ANTHROPOLOGY

Women's subsistence networks scaffold cultural transmission among BaYaka foragers in the Congo Basin

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In hunter-gatherer societies, women's subsistence activities are crucial for food provisioning and children's social learning but are understudied relative to men's activities. To understand the structure of women's foraging networks, we present 230 days of focal-follow data in a BaYaka community. To analyze these data, we develop a stochastic blockmodel for repeat observations with uneven sampling. We find that women's subsistence networks are characterized by cooperation between kin, gender homophily, and mixed age-group composition. During early childhood, individuals preferentially coforage with adult kin, but those in middle childhood and adolescence are likely to coforage with nonkin peers, providing opportunities for horizontal learning. By quantifying the probability of coforaging ties across age classes and relatedness levels, our findings provide insights into the scope for social learning during women's subsistence activities in a real-world foraging population and provide ground-truth values for key parameters used in formal models of cumulative culture.

INTRODUCTION

Collaborative foraging is central to the evolution of human cooperation, as humans have depended on high-value and difficult-to-acquire food sources obtained through organized hunting and gathering (*1*–*4*). Moreover, humans use elaborate techniques for extraction and time-intensive methods for processing and cooking food (*2*, *5*). Because of the complex nature of human foraging practices and frequently low and variable rates of return, humans often forage collaboratively to increase the probability of successful outcomes (*6*–*8*). Alongside this, humans rely on networks of social support (e.g., food sharing) to buffer day-to-day variation in hunting and gathering returns (*9*–*11*). Thus far, to understand such cooperative subsistence practices in humans, extant research has focused on the ways in which men solve the challenges presented during and after collaborative hunting (*7*, *10*, *12*–*18*). Although women's cooperation in subsistence activities—beyond alloparenting and food sharing—has received attention (*19*–*27*), the network structure of women's subsistence groups remains largely understudied [but see (*28*) for emerging work].

In many hunter-gatherer societies, women participate in the subsistence economy by gathering plant foods that can be used to subsidize the variable returns inherent in men's hunting (*29*, *30*). To improve the chances of acquiring food, women pool labor, knowledge, and material resources (*30*), and also divide tasks among themselves [e.g., by providing infant care during subsistence activities (*31*)]. Researchers have found that such cooperation typically occurs between kin, a finding that holds across many cultural and ecological settings (*32*, *33*). High rates of cooperation between individuals of the same sex are also expected among foragers—because of the sexual division of foraging labor (*34*) and preferences to assort socially on the basis of sex or gender (*35*). Moreover, food resources and labor are frequently exchanged across age classes within a community (*36*). By virtue of this age-graded cooperation, both adults and children contribute to, and gain from, the pooled energy of their communities (*37*).

For young individuals to become competent adult foragers, the transmission of ecological knowledge and skills across generations is necessary (*38*). Researchers have proposed three broad pathways through which such social learning might occur—vertical, horizontal, and oblique (*39*). A more nuanced multistage learning model, however, suggests that the preferred mode of cultural transmission may change across the life course (*39*–*41*). Existing evidence has suggested that social learning begins at infancy with vertical transmission from parents (*42*). In early and middle childhood, however, children appear to begin to preferentially learn from peers of the same age class through horizontal transmission (*43*). This preference for learning from more distantly related individuals becomes more pronounced during adolescence, with individuals learning from a specific set of community members—e.g., especially skilled or popular nonkin adults—via oblique transmission (*44*).

Beginning in early infancy, hunter-gather children join their mothers' subsistence expeditions and socially learn subsistence skills and knowledge through observation, active instruction, and participation (*45*). Hence, women's subsistence groups should be a nexus for social learning opportunities. If so, the age structure of women's subsistence networks should be consistent with predictions from the multistage learning model (*39*, *40*). Among hunter-gather societies—and perhaps more broadly—the structure and composition of women's subsistence networks may be fundamental in providing—or constraining—opportunities for social learning between kin and nonkin. However, there remains a paucity of quantitative evidence about the structure of women's subsistence networks.

