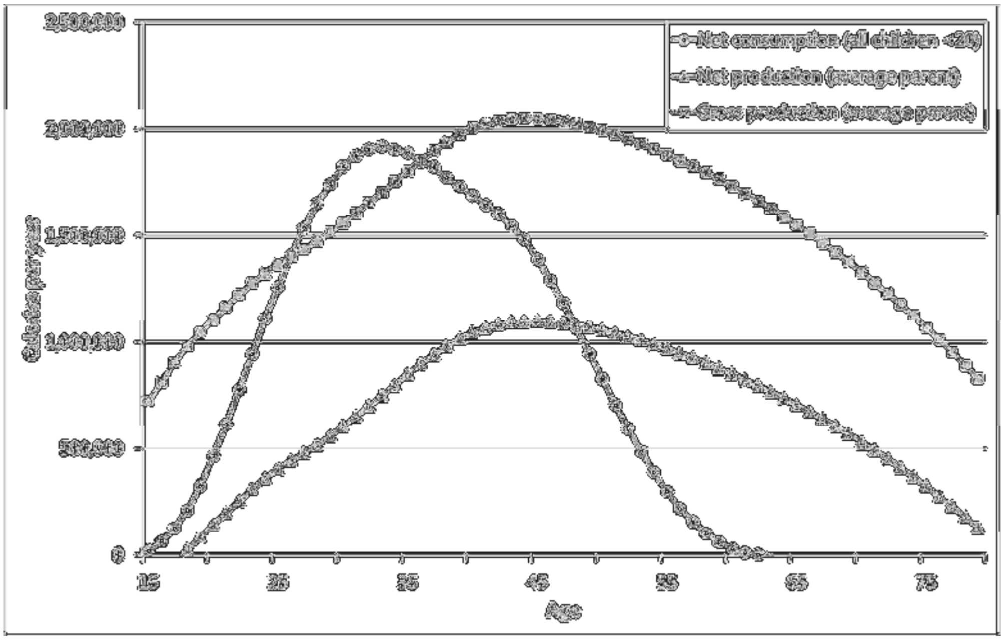

Fig. 3.

“Very proficient” self-ratings: (a) of food production & childrearing skills, and gross caloric production, and (b) of food production skills and gross caloric production.

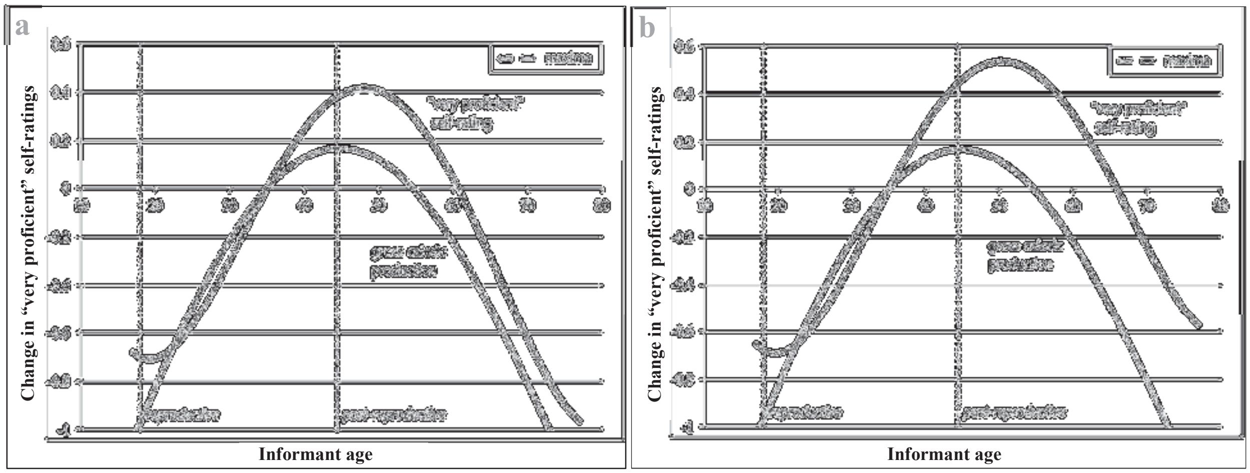

Fig. 4.

Consensus expertise: food production skills of (a) females and (b) males.

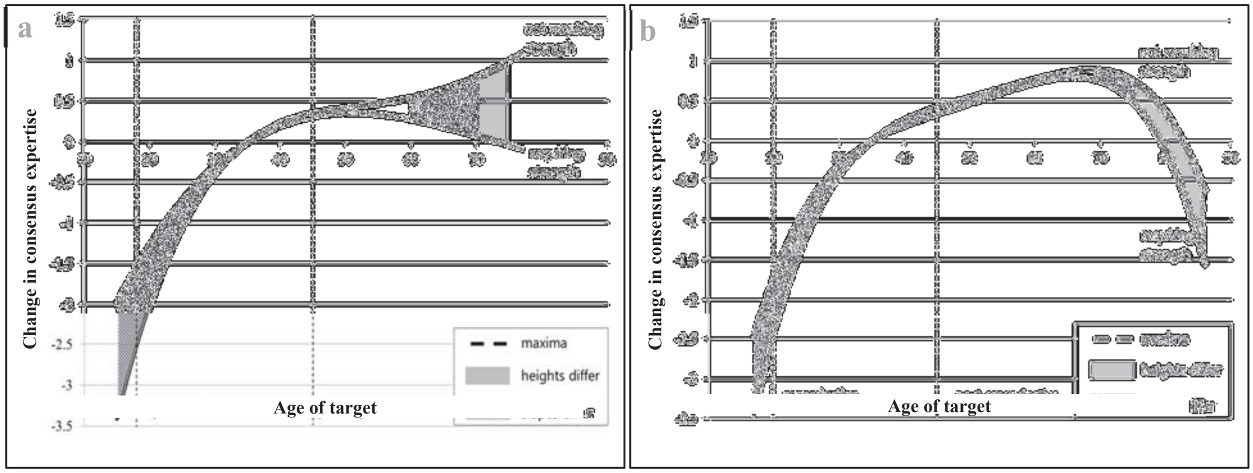

Fig. 5.

Tsimane Skill Ontogeny

Consensus expertise and "very proficient" self-ratings: non-food production skills, not requiring strength.

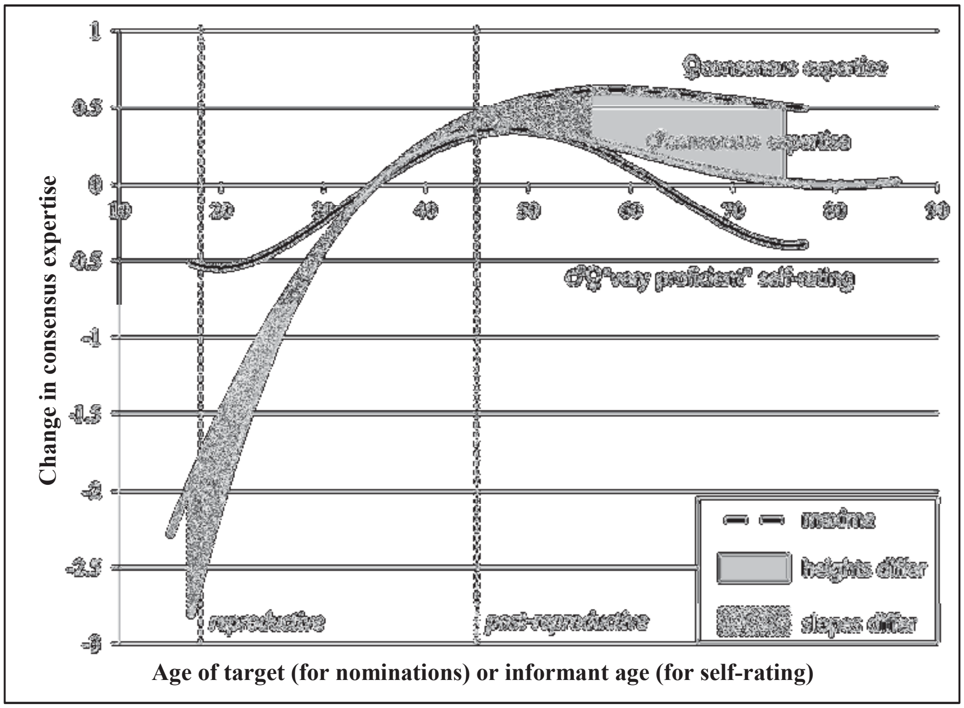

Fig. 6.

Scatterplots showing informants' shares of reported skills by informant age for the following: (a) females' skills requiring high strength, (b) females' most difficult skills, (c) males' skills requiring high strength, and (d) males' most difficult skills.