Theoreticians are increasingly interested in how social networks (*46*, *47*) and age structure (*48*) affect the dynamics of social learning and cultural change. Studies conducted in silico [e.g., (*48*)] indicate

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that network and age structure have substantial consequences for both theoretical models of cultural evolution and for empirical studies hoping to infer transmission processes from observational data. The development of more empirically plausible models of social learning thus requires estimation of knowledge transmission rates (or at least the scope for them) as a function of age class, kinship, and other aspects of social network structure. There is still a remarkable dearth in our knowledge of these rates. However, such information can be gleaned from long-form field research among subsistence populations. To address this knowledge gap and estimate rates of between-age-class interactions during subsistence activities quantitatively, we analyze data collected from daily focal follows of BaYaka women's subsistence groups over a period of nearly one year.

There are several reasons why it is important to study women's cooperative subsistence networks in collaboration with the BaYaka people of the Republic of the Congo. First and foremost, the BaYaka are one of only a few contemporary foraging populations, and they practice a wide range of skill-intensive subsistence activities—from hunting and gathering, to fishing, farming, and trading (*49*). Second, women's subsistence activities comprise a large proportion of the caloric intake of BaYaka communities, and so acquisition of knowledge related to such practices is of key importance for young BaYaka (*50*). Third, the BaYaka are relatively egalitarian, and individual roles in community politics and subsistence are not formally mandated (*51*). Therefore, individuals—including children—are able to freely decide when, and with whom, they participate in subsistence activities (*52*, *53*).

To examine theory on the age-graded nature of women's subsistence practices, we link 230 undirected daily subsistence networks—collected during focal-follow observations of a representative sample of 5 BaYaka women (31% of a total 16 adult women in the study community)—with daily records of camp composition and detailed demographic information. To analyze these data, we develop a stochastic blockmodel (*54*, *55*) for repeat-observation data with uneven sampling. We use a base model to assess how dyad-level effects (e.g., those based on kinship, gender homophily, and coresidence) and block-level effects (e.g., assortment based on age class) influence the structure of women's daily subsistence networks. In a second model, we include an interaction between kinship and age class to further assess the role that kinship plays in structuring subsistence activities between individuals in specific age classes. If women's subsistence networks facilitate transmission of important knowledge, then children and adolescents may benefit from seeking subsistence partnerships that provide opportunities for learning key foraging skills. This theory, however, has yet to be examined in a real-world population. Here, we test for evidence consistent with age-structured partner choice within BaYaka women's subsistence networks, following predictions from the multistage learning model (*40*). We also provide estimates of within- and between-age-class interaction rates that can be used to parameterize broad theoretical models of social learning with empirically grounded values.

RESULTS

Across the 230 days of research, we coded a dyadic tie as existing on a given day if two individuals were observed together at any point during a focal follow of subsistence activities outside of camp. There is appreciable variation in subsistence group composition across days, and ties were observed at some point between all but one member of the community ($N = 60$; one male in his 70s was never observed in women's subsistence groups). Comparable with other studies of human social networks, BaYaka women's subsistence networks were relatively sparse—with 15,008 ties being observed across the 230 days of active sampling. These observed ties represent around 3.6% of all potential ties over the same time period. In the subsections that follow, we outline how BaYaka women's subsistence networks are structured by age-class composition, kinship, and gender homophily. We present the results using the median of the posterior distribution for each parameter, θ, and its associated 90% credible interval (*CI*).

Women's subsistence networks are composed of a mixture of age classes

In Fig. 1, we visualize the structure of the aggregated subsistence networks over the 230-day period and show that there are a substantial number of both within- and between-age-class ties. To study the extent of mixed age-class ties quantitatively, we fit a stochastic blockmodel (*56*), where block membership is known data defined by age class, but within- and between-block tie probabilities are unknown. We define blocks so that they represent four developmental periods (*57*): early childhood (ages 4 to 6), middle childhood (ages 7 to 13), adolescence (ages 14 to 19), and adulthood (ages 20 and over). The stochastic blockmodel is useful here because it provides a low-dimensional representation of age structure in the community, allowing us to examine the relative frequency of ties between individuals in different developmental periods, controlling for the number of individuals of each age group available as potential foraging