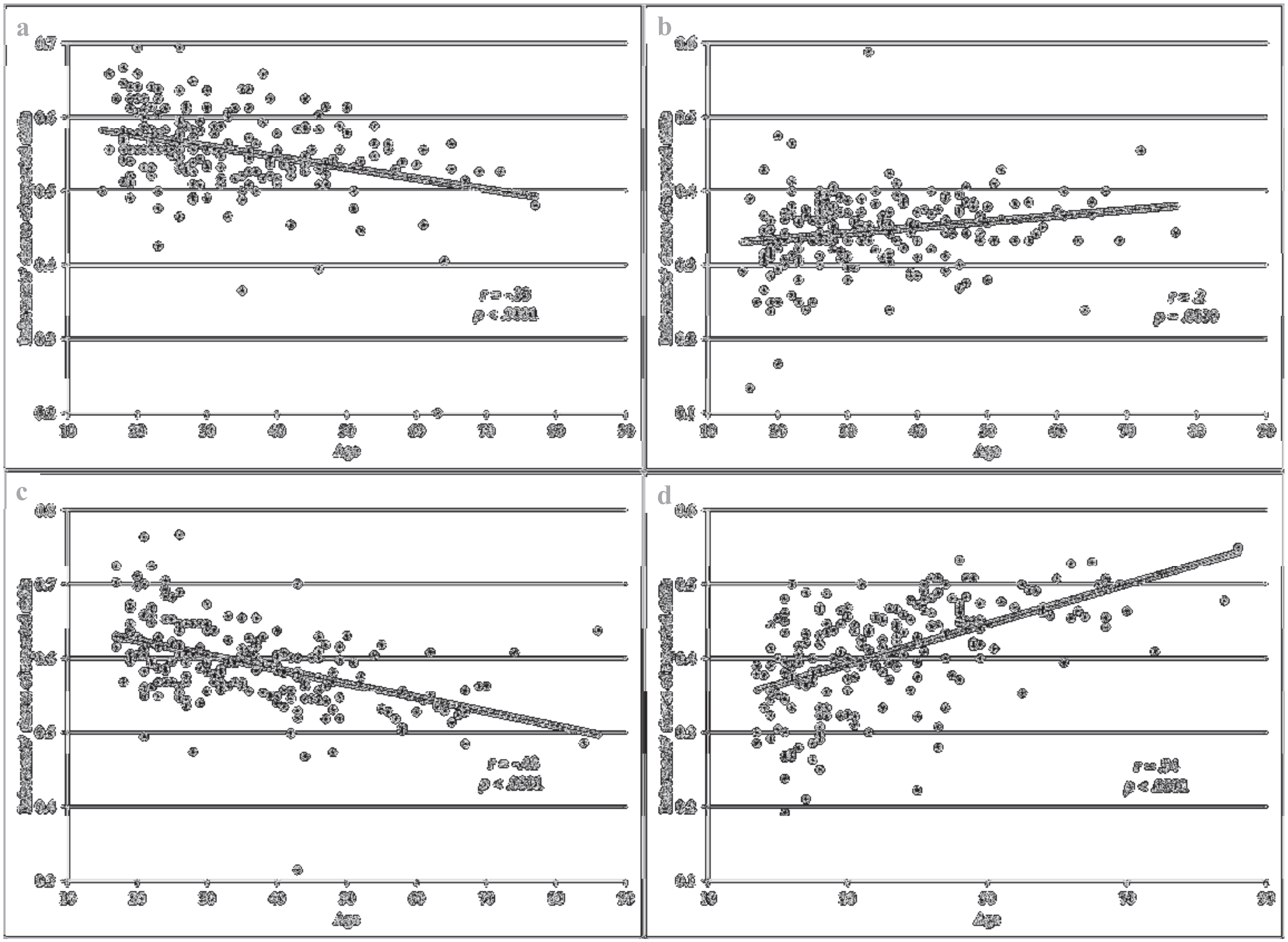

Fig. 7.

"Very proficient" self-ratings of skills varying by: (a) strength requirements, (b) difficulty.

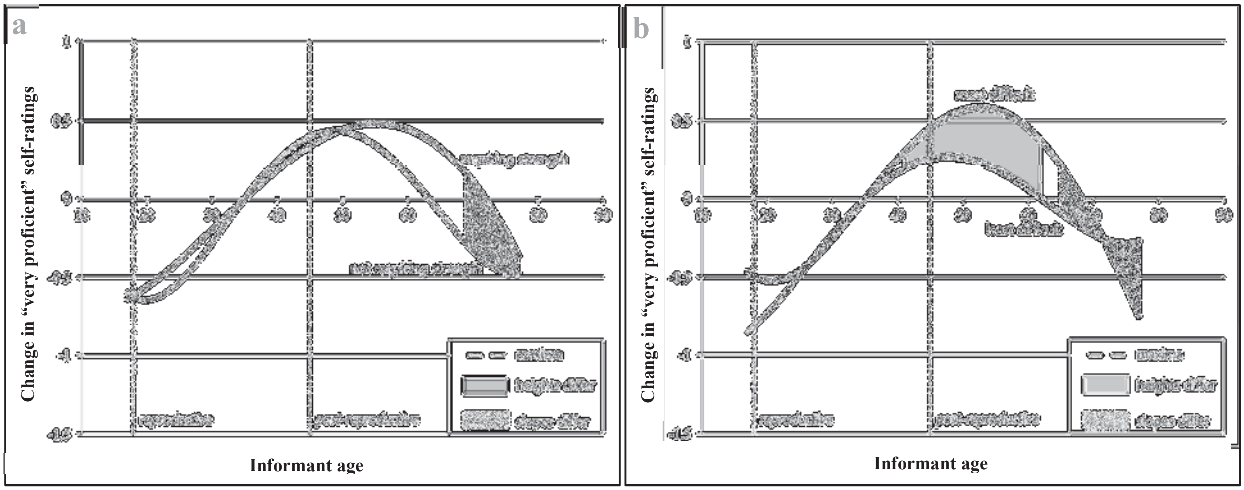

Fig. 8.

Consensus expertise and "very proficient" self-ratings: all skills.

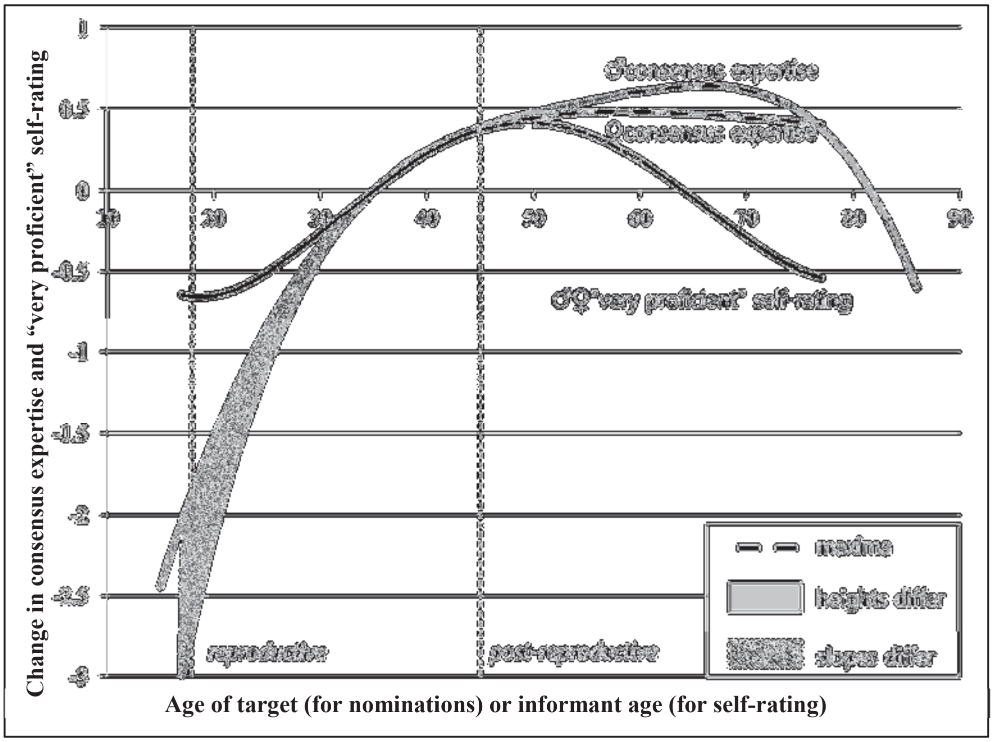

Fig. 9.

Consensus expertise for categories of skills.

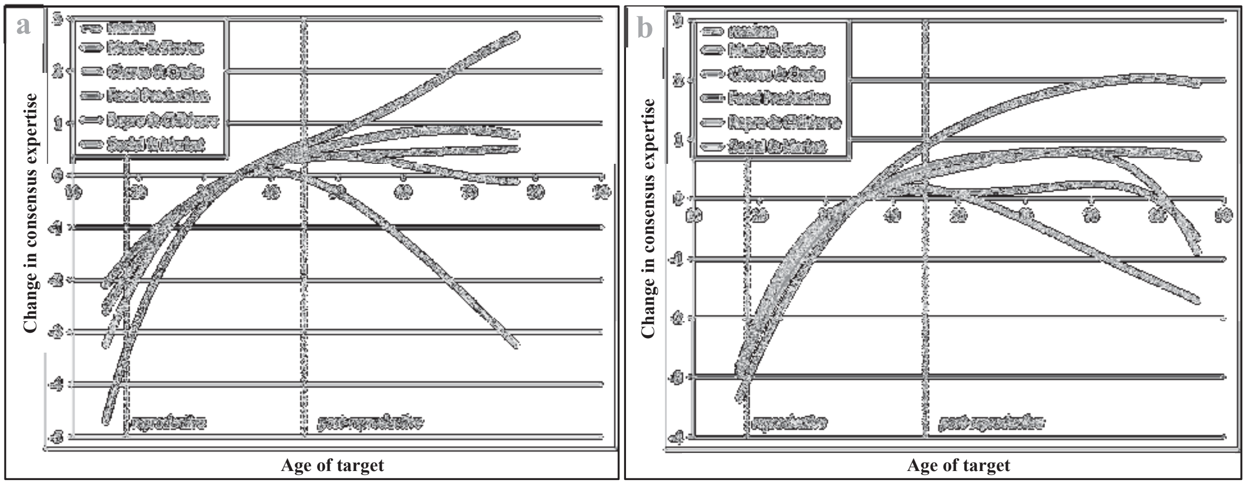

Fig. 10.

Online Supplement 1: 92 Essential skills investigated with the *Skills Survey*, ranked by difficulty.