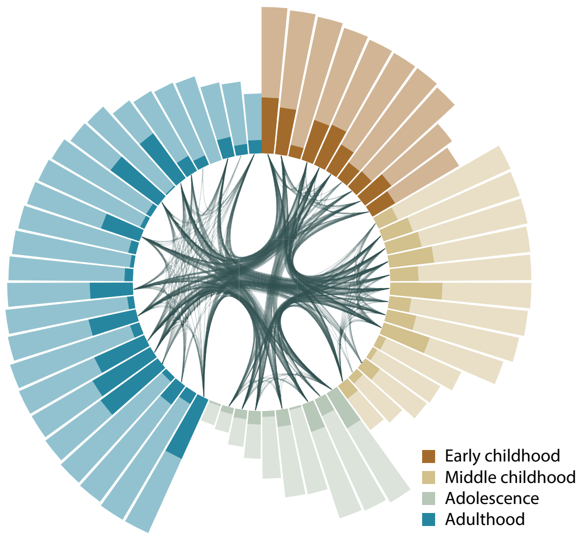

Fig. 1. Women's subsistence networks are composed of a mixture of age classes. Here, we visualize ties (lines) between individuals (bars) in women's subsistence networks across the 230-day study period. The transparency of each connecting line represents the number of days in which a tie was observed between two individuals. The average number of days that each dyad spent within the camp was 110 days (SD = 64.61, range = [1,212] days; fig. S1A), and the average number of days that each dyad appeared together in women's subsistence activities was 18.79 days (SD = 19.15, range = 0 − 59; fig. S1B). Each individual is represented as a bar, where the shaded region of the bar represents the number of days that the individual was observed in women's subsistence groups and the unshaded region of the bar represents the number of days that the individual was present in the camp. The color of each bar indicates age class.

partners. Figure 2 shows that there is substantial variation in the probability of ties across these developmental periods.

The extent of within- and between-age-class ties differs by focal age class

As visualized in Fig. 1, we find that BaYaka women's subsistence networks are composed of individuals from all age classes. The probability of observing ties with adults is noticeably low across all age classes (Fig. 2), in part because of adults comprising a large fraction of the total in-camp population while joining women's subsistence groups at lower rates than children. This result indicates that a substantial fraction of in-camp children—from early childhood to adolescence—routinely join BaYaka women's subsistence groups. BaYaka women engage in subsistence activities together with young children, rather than foraging alone or coforaging exclusively with adults or older children [e.g., as is typically seen in male-centric foraging groups; (*7*, *18*, *58*)]. This provides some indication that knowledge transmission, as opposed to simple return rate maximization, simple return rate, guides group composition.

Individuals in early childhood are observed with peers in their own age class, as well as with others in middle childhood (Fig. 2). We observe the same pattern for adolescents, with individuals having frequent ties to both peers and those in middle childhood. Ties between individuals in middle childhood are the most frequently observed (accounting for the relative abundance of individuals in each age class), and individuals in middle childhood had high rates of ties with those in both older and younger age classes.

Women's subsistence networks are structured by relatedness and gender

In Fig. 3, we plot the effects of the dyadic predictors included in our model. We test for effects of genetic relatedness [operationalized as Wright's coefficient, *R*; (*59*)], gender homophily, and household coresidence on the structure of women's daily subsistence networks. We find that women's subsistence group composition is structured by genetic relatedness (i.e., individuals who are more genetically related are more likely to participate in subsistence activities together) and gender homophily, especially between females (i.e., females are more likely to participate in subsistence activities with other females than they are with males). Coresidence in the same household, however, has no strong influence on group composition after accounting for age, gender, and relatedness.

Women's subsistence networks allow children to socially learn beyond what they can learn from kin

In Fig. 4A, we plot estimates of the log odds of observing ties between first-order kin (orange circles) and between nonkin (teal circles). In Fig. 4B, we plot differences in the log odds of observing ties between first-order kin and nonkin (black circles) by age class. As might be expected from simple ethnographic observation, children of all age classes are more likely to form ties with adult kin (normally their parents) than nonkin adults. Our model, however, permits the more nuanced inference that although individuals in early childhood have a strong tendency to coforage with adult kin (most frequently their parents), this kin bias becomes appreciably weaker during middle childhood and