Gender Specific	Skill #	Skill Description	Performance Difficulty (SEM) μ = 1.96	Learning Difficulty (SEM) μ = 1.55	Difficulty Composite[1]
♀	1	make ceramic vessels	2.50 (.289)	2.25 (.250)	2.518
♀	2	give birth	2.91 (.026)	2.02 (.033)	2.470
♂	3	make wheel barrow / cart	2.76 (.106)	2.06 (.059)	2.357
♂	4	make canoe	2.78 (.060)	2.03 (.048)	2.300
♂	5	make trough	2.77 (.054)	1.94 (.049)	2.019
♂	6	make bass drum	2.59 (.093)	1.97 (.060)	1.830
♀	7	make loom rod for weaving	2.56 (.166)	1.94 (.127)	1.695
♂	8	make wood grinding plate	2.73 (.056)	1.82 (.043)	1.603
♂	9	make snare drum	2.66 (.081)	1.77 (.072)	1.348
	10	get / process bark cloth	2.73 (.065)	1.73 (.056)	1.338
♂	11	make violin	2.66 (.094)	1.76 (.088)	1.318
	12	make beer strainer	2.52 (.084)	1.83 (.067)	1.309
♂	13	make rice pounder	2.49 (.059)	1.80 (.040)	1.175
	14	treat / heal sick children	2.53 (.040)	1.76 (.028)	1.118
	15	obtain honey	2.60 (.050)	1.72 (.038)	1.108
♂	16	make comb	2.48 (.075)	1.76 (.062)	1.041
♂	17	make house	2.44 (.045)	1.78 (.033)	1.039
♀	18	weave purse	2.44 (.059)	1.77 (.037)	1.009
♂	19	play violin	2.37 (.105)	1.77 (.073)	0.901
	20	get to San Borja	2.42 (.042)	1.74 (.024)	0.890
	21	direct and order	2.32 (.092)	1.76 (.061)	0.795
♂	22	play flute	2.26 (.110)	1.78 (.082)	0.761
♂	23	make axe handle	2.33 (.057)	1.73 (.040)	0.722
♂	24	use magic amber	2.46 (.090)	1.66 (.058)	0.715
	25	make woven hat	2.23 (.145)	1.77 (.089)	0.686
♂	26	organize a group of community members	2.13 (.124)	1.80 (.088)	0.620
	27	use axe	2.30 (.037)	1.71 (.025)	0.617
♀	28	make thread	2.32 (.060)	1.69 (.042)	0.588
	29	train hunting dogs	2.37 (.054)	1.66 (.037)	0.577
	30	compose music	2.27 (.135)	1.70 (.098)	0.541
♂	31	play snare drum	2.26 (.098)	1.70 (.079)	0.525
	32	how to weed garden	2.39 (.036)	1.63 (.026)	0.519
	33	make smoking rack	2.32 (.064)	1.65 (.045)	0.470
♀	34	make small square mat	2.28 (.113)	1.67 (.065)	0.468
♂	35	track animals	2.29 (.057)	1.66 (.035)	0.454
	36	find, produce and use various barbascos	2.23 (.047)	1.68 (.032)	0.420
♂	37	make bow	2.24 (.063)	1.67 (.041)	0.406
	38	know traditional stories / myths	2.22 (.102)	1.68 (.088)	0.405
	39	obtain work with traders, loggers, ranchers	2.27 (.062)	1.65 (.039)	0.393
	40	sing in front of group	1.86 (.155)	1.86 (.108)	0.381
	41	beat or punish the bad	2.27 (.237)	1.64 (.152)	0.364
♀	42	make clothes	2.25 (.078)	1.64 (.050)	0.333
	43	identify medicinal plants	2.26 (.050)	1.62 (.035)	0.289
	44	sing in private	1.93 (.074)	1.78 (.044)	0.253
	45	obtain government subsidies	2.18 (.296)	1.64 (.152)	0.225
♂	46	speak in front of group	2.14 (.143)	1.66 (.091)	0.223

[1] $\text{Difficulty composite} = -7.97 + 1.54 \cdot \text{Performance Difficulty} + 2.95 \cdot \text{Learning Difficulty}$

Gender Specific	Skill #	Skill Description	Performance Difficulty (SEM) μ = 1.96	Learning Difficulty (SEM) μ = 1.55	Difficulty Composite[1]
	47	care for children to make them stop crying	2.22 (.046)	1.59 (.029)	0.139
♂	48	make weir / fish trap	2.21 (.066)	1.59 (.046)	0.124
	49	weave jatata	2.12 (.045)	1.59 (.028)	-0.015
♂	50	skin animal hides	2.29 (.090)	1.49 (.060)	-0.048
	51	know how women can avoid having children	2.15 (.099)	1.55 (.066)	-0.086
♂	52	make flute	1.88 (.106)	1.68 (.066)	-0.119
	53	sell products	2.00 (.049)	1.61 (.030)	-0.140
	54	know wild animals diet, habits, and where to find	2.05 (.039)	1.58 (.029)	-0.152
♂	55	travel in the woods without fear	2.02 (.059)	1.57 (.039)	-0.228
	56	interpret dreams	2.10 (.065)	1.51 (.043)	-0.281
	57	process rice	2.03 (.041)	1.53 (.027)	-0.330
♂	58	obtain sexual exploits	2.01 (.079)	1.53 (.048)	-0.361
	59	play bass drum	2.00 (.088)	1.51 (.062)	-0.435
	60	treat / heal children suffering from insect bites, wounds	1.91 (.048)	1.55 (.032)	-0.456
	61	how to sow or harvest with a machine	1.79 (.059)	1.61 (.039)	-0.464
♂	62	make arrows	1.81 (.061)	1.59 (.041)	-0.492
♀	63	dye thread	1.90 (.073)	1.51 (.044)	-0.590
♂	64	make raft	1.93 (.063)	1.49 (.040)	-0.602
	65	care for fowl and animal domesticates	1.95 (.050)	1.47 (.029)	-0.631
	66	use machete	1.86 (.039)	1.51 (.026)	-0.651
	67	know how to find a good place for garden	1.93 (.046)	1.47 (.029)	-0.661
	68	collect fire wood / build and tend fire	1.92 (.041)	1.47 (.026)	-0.677
	69	pole canoe / raft	1.78 (.051)	1.52 (.032)	-0.745
	70	make large hamper basket	1.74 (.052)	1.52 (.033)	-0.806
♀	71	make large woven mat	1.81 (.060)	1.48 (.037)	-0.817
	72	quarter, clean meat	1.78 (.043)	1.48 (.027)	-0.863
	73	smoke fish and meats	1.75 (.042)	1.46 (.027)	-0.968
♂	74	get in the water without fear	1.97 (.077)	1.34 (.055)	-0.983
	75	identify wild animals	1.75 (.037)	1.45 (.026)	-0.998
	76	identify animal tracks and markings	1.72 (.040)	1.46 (.026)	-1.014
	77	house-sit	1.74 (.058)	1.44 (.034)	-1.042
♂	78	shoot arrows	1.62 (.057)	1.50 (.039)	-1.050
	79	identify different fish	1.74 (.040)	1.43 (.026)	-1.072
♀	80	breast feed	1.71 (.062)	1.43 (.039)	-1.118
♂	81	fire shotgun or rifle	1.60 (.051)	1.48 (.037)	-1.140
	82	clean and change children	1.65 (.042)	1.42 (.028)	-1.240
	83	repair clothes	1.61 (.043)	1.43 (.029)	-1.272
♀	84	make baby diaper / sling	1.68 (.077)	1.38 (.046)	-1.312
	85	feed children	1.61 (.042)	1.40 (.025)	-1.361
♂	86	arrow shoot fish	1.52 (.054)	1.44 (.038)	-1.381
	87	know how and when to burn field	1.60 (.041)	1.35 (.026)	-1.524
	88	know where to find fish	1.51 (.037)	1.37 (.025)	-1.603
	89	identify wild fruits	1.43 (.035)	1.36 (.024)	-1.756
	90	make fan	1.39 (.039)	1.38 (.029)	-1.758
	91	joke around with people /make others laugh	1.46 (.044)	1.34 (.031)	-1.769
	92	gut fish	1.22 (.026)	1.28 (.023)	-2.315

[1] Difficulty composite $= -7.97 + 1.54 \cdot \text{Performance Difficulty} + 2.95 \cdot \text{Learning Difficulty}$

Online Supplement 2: Skill Categories
Categories (1) and (2) contain all skills from the *Skills Survey*. Categories (1) and (2) and the subsets within are mutually exclusive.

(1) Food production and childrearing

food production: 15, 24, 27, 29, 32, 33, 35, 36, 48, 50, 54, 55, 57, 61, 66, 67, 69, 72, 74, 75, 76, 78, 79, 81, 86, 87, 88, 89, 92

tool use: 27, 66, 69

hunting: 15, 24, 29, 35, 54, 55, 75, 76, 78, 81, 89

fishing: 36, 48, 74, 79, 86, 88

gardening & husbandry: 32, 61, 65, 67, 87

food processing: 33, 50, 57, 72, 73, 92

childcare and reproduction: 2, 14, 43, 47, 51, 58, 60, 80, 82, 85

(2) Complementary skills important to family organization, cooperation, and socialization

household chores & craft production: 1, 3, 5, 7, 8, 10, 12, 13, 16, 17, 18, 23, 25, 28, 34, 37, 42, 49, 62, 63, 64, 67, 68, 70, 71, 77, 83, 84, 90

household chores: 68, 77

craft production: 1, 3, 5, 7, 8, 10, 12, 13, 16, 17, 18, 23, 25, 28, 34, 37, 42, 49, 62, 63, 64, 67, 70, 71, 83, 84, 90

large or hardwood woodwork: 3, 5, 8, 13, 17, 23, 64, 67

small item woodwork: 7, 16, 37, 62

textiles: 18, 28, 42, 63, 83, 84

coarse woven: 12, 34, 49, 70, 71, 90

old tradition: 1, 10, 25

social and market: 20, 21, 26, 39, 41, 45, 46, 53, 91

social activity: 21, 26, 41, 46, 91

market activity: 20, 39, 45, 53

music and stories: 6, 9, 11, 19, 22, 30, 31, 38, 40, 44, 52, 56, 59

music: 6, 9, 11, 19, 22, 30, 31, 40, 44, 52, 59

stories & dreams: 38, 56

(3) Other categories for comparing skills (alternative to categories (1) and (2) above)

categories capturing secular trends

traditional skills common in the sample and expected to be common in samples of subsequent generations: 14, 27, 32, 60, 65, 66, 69, 75, 87, 88

traditional skills suspected to be "vanishing" (i.e., will not be acquired by younger or next generations): 1, 3, 6, 9, 10, 11, 25, 37, 38, 43, 62

"modern" skills: 26, 39, 61

categories based on high strength-requirement for practicing skill

requiring strength: 2, 15, 17, 27, 32, 35, 36, 39, 41, 57, 61, 66, 67, 69, 74

not-requiring strength: 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 28, 29, 30, 31, 33, 34, 37, 38, 40, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 58, 59, 60, 62, 63, 64, 65, 68, 70, 71, 72, 73, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92

categories based on type of production associated with skill

food production: 15, 24, 27, 29, 32, 33, 35, 36, 48, 50, 54, 55, 57, 61, 66, 67, 68, 69, 72, 73, 74, 75, 76, 78, 79, 81, 86, 87, 88, 89, 92

non-food production: 1, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 17, 18, 19, 22, 23, 25, 28, 30, 31, 34, 37, 38, 40, 42, 43, 44, 45, 49, 51, 52, 56, 59, 62, 63, 64, 65, 67, 70, 71, 77, 83, 84, 90

Online Supplement 3: Ethnographic information about food production and childcare, and complementary skill categories.

(1) Food production and childrearing

Food Production

Food production requires competence with basic tool use skills and is dependent on food sourced through hunting, fishing, gardening, and animal husbandry. Food material typically requires processing before it is available for consumption. Below we discuss food production skills (twenty nine of which were investigated in the *Skills Survey*) organized into five subcategories: tool use, hunting, fishing, gardening and animal husbandry, and food processing.

Tool Use

Three skills were investigated in the tool use category: use an axe, use a machete, pole a canoe/ raft. These skills are important requisites for basic transportation, foraging, garden work, food production, and craft production.

Hunting

Despite lack of the superior strength, tough hides, sharp teeth, claws, and speed that non-human predators in the Amazon rely upon, Tsimane hunters are extremely successful predators due to their utilization of skills that often rely on stealth, ambush, clever pursuit techniques, culturally and individually learned strategies, and weaponry. Human hunters' skills utilize inter-generationally transmitted and accumulated knowledge with context specific applications concerning information about the local environment, geographic and seasonal distributions and variations, patterns of animal behavior, tools for improving hunting success, and specific knowledge of what to do when specific game is encountered (Liebenberg, 1990; MacDonald, 2007). With experience, Tsimane hunters not only acquire a variety of practical hunting skills and knowledge that they can apply to a wide variety of hunting situations to increase their efficiency and productivity, but they also acquire the confidence that allows them to travel through remote or unknown areas of forest, effectively find their way when disoriented, and to hunt without fear. Less experienced hunters are often inhibited by their lack of skills, poor navigation, poor reactions to problems, and fear of both dangers and the unknown. The greatest source of protein for Tsimane is from hunted game (Chicchón, 1992) that plays a varyingly important role in the diet depending on the game densities surrounding each community. A wide variety of game (birds, mammals, reptiles) are hunted for consumption, making the identifications and knowledge of their distinctions important.[1] Natural resources like fruiting trees, fresh water, and salt licks attract wild fauna while anthropic products (e.g. motorized equipment) and locations (especially San Borja) deter them.

Among the Tsimane, hunting is generally an activity for men and adolescent males, and along with fishing, is practiced year-round and throughout Tsimaneland. Hunting styles vary considerably, based on weaponry, strategy, route, prey choice, time of day, weather, use of calls, dogs, and many more factors. When hunting with dogs, women will sometimes assist, but not often. Before ever being brought along on serious hunting excursions, male children as young as 3 years of age begin playing at hunting and related activities within the safety of their homes and villages, using scaled down versions of bows and arrows, worn out and discarded machetes, and by practicing

[1] The most sought after and valued types of meat are from collared peccary or "taitetu" (*quitivare*), agouti paca or "jochi pintado" (*naca'*), gray brocket deer or "huaso" (*ñej*) (Gurven & von Rueden, 2006), as well as tapir or "anta" (*shi'*). In terms of biomass harvested from hunting, a multi-season sample of Cuverene and Aperecito hunts (Gurven et al., 2006) determined that the most abundant resources – in order from more to less—are collared peccary, tapir, deer, howler monkey or "mono manechi" (*uru'*), agouti paca, white-faced capuchin monkey or "mono silbador" (*oyoj'*), and ring-tailed coati or "tejon" (*chu'*). Together, these seven species constituted 82% of the biomass, or 70% of all kills in recorded in the sampled presented by Gurven, Kaplan, & Gutierrez (2006). Other common prey animals include capibara (*oto'*), turtle or "peta" (*quijbo*), seven-banded and nine-banded armadillo or "tatú" (*curibu*, *väsh*), and cracid birds: "mutun" (*opaj*), "pava roncadora" (*emej*), "perdiz" (*fofor*), and "tapacare" *(chajaj*). Less common prey animals are white-lipped peccaries or "chancho de tropa" (*mumujñi*), spider monkeys or "marimono" (*odo'*), squirrel monkey or "chichilo" (*chichi*), owl monkey or "mono nocturno" (*isbara'*), collared anteater or "oso bandera" (*yushi'*), giant anteater or "oso hormiguero" (*o'oyo*), and kinkajou or "mono michi" (*voyo'*).

throwing objects and aiming at targets. As a result of child involvement with and proximity to game processing, and the simultaneity of hunting stories that are often told and retold by hunters, children become familiar with identification of the various game species and acquainted with knowledge of hunting strategies and corresponding animal behaviors, long before they have had their first opportunities to sample these hunting experiences first hand or view live prey in their natural habitats. In addition to accompanying adult hunters, adolescents will often go on small hunting and fishing expeditions with only a sibling or a friend close in age. By the time that males are in their upper teens or early twenties they often begin hunting by themselves. Hunting is most often a solitary activity, but hunting parties are sometimes composed of small groups of related individuals or friends. Most men hunt about twice a week, although some men hunt more and others less (Gurven et al., 2006). Tsimane men often comment that they enjoy and find excitement —and even a sense of peace—in the activity of hunting, and that hunting excursions provide them an opportunity to get away from their home lives, garden work, and other daily activities. Hunting excursions also provide opportunity for fishing (see below) and collecting honey from wild bee colonies. Honey "hunting" and collection requires knowledge of bees and their ecology (some flying hive species are ferocious, potentially deadly, and to be avoided) and typically involves tree climbing or tree felling, honey-comb removal and storage, and may involve the use of smoke (e.g. see Demps et al 2012 discussion of the Jenu Kurubu).

Hunting ability and success make strong contributions to male status and mate value (Gurven and von Rueden, 2006), probably through demonstrating productivity, formidability, knowledge, and valuable experience. When asked, many Tsimane report that hunting success is dependent on strength, knowledge, and experience, but also behaving in accordance with certain superstitious beliefs. In the Tsimane cosmology, animals, fish and plants all have their own guardians and masters or *a'mo'* (Huanca, 2006). Tsimane believe in these spiritual agents with specific relationships to the ecology and dominion over game animals and who have sensitivities to the "right" and "wrong" behaviors of humans, as well as dreams foretelling the future, and magical relationships involving charms and objects. Perhaps one of the most pervasive superstitions regarding hunting success is the belief that possession and use of magic amber (*isatriz*) by hunters and hunting dogs can improve hunting success. Amber is believed to be capable of increasing the frequency of animal encounters for the hunter and is also believed to be capable of increasing stamina, giving strength, improving morale and motivation, and combating apathy and sloth. Some men claim they know where sources of the magic amber can be found (at least a two days journey or further into remote areas of Serrania Eva Eva within the Tsimane territory) and have found their own *isatriz*, while others have received amulets of magic amber and instructions for their use from older kin.

Eleven hunting skills were investigated: six pertaining to both men and women (i.e., identify wild fruits, identify animal tracks and markings, identify wild animals, know the habits of wild animals, train hunting dogs, collect honey), and six exclusive to men (i.e., shoot arrows, fire shotgun or rifle, track animals, travel in the woods without fear, use magic amber).

Fishing

Fish provide an important dietary contribution of fatty acids and protein to Tsimane, who by both hunting and fishing, diversify their diet. A wide variety of fish are extracted for consumption, making the identifications and knowledge of their distinctions important.[2]The amount of fishing that an individual practices varies with access to major rivers and streams, and with age (Gurven et al., 2009). Often hunting and fishing go hand-in-hand, with hunters stopping to fish when they encounter promising fishing holes along their way through the forest. Even small catches—to contribute to the family pot— may be worthwhile from the perspective of an unsuccessful hunter trying to hedge his bets against returning home empty handed. It may be that fishing also provides utility to the hunter by breaking up the hunting activity. Hook and line fishing, for example, gives hunters an opportunity to both rest a while and sit silently by the water, all the while keeping vigilant of sounds from animals visiting the water source or nearby. In general, returns from fishing are less productive than what might be achieved from hunting, but are less risky, especially for women and young adults, guaranteeing a contribution of protein that adds breadth to the diet.

[2] The most commonly caught fish is *Prochiludus nigricans* "sábalo" (*vonej*), a medium-sized spine-filled fish. Other commonly caught fish include various catfish, *Pimelodus clarias and Pimelodus* spp. or "bagre", sorubim fish *Pseudoplatystoma fasciatum* and *Pseudoplatystoma tigrinum* or "surubí" and "pintado" (*pishva, ítsiquidye, sona're'*), *Hoplias malabaricus* or "ventón" (*sheresherej*), *Schizodon fasiatum* or "pacusillo", and *Surubim lima* or "paleta" (*vatajta'*). Other fish that are caught also include *Brycon* spp. or "mamure", "mamure pintado", *Colossoma macropomum* or "pacú", various species of the Pimelodidae family or "blanquillo", *Salminus maxillosus* "dorado", *Brachyplatystoma filamentosum* "piraiba", and *Astronotus ocellatus* or "palometa real". This list is not exhaustive and many other caught varieties are unmentioned.