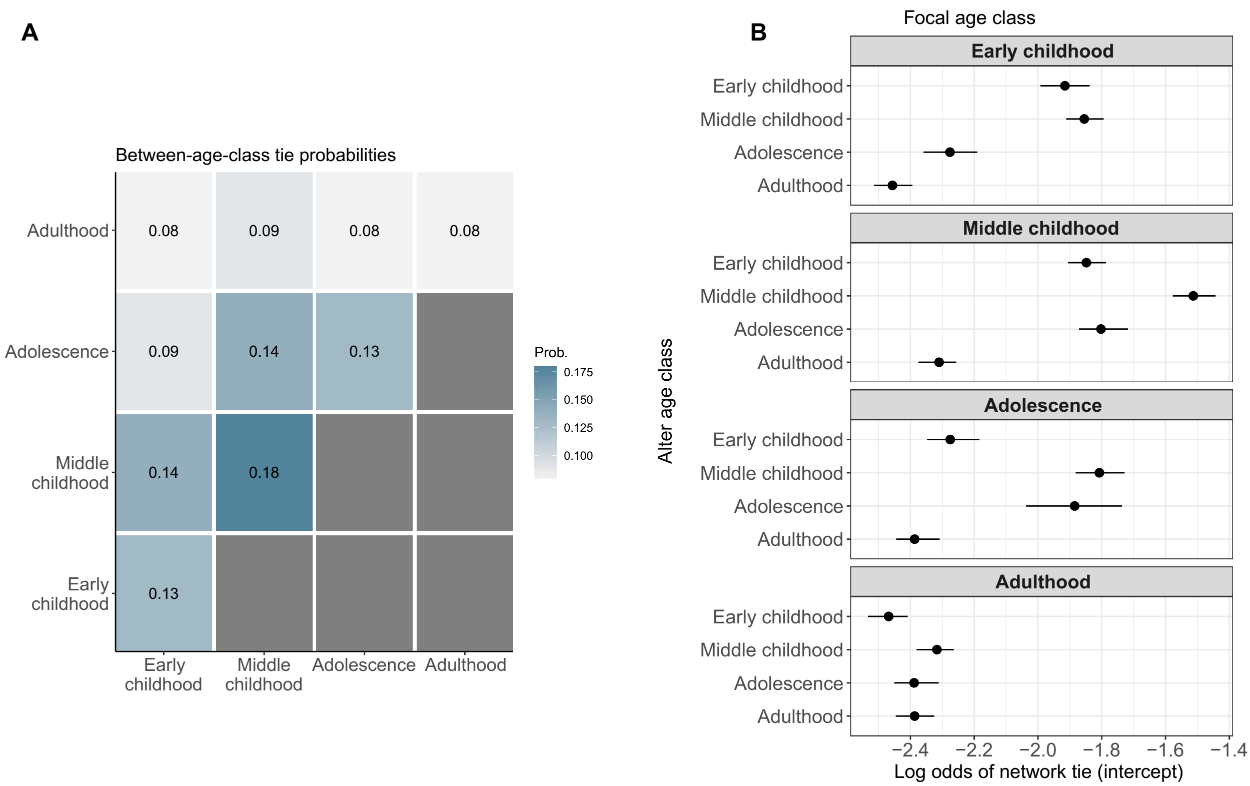

Fig. 2. Women's subsistence networks allow children to socially learn with peers. Here, we plot posterior estimates of within- and between-age-class tie probabilities from the stochastic blockmodel. (**A**) Heatmap of predicted daily between-age-class tie probabilities for non-coresident, unrelated, female-female dyads. (**B**) Log-odds offsets (with 90% credible intervals) for between-age-class ties, corresponding to the point estimates in (A).

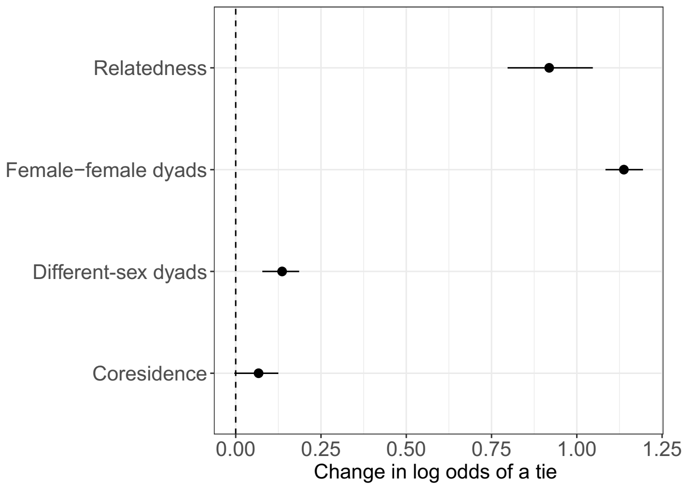

Fig. 3. Women's subsistence networks are structured by relatedness and gender. Here, we plot dyadic parameter estimates and credible intervals. The base case of the model is for an unrelated, non-coresident, male-male dyad. Hence, these estimates are indicative of the change in log odds of a tie as a function of a unit change in the indicated predictors. Note that the female-female dyad, different-sex dyad, and coresidence variables are binary indicators.

adolescence (Fig. 4). This change suggests that children in early childhood have more opportunities to learn from their parents through vertical transmission, while those in middle childhood and adolescence might also be seeking to coforage more broadly with other adult community members, who might have particular expertise.