Fishing is usually done with line and hook, bow and arrow, with weirs and, or nets. Shooting fish with an arrow requires good shooting skill and is done by men in clear water or when fish are at the surface of the water, such as when poisoned by "barbasco" (any of a variety of botanical fish poisons). As it is often hard to see fish in murky water, bow and arrow are not always ideal and best suited for use under clean water conditions that occur in the dry season. Many fishing tasks require entering the water without fear, despite venturing out into deep sections of water, or entering areas with known rays, and biting fish (e.g. piranhas) or snakes. Barbasco fishing is often associated with group fishing events, where once or twice a year groups of families, and sometimes entire villages, use plant poisons to stun fish in closed-off sections of rivers, streams, and lagoons. During these events, several men perform most of the initial work (acquiring the plant poisons, selecting, routing, damming the body of water, prepared traps, cutting, processing, and administering the poison), and many more individuals, including women and children, harvest the fish with trap, machete, or knife. Women of all ages work at processing, smoking, and packaging the fish for transport. Smaller events that take place in a similar fashion, but with between one and three families on smaller tributaries and often with less field processing, tend to yield smaller fish but can still be quite productive. Modern technology (e.g. nylon netting, electrocution, dynamite) is not used much and does not have a large impact on Tsimane fishing.

While children are taken out on large barbasco outings even as babies, children will often start fishing at ages as young as 6-8 years, and even contribute their catches to the family meals. It is common for young boys and girls under the age of 15 to spend some of their time bathing and playing at water holes, while occasionally trying hook and line fishing somewhere in or close to the village. Some adolescents are avid fishers and will spend more time fishing daily than adults.

Six fishing skills were investigated: three pertaining to both men and women (know where to find fish, identify different fish, produce and use barbascos), and three exclusive to men (arrow shoot fish, make weir / fish trap, get in water without fear).

Gardening and Animal Husbandry

For the Tsimane, gardens are an extremely important subsistence source where they cultivate more than 80 species of plants (Piland, 1991) including tree crops, medicinal plants, palms for construction, tools, and weapons, cotton for textiles, fish poisons, 30 distinct varieties of manioc, 8 varieties of rice, 6 varieties of corn, and 11 varieties of plantain (Huanca, 1999). Studies among other Amazonian hunter-horticulturalists (Yanomamö, Achuar, Machiguenga, and Piro) have estimated that garden products (esp. plantains, manioc, corn and in some places, rice) make up over 70% of all consumed calories (see Hames, 1989; Gurven and Kaplan, 2006). While the bulk of protein and fat comes from faunal sources (including domesticated animals such as chicken, ducks, pigs), plant foods provide carbohydrates, dietary fiber, and a compliment of important macro and micronutrients. Almost all Tsimane adults practice polycrop horticulture with families maintaining several fields (each between approximately 0.1 and 1.25 hectares) in various stages of multi-year use, growth, and fallow.

Horticulture relies primarily on human labor input rather than machines, animals, plows, herbicides, pesticides, or irrigation. The responsibility of garden work is managed at the nuclear family level, although the most difficult chores, like clearing large garden spaces for marketable monocrops and rice harvest, are sometimes done with the help of extended family members or even migrant Tsimane workers (as is becoming increasingly commonplace among large mono-crop sites). Garden activities include burning of cut and dried plant materials and the use of steel machetes and axes for tree felling, garden clearing, weeding, planting, tending, and harvesting. The more strength intensive garden tasks (felling large trees and clearing thick underbrush) are male-specific, while much of general work such as planting, weeding, and tending is done by both genders. There are also two carrying tasks-- transporting firewood and harvests from the garden to the home--- that require great neck and back strength, and are frequently performed by women. Charred and dried logs that have remained after burning the fields are ideal for firewood. Women returning from work in the fields will typically transport firewood, or harvests – weighing up to 80 pounds per load— to their houses in cotton bags, baskets or makeshift slings suspended from their heads. Children frequently assist with harvesting and make significant contributions to the food processing tasks described below.

This small-scale gardening approach yields a moderate and consistent level of production, which distributes well among extended nuclear family production units but leaves little surplus (except that which goes toward social celebration in the form of *shocdye,* fermented manioc beverage).

Successful gardening, such as seen with the Tsimane involves a great deal of knowledge about cultigen varieties, and requires execution of many careful decisions based on knowledge and risk assessment: garden site choice, timing of garden preparation, burning, and planting, choice of crops to plant, strategy for tending crops and weeding, and how long to leave plots fallow. When asked, many Tsimane report that success with horticulture is dependent on hard work, knowledge of plants, soils, and garden requirements, but also behaving in accordance with certain beliefs. Tsimane believe that every plant has an *amo* (protector), and that aspects of human behavior (either angering or pleasing the spirits) can affect the success one has with planting and harvesting crops. Piland (1991) has identified a Tsimane horticultural knowledge system that, in addition to precautionary rules, behavior taboos, and folklore, includes a detailed taxonomy of soil types and their optimal uses, as well as three conceptually distinct productive systems that the average adult exploits: house gardens, horticultural fields or “chacos” *(quijodye')*, and fallows or “barbechos” (*cum*).

Tsimane also practice a simple form of animal husbandry that allows them to allocate capital to small edible domesticated animals such as chickens, ducks, pigs, and, occasionally, cattle. While necessary for the keeping of animal stocks, Tsimane tend to invest minimally in structures built for the confinement of domesticated animals and in provisioning of feed. Chicken and pigs often wander freely during the day, foraging on available resources and any feed provided by humans. Consequentially, domesticated animals are regularly intruding into homes and gardens, requiring that they be shooed and blocked access to restricted areas. By cultivating a stock of edible domesticated animals (e.g. chickens, ducks, pigs), one develops a buffer against seasonal food shortage (Undurraga et al., 2013) and amasses a stock of goods available for sale or barter. According to a survey of Tsimane households by Undurraga and colleagues (2013), 88% owned chickens, 27% owned pigs, 13% owned ducks, and 8% owned cattle.

In addition to using an axe and a machete (investigated as part of the tool use category described above), five skills used by both men and women in the gardening and husbandry category were investigated: knowing how to find a good place for a garden, knowing how and when to burn field, knowing how to weed a garden, feeding and shooing domesticated animals, and knowing how to sow with a machine.

Food Processing

Food processing (following harvest) of corn, rice, and manioc into edible forms, which is an on-going daily activity, requires a considerable amount of time and energy (Gurven et al. 2009). Women and female children are largely responsible for the processing. While larger game animals are often quartered in the forest for easier transport, and fish are often cleaned and processed on site at the water’s edge, smaller game animals often arrive at the house whole, where they are butchered and prepared for cooking. Salting and smoking are the only food preparation options available that can extend the storage life of food items. When large quantities of perishable food become available (e.g. from a successful fishing trip), smoking racks are often constructed and the watchful task of smoking fish follows. These game processing tasks are commonly carried out by older female children, sometimes with assistance of siblings, or else by adult females with the assistance of children. The skinning stretching, and tanning of animal hides is a time consuming task performed exclusively by men. Unless economic value can be likely produced (e.g. from the sale of a prepared ocelot hide to interested tourists), many men do not consider it worthwhile to skin animal hides and choose to forgo the activity when processing game.

In addition to using a machete (investigated as part of the tool use category described above), six skills used by both men and women in the food processing category were investigated: quarter and clean meat, skin animal hides, gut fish, make smoking rack, smoke fish and meats, and process rice.

Childcare and Reproduction

Infants, babies, and children are primarily cared for by their mothers, but also by older siblings, fathers, and grandparents, though childbirth and breastfeeding are clearly obligations of females. Breastfeeding is exclusively performed by biological mothers, maternal age is not a predictor of breastfeeding patterns, and full weaning occurs at 19.2(+/- 7.3) months (Veile et al., 2014). Caretakers of Tsimane children engage in many of the same forms of care seen around the world, including holding, swinging, rocking, playing, comforting, cooing, kissing, hugging, grooming hair and body, dressing, cleaning and changing clothes, bathing, fanning when hot, and keeping out of harm’s way. These caretaking behaviors, along with feeding, treating sickness, and treating insect bites are crucial for making children comfortable and stopping them from crying. Additionally, children are both directly and indirectly educated about how to properly treat others, deal with food and body waste, and, when they engage in serious transgressions, are reprimanded and scolded. Samples of time allocations made in villages by Winking (Winking et al. 2009) reveal that men contributed 8.6% of their time in the village to parental care (mostly in the form of play), as opposed to women who contributed 39.4% of their time to parental care (with 17% of this mothering time accounted for by breastfeeding, and much of the remaining time in the form of grooming). Tsimane woman, on average, become mothers by age 18, grandmothers by age 36, and great-grandmothers by age 54 (Gurven and Kaplan 2007). Within marriages, inter-birth intervals average approximately two and a half years. The relatively high fertility of Tsimane (Total Fertility Rate is 9 children, Gurven et al., 2012) gives older individuals greater opportunity to help descendant kin.

Ten skills in the childcare and reproduction category were investigated including seven skills pertaining to both genders (identify medicinal plants, know how a woman can avoid reproducing, care for children to make them stop crying, feed children, clean and change children, treat and heal children when they suffer from insect bites, skin problems, or wounds, and treat sick children), two skills exclusive to women (give birth and breast feed), and one skill exclusive to men (obtain sexual exploits).