Focusing just on the estimates for early childhood, we see that when young children form ties with nonkin (teal circles in Fig. 4A), those ties are more likely to be observed with peers in early and middle childhood than with nonkin adults or adolescents (again, accounting for difference in the relative abundance of individuals in each age class). In sum, the estimates for early childhood are consistent with the idea that young children preferentially participate in the subsistence trips of their own mothers, where siblings frequently appear and unrelated peers sometimes appear. This provides individuals in early childhood with opportunities to observe and learn from mothers through vertical transmission but also from siblings and friends in similar age classes through horizontal transmission.

Focusing next on the estimates for middle childhood, we find that there is no evidence of a kin bias when considering ties between dyads composed of two individuals in middle childhood or dyads composed of one individual in middle childhood and one individual in adolescence. However, a kin bias remains when considering ties between dyad composed of one individual in early childhood and one individual in middle childhood. These results are consistent with the idea that

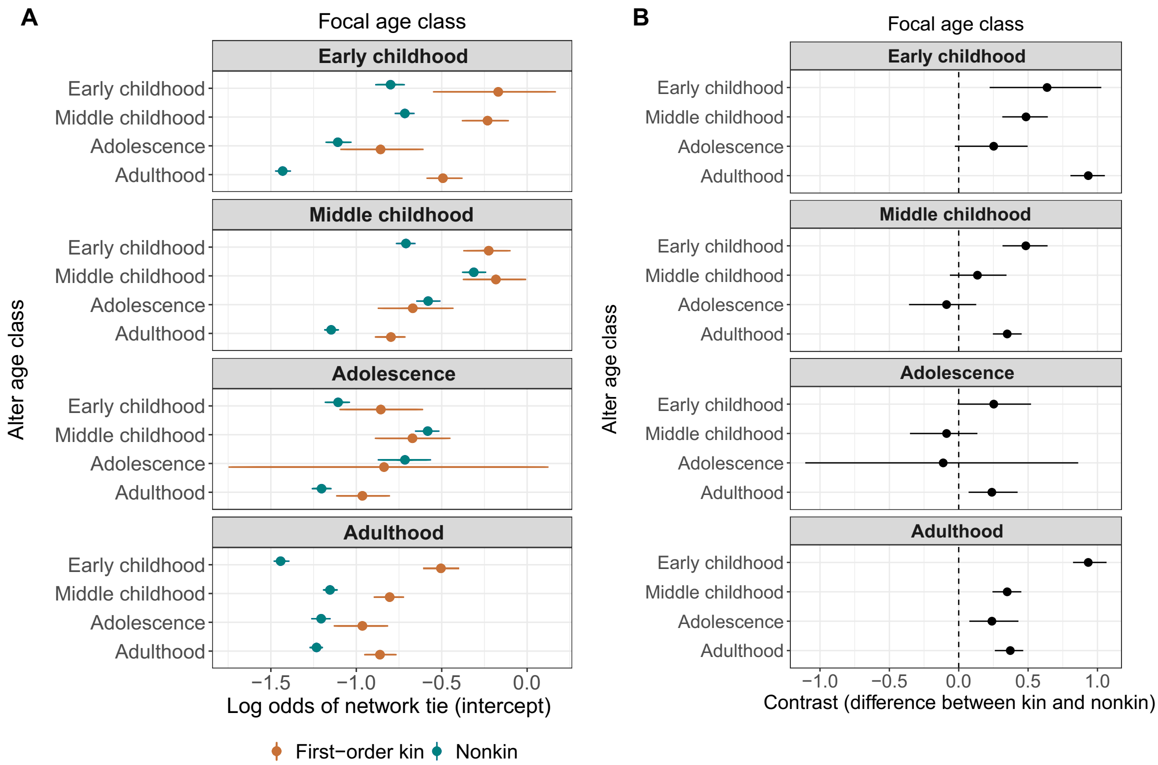

Fig. 4. Women's subsistence networks allow children to socially learn beyond what they can learn from kin. Here, we plot the interaction of relatedness and age class. (**A**) Predicted log odds of ties for each age class for kin with $r = 0.5$ (e.g., parents and children, or full siblings; orange) and for nonkin ($r = 0$, teal). (**B**) Difference between the kin and nonkin estimates, for each combination of age-class categories. In (B), a positive coefficient, with a *CI* not overlapping 0, represents a higher likelihood of ties between kin than between nonkin, while a negative coefficient would suggest the opposite. We note that the strength of the kin bias between children and adults decreases as children pass into older age categories.

children in middle childhood learn from, and practice skills with, peers and adolescents—regardless of whether they are kin—creating scope for horizontal and oblique social learning.

Last, adolescents show reduced kin bias when making ties with others across all age classes. Although adolescents have a slight preference toward making ties with (presumably) siblings in early childhood and with adult kin (presumably parents), these effects are much smaller than comparable effects in other age classes. Note that we observe a wide credible interval for ties between adolescent kin due to the small sample size of such individuals in our dataset.

In summary, the scope for the transmission of foraging skills during early childhood appears to be linked to first-order kin. However, this kin bias disappears during middle childhood and especially adolescence, suggesting greater opportunities for social learning beyond first-order kin as individuals grow up and seek out potential mentors. Our results also provide evidence of substantial scope for horizontal transmission of foraging skills in middle childhood and adolescence, as individuals in these age classes spend substantial time coforaging with siblings and friends in similar age classes.