(2) Complementary skills important to family organization, cooperation, and socialization

Household Chores and Craft Production

Households can consist of one to four nuclear families. While a Tsimane encountered at home might not be considered to be "working" as he or she would be if in the garden or forest, a number of activities usually keep men, women, and children occupied around home (particularly women and female children, see Gurven et al. 2009). Household activities –which can often be engaged in simultaneously while having conversation or singing to one's self—include food processing and childcare (see above), household chores and craft production (see below). The Tsimane household is also a social unit. High levels of visiting and sharing among members of different households are usually associated with beer consumption. Huge vats of *shocdye*, (manioc beer, often with corn, plantain, or palm fruit adjuncts) attract visitors from other household clusters and even other villages, who gather around to drink and talk about hunting, fishing, other activities, and social gossip. Serving *shocdye* is a form of hospitality, and women often act as servers, providing bowls of the thick beer to guests. Older adults often provide entertainment to their peers and juniors by retelling the hunt, telling traditional stories, interpreting dreams, singing and performing instrumental music (see below).

Household Chores

Household chores include sewing and mending clothes (see craft production below), washing clothes (usually done at a water source near the house), cleaning dishes, cleaning the floor, putting things away, watching the house while others are gone, getting water, sharpening sticks, knives, machetes, and axes, processing forest materials for crafts, feeding and shooing domesticated animals (see animal husbandry above), tending the fire, and collecting firewood. Across adult ages, women spend approximately 6-10% of their time around the house (compared to 4-6% for men) devoted to household chores (Gurven et al. 2009). Children (especially females) help with all manner of household chores and processing work, and are often of service by caring for the youngest children and babies while mothers are busy preparing meals or *shocdye* (manioc beer.

Two skills in the household chores category, performed by both males and females, were investigated: collect fire wood / build and tend a fire, and house-sit.

Craft Production

Material culture among the Tsimane is fairly limited to tools and items used for childcare, the home, hunting, fishing, garden production, food processing, clothing, and music. Collected materials from wild and semi-cultivated trees, lianas, grasses, palms, as well as cultivated cotton, and captured prey are used to produce a wide variety of crafts (particular kinds of skilled hand-made works) and items put to use in daily life. Across adult ages, women spend approximately 6-8% of their time around the house (compared to 2-4% for men) devoted to 'manufacture' and craft production (Gurven et al. 2009). Men's and women's respective areas of craft production overlap considerably little (given the relatively gender-neutral nature of other skills domains). Women produce many woven items such as fans and the floor mats that Tsimane often sit on (in addition to the stools or chairs more used by men): the small mat (*tovo*) and the large double mat (*shipna*). They also prepare cotton thread (spinning it and dying it) from which fabric is woven in simple looms (using a loom rod or *sorota*), and with which clothing, "marico" bags (*saraij*), and baby slings/diapers (*cacdyes*) are made. Cotton thread is dyed with the pigments of any of 13 plants (see Reyes-Garcia, 2001). Increasingly, hand-made cotton thread is being replaced by industrially manufactured cotton thread and synthetic yarn obtained through market exchanges, which is preferred by some for its more vibrant colors and uniformity. Men, on the other hand, work mostly with wood (especially hard woods) producing: bows and arrows for hunting, cots (*waracha*) for sleeping, seats (*toco*) for sitting, wheel barrows and carts (*careto*) for transporting heavy objects, axe handles (*cutudye' jai`ñis),* pounders (*väquitydyes*), musical instruments, combs (*ƒetsi*), a masher (*cham'chudye'*) for cooked manioc, a spindle and spinner (*buma* and *chudye'*) for cotton, and a loom rod (*sorota*) for weaving, rice pounders (*tacu*) for dehusking rice, troughs (*raveta*), grinding plates (*ta'ta'*), houses (*aca*), and rafts and canoes for river and lagoon transportation. While rafts are often makeshift and assembled in a moment's notice, canoe building, based on careful choice of tree, axe work, and the use of fire, is considered a skill that requires much knowledge and expertise. Men and women both work with palms and bamboo to produce roofing panels, manioc beer strainers (*pasi*), and fans (*fifity*). Baskets (*canasto*) and a large hamper basket (*ubu*) are also made out of palms and sometimes grasses. The grass "jipijapa" is also used to make hats (*shomeroro*). Tsimane might dedicate their time to these handicrafts according to their interests, ambition, and other competing demands on time. Some forms of craft production were practiced in the past but no longer today, as the knowledge is no longer shared (except by very few of the oldest), and alternatives are more easily available. For example, before textile clothing was introduced to Tsimane and before they began growing, processing, and weaving cotton for making clothes, the Tsimane used bark of *Poulsenia armata* (*ashava'*), "corteza de corochó" that was processed from trees, for clothing, hammocks, and bags. Before tin, aluminum, and plastic containers were introduced, ceramic vessels such as the large jar "tinaja" or smaller pitcher "cantaro" (*puñuj po`tso*) were formed out of clay and fired. As ceramic vessels are no longer common and not everyone has obtained aluminum and plastic containers, the bowls that men and women make for serving manioc beer are now typically made out of "tutuma" gourds (*erepa*).

The production of twenty seven items (eight large and hardwood woodwork items, four small woodwork items, six textile items, six coarse woven items, and three old tradition items - see category details in Online Supplement 2) were investigated as part of the "craft production" skill category: seven among both men and women (i.e., weave jatata, make strainer, make fan, repair clothes, get/process bark cloth, make woven hat, make large hamper basket), nine among only women (i.e., make large mats, make small mats, weave purse, make thread, dye thread, make clothes, make loom rod for weaving, make baby diaper / sling, make ceramic vessels), and eleven among only men (i.e., make axe handle, make bow, make arrows, make canoe, make house, make comb, make rice pounder, make wheel barrow, make wood grinding plate, make trough, make raft). The production of four musical instruments by males (discussed below), is investigated but included as part of the "musical and oral tradition" skill category.

Social and Market

In the past, Tsimane lived and primarily socialized in family clusters, but would also travel frequently to visit with affinal kin or kin from a distant and natal group. Now that Tsimane live in more centralized indigenous villages, they still associate primarily among family clusters and extended kin networks, but also visit with fellow villagers, non-kin of neighboring villages, maintain relationships with merchants, ranchers, and loggers, and make visits to market centers like San Borja for market activity and benefit collection (from charity and government).

Social Activity

The sharing and consumption of *shocdye,* or "chicha de yuca" in Spanish– a fermented manioc beer, is an added incentive to many Tsimane for making social calls. Experiences, tales, myths, stories, songs and other cultural codes are shared at these times, both seriously and through humor.

Five skills in the social category were investigated, three pertain to both genders (joking around with others and making people laugh, directing and ordering, beating or punishing the bad) and two are performed by only males (organizing a group of community members and speaking in front of a group). These are only a small subset of social skills, and pertain more specifically to skills that are useful in dealing with community members and outsiders beyond the nuclear family.

Market Activity

Increasingly, Tsimane involvement in wage labor or sales of products is becoming a regular component of the set of essential skills. By working for people and selling goods, Tsimane gain access to market goods and services that are otherwise unavailable. Increased involvement in market activities in San Borja and throughout Tsimaneland enhances spatial knowledge of the terrain travelled and familiarity with the network of individuals found across space that can facilitate journeys to and from the market. Material items that are often acquired through trade with travelling merchants or on visits to San Borja market include: aluminum pots, knives, machetes, fabric, clothes, mosquito nets, utensils, kerosene, school supplies, sugar, salt, cooking oil, flour, pasta, and alcohol. In San Borja, sought after services include medical care, bars and food services (often providing audio, video, or karaoke entertainment), and prostitution. In San Borja, Tsimane can also meet with members of their tribal council and collect their “bono solidario” –a type of social welfare subsidy—from the Bolivian government.

Wage labor for Tsimane in the study region, during the years 2004-2008, was roughly 25 Bolivianos a day (during this time the value of 1$ US fluctuated between 6.5 and 7.8 Bolivianos). Tsimane' men find opportunities to engage in wage labor by finding work providing manual labor for ranchers, loggers, and merchants. Women rarely have opportunities to engage in wage labor and the few cases of Tsimane' women finding money opportunities include working as cooks for logging camps, domestic duties in San Borja, and an isolated case of prostitution in a San Borja brothel. Wage labor opportunities often require men, occasionally accompanied by their wives, to leave their homes and families for a period of time. It is often observed that parental absence affects the quality of life for children (e.g. children left behind receive inferior care from siblings or relatives, instead of parents, and are delegated additional tasks) and husband absences appear to coincide with marital problems, likely due to sexual jealousy and problem arising from spending money away from the home as well as the problems resulting from the consumption of alcohol (Stieglitz, 2009).

Tsimane also become involved in the market economy by selling products such as rice and jatata panels. The trend towards monocropping (occasionally plantain and more frequently rice) for the purpose of selling harvests, and away from polycropping, is increasing among villages closer to the San Borja market and roads that bring commerce (Alvarado, 1996), and has been documented as leading to a loss in agrobiodiversity (Ribera, 2002). Large rice fields are also occasionally planted with a simple non-motorized planting machine. Because of their intimate knowledge and targeting of local soils, use of rice varietals, staggered planting strategy, and careful tending of their crops, Tsimane are very effective rice farmers, with yields per hectare almost twice as productive as world-wide averages, and almost three times as productive as yields from colonist farmers in Yucumo (Piland, 1991). Jatata panels woven from leaves of the jatata palm (*Geonoma deversa)* are the primary product sold and exchanged with trader merchants along the rivers. Jatata panels are very desirable for use as roofing panels due to their durability, insect and water resistant properties, breathability (allowing smoke and ventilation to pass through) and tendency to not become heated by the sun like corrugated metal roof. Traders acquire large quantities of woven roofing panels of jatata often via barter, less frequently via cash purchase. Quite often, jatata is exchanged for alcohol, and in a highly inequitable manner when traded this way (Añez 1992).

Four skills, performed by both men and women that relate to the pursuit of economic “opportunities” are investigated with the *Skills Survey*: getting to San Borja, obtaining work (e.g. with traders, loggers, and ranchers), selling products, and collecting government subsidies.