DISCUSSION

We have found that the age structure of BaYaka women's subsistence networks is largely consistent with the predictions of the multistage learning model (*39*, *40*). However, our current data only include information about the sociodemographic composition of daily subsistence groups—and do not feature quantitative measures of directed teaching events, for example—so our inferences are limited to describing the scope for different types of social learning to occur on the basis of the frequency of coforaging trips. Future work might wish to integrate behaviorally annotated network data, such that the count or duration of teaching and learning events occurring between individuals is measured over the course of focal follows. Although difficult to collect, these data will help to more directly test models of age-structured learning. Ethnographic studies of the Hadza and BaYaka (*60*), the Aka and Ngandu (*61*), Baka (*62*), Maya (*63*), and Fijians (*64*), however, have found that teaching events occur frequently when children spend time together—supporting our use of simple interaction data to infer scope for information and skill sharing.

Previous work has found that BaYaka children spend around 52.4% of their foraging time in peer groups without adults (*53*). In this study, we further show that children are also likely to spend time interacting with other children across different age classes during women's subsistence activities. In support of the multistage learning model, child-child dyads are observed in women's subsistence groups throughout developmental periods. Noting that children can be more efficient at teaching or learning from other children in similar developmental periods (*65*), our findings suggest that women's foraging networks provide opportunities for horizontal and oblique social learning. During focal follows, we indeed observed that children participated in foraging activities—especially fishing and digging of wild yams—in small subgroups comprised mostly of peers similar in age. This was more prominent for individuals in middle childhood and adolescence than individuals in early childhood, who were more likely to stay close to adult women (*31*).

Our study also provides insights into the variable role of relatedness on the scope for social learning, especially in middle childhood and adolescence, when children begin to reach beyond kin when coforaging with community members. On the one hand, adults were more likely to coforage with children to whom they are related than unrelated children (a finding that holds across all childhood age classes). This finding matches our ethnographic intuition that children—and especially young children—are frequently under the supervision of parents or other close adult kin. On the other hand, the strength of this kin bias becomes quite muted during middle childhood and adolescence. This may reflect a preference among adolescents to refine their skills by learning from preferred models, such as particularly skilled peers and adults, by joining the foraging trips of nonkin. In sum, women's subsistence networks provide an important setting for children to learn or practice skills that they might not be able to acquire within the confines of an insular nuclear setting.

In line with evidence for sibling teaching [e.g., (*60*, *63*)], we also found that young children preferentially formed ties with kin (especially siblings) during subsistence activities. Children in middle childhood preferentially formed ties with siblings in the same age class and with adolescent siblings, but they also formed ties with nonkin peers and adolescents. These same children, however, were less likely to make ties with younger, unrelated children. This kin bias between children in early and middle childhood suggests that BaYaka children in middle childhood might learn from both peers and adolescents—regardless of kinship—but preferentially teach their younger siblings.

Such results suggest that middle childhood may not only be a crucial period for learning foraging skills from older children and practicing skills with peers but is also an important life stage in transmitting more basic acquired knowledge to younger siblings. In other words, there is scope for children in middle childhood to play an important role in bridging knowledge and skill transmission between those in adolescence and those in early childhood. Some cultural evolutionary theory suggests that foraging knowledge and skills can be more rapidly transmitted through horizontal relationships (i.e., through peers), than through parent-to-child transmission [e.g., (*39*, *42*)]. Our study provides some empirical evidence for such theory by showing that the age structure of women's subsistence networks among the BaYaka is poised to facilitate such social learning opportunities.

Last, our results provide evidence that kinship and gender structure women's subsistence networks, with females being more likely to assort with close kin and other females. Consistent with kin selection theory (*66*), individuals tended to participate in cooperative subsistence activities with their close relatives. This kin bias in women's subsistence groups lies in contrast with the composition of men's cooperative hunting groups, which are often composed of unrelated men [e.g., who form alliances for hunting; (*12*)]. Alongside this, men normally hunt alone or in groups consisting of male adolescents and adults [e.g., (*7*, *18*, *58*)]. However, here we find that young children, as well as adolescents, join women's subsistence expeditions, resulting in mixed-age subsistence networks that often consist of close kin. These results contribute to an established literature that emphasizes a gender-based diversification of subsistence strategies in hunter-gatherer societies (*7*, *16*, *67*, *68*). That is, gender homophily between females during subsistence activities may result from the sexual division of foraging labor in this hunter-gatherer society (*69*) and therefore affect children's need to learn gender-specific information and skills associated with subsistence (*53*, *70*).

In conclusion, our results provide quantitative support for the long recognized—but largely understudied—theory that the age structure of women's subsistence groups might scaffold age-graded cultural learning in a hunter-gatherer society. Our findings are also consistent with ideas that such mixed-age groups may facilitate both bidirectional and intergenerational cooperation across all age classes—e.g., as in the pooled energy model (*37*). Under adults' care and supervision during subsistence expeditions, children contribute by producing their own foraging outputs (*45*), or by providing infant care while mothers are collecting food (*31*). In turn, children may receive food as compensation (*61*). Alongside this, children may also be provided with opportunities to learn subsistence skills, as well as cultural norms, from their parents, siblings, and nonkin peers (*45*, *71*). By quantifying the probability of coforaging ties across age classes and relatedness levels, our study allows researchers interested in the effects of age structure and kinship on social learning to parameterize formal models using values reflective of a real-world foraging population. Future work should extend our network-based approach and study such phenomena using finer-resolution–directed, quantitative, teaching/learning networks [see (*72*)].

MATERIALS AND METHODS

Ethics statement

Field research with BaYaka people was conducted under all necessary permissions from the relevant authorities of the Republic of the Congo (ethics approval number: No. 070/MRSIT/IRSEN/DG/DS from the Ministère de la Recherche Scientifique et de l'Innovation Technologique, the Republic of the Congo). All study procedures complied with the national laws and regulations of the Republic of the Congo, the ethical standards of the Max Planck Institute for Evolutionary Anthropology, and ethical guidelines of the Comitè d'Ethique de la Recherche en Sciences de la Santè (No. 095/MRSIT/IRSA/CERSSA) in Brazzaville. We obtained informed consent from focal women, their families, and all coresidents in the camp before accompanying people during subsistence expeditions.

The BaYaka

The BaYaka are a group of several populations of Congo-Basin forest foragers who practice mixed subsistence, which involves hunting and gathering, fishing, cultivation, wage labor, and trade (*49*). Some BaYaka families are more mobile, whereas others are more sedentary. Some individuals spend more time foraging in the forest; others work in crop fields while staying in a village. The trade of forest foods with villagers is common. Both BaYaka men and women actively participate in daily subsistence activities, which include gathering wild plants, fishing, and hunting (*50*), but there is appreciable individual and group variation in the extent of engaging in wild-food foraging activities and crop cultivation. BaYaka women go on expeditions for subsistence (e.g., gathering forest food items, fishing, hunting, and cultivating crops), in small or large groups of individuals including a mix of adults and children (*73*). BaYaka children often join adults' subsistence trips but also start foraging independently from ages as young as 5 years old (*53*).