Music and Stories

Prior to introduction of modern forms of standardized scholastic education, the historic record, and popular media (often transmitted by outsiders), oral traditions of storytelling and singing (and musical traditions that accompanied them) acted as culturally styled systems of socialization (Coe et al., 2006) and cumulative knowledge broadcast by local experts (Scalise Sugiyama, 2011). These experts were regularly encountered among one’s family at home, but also through social contact with and extended network of relatives, friends, and neighbors.

Music

The themes of traditional Tsimane songs are forest plants, garden plants, mythical creatures, animals, and people. Songs are sung to others, usually among the confidence of close kin, and sometimes to larger groups of people during festivals where there is much drinking, but also many adults sing in private and would not be comfortable singing in the presence of others. Perhaps due to decreased levels of social anxiety, older adults who are more recognized as musicians (though not necessarily better musicians) tend to perform music more readily at the request of others, or even volunteer to play instruments or sing to groups of people during social gatherings. Instrumental music using flutes or violins that may or may not accompany singing often is based on the recognizable melodies from well-known songs with lyrics and may also be played as traditional party music (played by a band usually composed of a flute along with percussion: *bombo* – the bass drum, and *ricarica* – the snare drum). The hand-making of musical instruments investigated (flute, bass drum, violin, and snare drum) is considered a musician’s skill because Tsimane musicians typically fashion their own instruments.

Eleven music related skills were investigated: seven exclusive to men (making a flute, making a bass drum, making a violin, making a snare drum, playing violin, playing flute, playing snare drum) and four pertaining to either gender (singing in front of a group, singing in private, composing music, playing a bass drum).

Stories and Dreams

Storytelling among Tsimane (whether myths, fables, historical or personal stories) shows the same three thematic elements that have been consistently noted for storytelling across cultures: social information, subsistence information, and information about structuring of the world (Huanca, 2006, Scalise Sugiyama, 2001). For example, many Tsimane myths explain the origins and destiny of people, plants and animals, structuring of the world, astral phenomenon, and special events (solar eclipse, wildfires, windstorms). Things and ways of life important to Tsimane, such as salt (specifically local sources), horticulture (e.g., manioc, plantain, maize, tobacco, and cotton), making fire, preparing and preserving meat, acquiring metal tools, marriage, sexual affairs and murder all appear in the traditional stories. Also embedded in many myths and stories is spatial and foraging knowledge specific to the group and local ecology (Scalise-Sugiyama, 2011). For example, according to Huanca (2006, p.7), a specific alignment of the Milky Way with respect to the Maniqui River as described in a myth, serves to indicate to Tsimane "the right time to use poison for fishing". Myths about forest spirits (various gods over trees, wild animals and fish) and their abodes correspond to knowledge about locations of good salt sources and hunting grounds. Other stories, which feature the travels, sexual pursuits, problems, and adventures of various ancestral or mythical characters, transmit various social norms, morals, and respect for emotions that helps socialize children.

It has been suggested that with modern schooling and other new forms of information broadcast (television and movies, the radio, news media, the Internet) being increasingly utilized in forager societies – the perceived value of musical and oral tradition diminishes, and the system of vertical transmission by which it has been maintained over generations breaks down (Zent, 2001). In addition to traditional stories and traditional songs with lyrics, there is a repertoire of more improvisational and personally relevant oral transmission, for example Tsimane will "retell the hunt" (a common practice across foragers: see Blurton Jones and Konner, 1976 ; Bieselle 1993; Scalise Sugiyama 2011) and perform something like "blues singing" (where details of love affairs, sexual exploits, complaints, lamentations, and confessions are sung -- often in a drunken state). Tsimane will also retell their dreams (typically during early hours of the morning in the company of family members) and older specialists will offer interpretations of the dream elements and possible omens.

Two skills relevant to oral transmission were investigated: knowing the traditional stories and myths, and interpreting dreams. To examine the relationship between knowledge of a traditional story and propensity to tell it, a follow-up *Traditional Stories Survey* of 120 stories and myths was conducted among 54 informants knowledgeable of traditional stories and myths.[3]

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[3] While space does not allow a complete report of results from the *Traditional Stories Survey*, we report that there was substantial variation among those reporting knowledge of traditional stories indicating the specialized nature of this skill: among the 54 interviewed informants knowing traditional stories and myths, an average of 32.4 stories (27% of 120 stories) were reported "known". 52 of 54 informants (96%) reported also regularly "telling" one or more of the traditional stories they knew. While some of these story tellers reported a repertoire of as many as 110 stories (and others reportedly told only 1 story), the average storyteller reported a repertoire of 22 stories.

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Online Supplement 4: Statistical Model of Expert Nominations

The statistical analysis of expert nominations N_{ie}^{s} resembles that of the proficiency reports P_i^s but introduces new conditioning variables and requires attention to some additional statistical issues. We view the probability Π_{ie}^{s} that informant *i* nominates potential expert *e* as an actual expert at skill *s* as $Prob(N_{ie}^{s} = 1|A_e, X_e, A_i, X_i, R_{ie}, Z^s, \overline{H}_e^s)$. The focus of attention here is how the likelihood of expert nomination depends on the age A_e of the potential expert. Six other conditioning factors appear in this probability:

(1) other characteristics of potential expert *e*, captured by a vector of characteristics X_e (potential experts' gender and village);
(2) informant *i*'s current age A_i (knowledge of others' expertise may depend on informant age);
(3) other characteristics of informant *i*, captured by a vector of informant characteristics X_i (informants' gender and interviewer);
(4) relationships between informant *i* and potential expert *e*, captured by a vector of indicator variables R_{ie} (spatial relationships and kin relationships discussed below, identical versus contrasting gender, and whether the potential expert is older or younger than the informant);
(5) other characteristics of skill *s*, captured by a vector of skill characteristics Z^s (skill category, skill difficulty D^s and strength requirement M^s); and
(6) the gender-specific base rate $\overline{H}_e^s$ of having skill *s* in the sample of informants. $\overline{H}_e^s$ is the mean of H_i^s over all informants *i* of the same gender as potential expert *e*.

The single most important determinant of expert nomination is spatial proximity. Nomination of a potential expert in a village other than the informant's own village is exceedingly rare (<1% of all expert nominations), so R_{ie} includes an indicator for *i* and *e* residing in the same village. Within each village, the first author further categorized GPS locations of structures into mutually exclusive and exhaustive "residential clusters" of spatially proximate structures, and R_{ie} includes an indicator for *i* and *e* residing in the same residential cluster within the given village. R_{ie} also includes an indicator for *i* and *e* residing in the same structure as indicated by GPS locations, though this turns out to be an insignificant predictor above and beyond the village and residential cluster indicators.

Figure OS4-1 shows how expert nomination rates depend on both consanguinal and affinal relatedness between informants and potential experts. Consanguinal relatedness is expressed with the coefficient of relationship *r*, as defined by Wright (1922).[1] We also use an affinal coefficient of relatedness, based on consanguinal relatedness (*r*) calculated from the spouse's perspective. In the region of the figure where both the consanguinal and affinal coefficients of relatedness are less than one-fourth, the expert nomination rate is a mere 0.0014: outside of that region the expert nomination rate is 0.038, easily an order of magnitude higher. The figure also makes it clear that there are very high rates of nomination of selves (0.22) and spouses (0.085). To control for these effects, R_{ie} includes two sets of six category indicators of consanguinal and affinal coefficients of relatedness as given on the axes of Figure OS4-1.

The skill base rates $\overline{H}_e^s$ appear in the model in a specific manner that meets a specific purpose. To illustrate this, consider the following simplified inference situation where the focus of attention, A_e, is the only conditioning variable aside from knowing whether potential expert *e* has skill *s*, which we will denote by $H_e^s = 1$ (zero otherwise). When we analyze expert nominations, we really want to analyze $Prob(N_{ie}^{s} = 1|A_e, H_e^s = 1)$, that is, the probability of nomination given the age of potential expert *e* and also given that potential expert *e* actually has skill *s*. The analytical problem is that we do not always observe H_e^s (we only observe it when potential expert *e* is among our 421informants; and as discussed in the text, there are an additional 176 potential experts who are not informants—none of these were interviewed and hence we do not know H_e^s for these individuals). By the law of iterated expectations, we have:

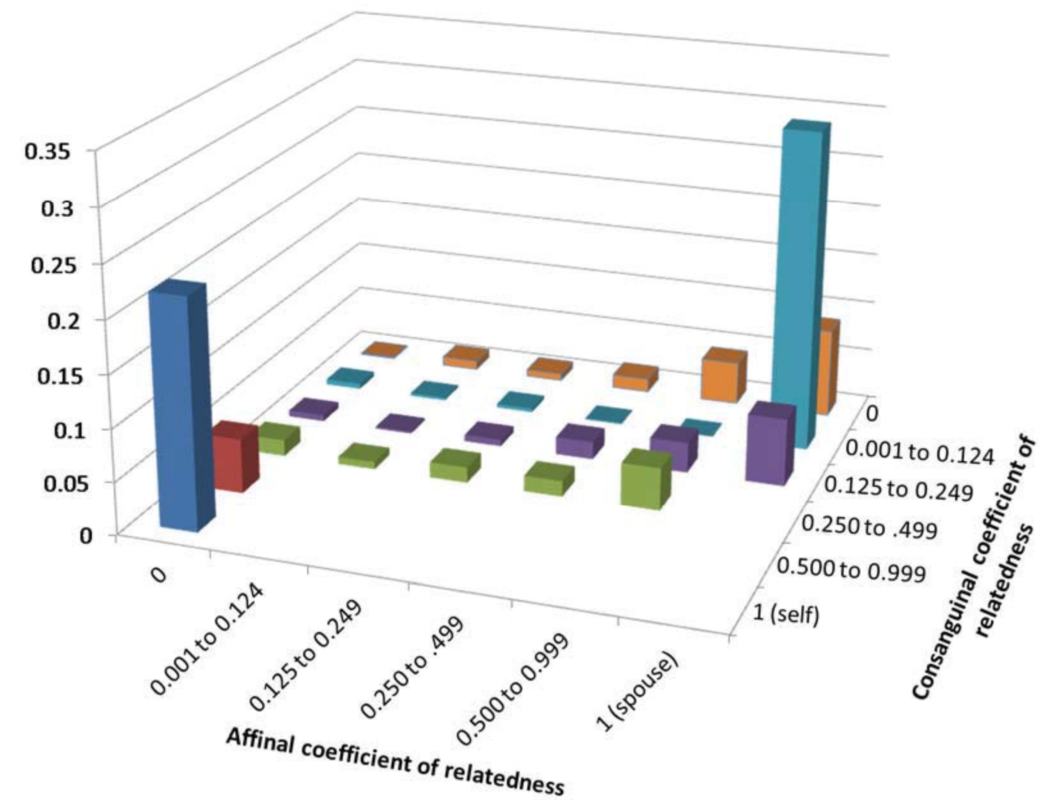
$$Prob(N_{ie}^{s} = 1|A_e) = Prob(N_{ie}^{s} = 1|A_e, H_e^s = 1)Prob(H_e^s = 1) + Prob(N_{ie}^{s} = 1|A_e, H_e^s = 0)Prob(H_e^s = 0).$$

As mentioned in the text, $N_{ie}^{s} = 1$ is extraordinarily rare when we know that $H_e^s = 0$ (that is, when *e* is one of our 421 informants and *e* says she does not have skill *s*), so we are willing to assume that $Prob(N_{ie}^{s} = 1|A_e, H_e^s = 0) \approx$

[1] Wright, Sewall (1922). Coefficients of inbreeding and relationship. *American Naturalist 56*: 330–338

0 everywhere. This is the assumption that informants never nominate an individual who does not have skill *s*—whether or not we can observe H_e^s. Under this assumption, the previous expression becomes:

Figure OS4-1. Conditional probabilities of expert nomination, given consanguinal and affinal coefficients of relatedness to the informant



$Prob(N_{ie}^s = 1|A_e) \approx \ Prob(N_{ie}^s = 1|A_e, H_e^s = 1)Prob(H_e^s = 1)$.

The next important assumption is that the 421 informants and the 176 extra potential experts have essentially the same values of $Prob(H_e^s = 1)$. Given that assumption, we may approximate $Prob(H_e^s = 1)$, the base rate for having skill *s*, by the sample proportion of informants who have skill *s*, in which case the expression becomes:

$Prob(N_{ie}^s = 1|A_e) \approx \ Prob(N_{ie}^s = 1|A_e, H_e^s = 1)\overline{H}_e^s$.

This gives us the form of our model of expert nomination probabilities Π_{ie}^s. We use the generalized linear model for the term $Prob(N_{ie}^s = 1|A_e, H_e^s = 1)$, as in the case of proficiency reports; however, we now multiply this by the base rate estimate $\overline{H}_e^s$. In this simple case where A_e is the only conditioning variable, this gives the model:

$\Pi_{ie}^s = Prob(N_{ie}^s = 1|A_e) = \ [1 + exp(-\eta_{ie}^s)]^{-1}\overline{H}_e^s$, where

$$\eta_{ie}^s = a_1(A_e - 35) + a_2(A_e - 35)^2 + a_3(A_e - 35)^3 + a_4(A_e - 35)^4 + \ f.$$

In the simple case, *f* is just a constant representing the value of the linear predictor for potential experts of age 35 and, as before, the polynomial in A_e represents changes in the linear predictor relative to the age 35 value. Going back to the full model simply involves replacing the constant f by a function $f(X_e, A_i, X_i, R_{ie}, Z^s, \theta)$, linearly composed of the conditioning variables, each weighted by estimable parameters in a vector θ. The parameters θ and a are estimated by maximum likelihood.

One other important matter needs comment. As mentioned in the text, each informant *i* could nominate up to three potential experts *e* as actual experts in each skill *s*: In the pilot study, no one ever nominated more than three individuals, so we imposed this constraint on total nominations in the full study. This implies that observations for which $N_{ie}^{s} = 0$ add no new error degrees of freedom above and beyond the error degrees of freedom added by observations for which $N_{ie}^{s} = 1$. Put somewhat differently, consider a unisex skill, for which there are 597 potential experts. When informant *i* nominates three specific experts, we may think of her response as a 597-element vector composed of 3 ones (the individuals she nominated) and 594 zeroes. Because the 594 zeroes are fully determined by the locations of the 3 ones, none of these zeroes add anything to error degrees of freedom. The locations of these zeroes *are* useful sample information since the identity and conditioning variable values for un-nominated individuals are just as informative as the identity and conditioning variable values of nominated individuals. But the entire 597-element vector only adds three error degrees of freedom to any finite sample statistic that depends on total error degrees of freedom, such as *t*-tests or *F*-tests—not 597 degrees of freedom. Fortunately, correcting the degrees of freedom of any finite sample test statistics is very simple, and we do so as needed.

Online Supplement 5: Table showing estimated acquisition hazard rates[a] and test for rate change[b] across age cohorts for 92 skills investigated with the *Skills Survey*

Skill Category	skill #	Skill	est % change[a]	Z[b]
food production	92	gut fish	5.02	0.70
	89	identify wild fruits	1.08	0.15
	88	know where to find fish	–0.30	–0.04
	66	use a machete	–2.73	–0.38
	86	arrow shoot fish	–3.24	–0.44
	57	process rice	–4.67	–0.64
	79	identify different fish	–4.92	–0.68
	75	identify wild animals	–5.27	–0.73
	78	shoot arrows	–7.11	–0.97
	76	identify animal tracks and markings	–7.92	–1.09
	73	smoke fish and meats	–9.44	–1.31
	32	weed garden	–10.34	–1.43
	87	know how and when to burn field	–12.35	–1.72
	27	use an axe	–12.53	–1.74
	81	fire shotgun or rifle	–12.90	–1.77
	65	care for fowl and animal domesticates	–12.97	–1.81
	35	track animals	–13.40	–1.84
	54	know what wild animals eat, habits, where to find them	–13.68	–1.91
	72	quarter, clean meat	–13.99	–1.95
	55	travel in the woods without fear	–15.03	–2.07
	69	pole a canoe/raft	–16.05	–2.25
	48	make weir / fish trap	–19.52	–2.71
	67	find a good place for a garden	–19.25	–2.72
	36	find and get various barbascos	–21.16	–3.01
	29	train hunting dogs	–32.02	–4.73
	50	skin animal hides	–34.48	–5.00
	24	use magic amber	–35.02	–5.08
	74	get in the water without fear	–35.32	–5.12
	15	obtain honey	–34.56	–5.16
	61	sow with a machine	–36.58	–5.52
	33	make smoking rack	–36.72	–5.53
childcare and reproduction	85	feed children	32.14	0.88
	82	clean and change children	18.09	0.57
	47	care for children to make them stop crying	17.59	0.51
	2	give birth	11.03	0.28
	80	breast feed	7.58	0.19
	14	treat / heal sick children	5.72	0.14
	60	treat / heal children when they suffer from insect bites	–2.78	–0.10
	58	obtain sexual exploits	–18.41	–0.58
	43	identify medicinal plants	–17.41	–0.80
	51	know how a woman can avoid having children	–64.20	–1.35

Online Supplement 5 Table (continued)

Skill Category	skill #	Skill	est % change[a]	Z[b]
household chores and craft production	68	collect fire wood and build a fire	–13.01	–0.85
	83	repair clothes	–14.26	–0.93
	71	make lg. woven mat	–16.13	–1.05
	62	make arrows	–19.17	–1.26
	28	make thread	–24.57	–1.64
	90	make fan	–25.99	–1.77
	18	weave purse	–26.63	–1.80
	49	weave jatata	–28.17	–1.94
	37	make a bow	–29.02	–1.98
	17	make a house	–29.21	–2.00
	63	dye thread	–31.35	–2.16
	23	make an axe handle	–32.09	–2.22
	64	make raft	–32.43	–2.25
	13	make rice pounder	–41.13	–2.99
	42	make clothes	–43.39	–3.18
	70	make lg. hamper basket	–43.98	–3.30
	77	house-sit	–45.50	–3.45
	84	make baby diaper/sling	–47.38	–3.55
	8	make wood grinding plate	–54.34	–4.28
	5	make trough	–56.55	–4.52
	16	make a comb	–60.23	–4.94
	4	make a canoe	–62.72	–5.23
	34	make small square mat	–64.12	–5.38
	12	make chicha strainer	–72.30	–6.81
	10	get/process bark cloth	–72.58	–6.85
	7	make loom rod for weaving	–81.58	–7.50
	3	make wheel barrow	–81.55	–7.69
	1	make ceramic vessels	–88.37	–7.78
	25	make woven hat	–81.08	–8.27
social and market	20	get to San Borja	18.19	1.05
	91	joke around with people / make others laugh	6.25	0.37
	53	sell products	5.12	0.30
	39	obtain work with traders, loggers, ranchers	–11.94	–0.75
	21	direct and order	–24.72	–1.65
	46	speak in front of a group	–25.15	–1.67
	26	organize a group of community members	–26.59	–1.77
	41	beat and punish the bad	–45.24	–3.33
	45	obtain government subsidies	–54.00	–4.02
music and stories	56	interpret dreams	–56.22	–3.22
	44	sing in private	–64.53	–3.99
	31	play snare drum	–66.72	–4.07
	52	make flute	–67.44	–4.14
	22	play flute	–69.93	–4.41
	19	play violin	–70.51	–4.48
	9	make a snare drum	–75.03	–4.98
	11	make a violin	–76.16	–5.12
	59	play bass drum	–74.50	–5.12
	6	make bass drum	–81.35	–5.78
	38	know the old stories/myths	–80.00	–5.91
	30	compose music	–87.48	–7.23
	40	sing in front of group	–88.44	–7.41

Notes:
[a]The estimated percent change in the skill acquisition hazard rate per year between 1960 and 1993.
[b]z-score against the null hypothesis that the skill acquisition hazard rate is constant between 1960 and 1993.