Data collection

Across 230 days of sampling, we collected data from 60 individuals (32 females) in one BaYaka camp in the forest of the northern Republic of the Congo. Within the camp, there were 10 children in early childhood (from 4 to 6 years), 14 children in middle childhood (from 7 to 13 years), 10 adolescents (from 14 to 19 years), and 26 adults (≥20 years). During any one day, there was a maximum of 1770 possible dyads that could have been observed coforaging. During the study period, however, camp composition fluctuated as some individuals joined and left the community. To account for variation in "risk of co-foraging" introduced by such changes in camp composition, we recorded daily camp composition across the 230-day period and defined the model to account for the probability of coforaging conditional on coresidence in-camp on the same day. The average camp size throughout the study was 47 individuals (SD = 6.5; range = [20 − 79]). These individuals comprised, on average, 12 households (SD = 1.4, range = [8,13]). Across 230 days, the average number of days that each dyad spent within the camp was 110 days (SD = 64.61, range = [1,212]; fig. S1A).

We constructed subsistence networks that included the entire community using focal-follow data from five BaYaka women. We followed each focal woman's expeditions from the moment the focal woman left the camp until her return (mean duration per day = 5.20 hours, SD = 2.43, range = [0.45,11.83]), and we continuously recorded the foraging group composition and behaviors of the focal women. These expeditions involved a variety of subsistence activities—such as searching for and picking edible forest food resources, building dams and catching fish, extracting wild yams, hunting small animals, and harvesting crops—and thus provide diverse food returns (*31*). More specifically, across the 230 days of the study, 225 days featured gathering activities (e.g., collecting mushrooms, nuts, leaves, fruits, caterpillars, etc.), 107 days featured extraction of wild yams, 57 days featured fishing activities, 24 days featured honey collection, 14 days featured active hunting, and 68 days featured crop harvesting. Therefore, in any given foraging trip, women may go into the forest (for example) to fish but, during that trip, they may encounter an animal, or some mushrooms or tubers, which they would also opportunistically hunt and/or collect. Hence, each focal follow represents a mixed-activity foraging trip—and thus, it is difficult to classify each foraging trip as representing a single kind of foraging activity, which impedes creation of activity-specific learning networks from our data.

Each focal woman was followed, on average, for 46 days (SD = 5.24, range = [40,53]). These focal women represent 31.25% of the total number of women residing within the camp ($N = 16$). The average group size for women's subsistence activities was 5 (with a range of between 1 and 16 individuals). We coded a network tie between two individuals on a given day as being present if those two individuals were observed together at any point during a daily focal follow of subsistence activities outside of the camp. That is, if individual i and individual j were both present during a focal follow on day 1 of the focal follow of individual f, then we coded undirected ties to be present between i-j, j-f, and i-f during that day. We consider these unweighted ties as representing opportunities or "exposure time" for social learning, reflecting the assumptions of many formal theoretical models [e.g., (*39*, *46*, *74*)]. In addition, empirical studies across several societies (including the BaYaka) have shown that teaching events frequently occur between individuals who spend time with one another (*60*–*64*, *75*)—justifying our approach of using of simple interaction data to infer scope for information and skill sharing. Within the subsistence activity networks across 230 days, the average number of days that each dyad appeared together varied greatly, with an average number of 18.79 days (SD = 19.15, range = 0 to 59; fig. S1B).

Data on genetic relatedness, gender, and age class were collected during household surveys that were conducted at the beginning of the study period. We used these data to construct a relatedness matrix that contains the coefficient of relatedness, r, for each pair of individuals in our sample. In total, 13.22% of dyads were close kin ($0.25 \leq r \leq 0.5$), 30.62% were distant kin ($0 < r < 0.25$), and 56.2% were nonkin ($r = 0$). See the Supplementary Materials for further description of the data.

Statistical analyses

Our data consist of daily, undirected, observational coforaging networks. The networks were unevenly sampled, as focal women were more likely to be observed than nonfocal individuals within the sample. To analyze these networks, we developed a stochastic blockmodel that accounts for censoring introduced by the focal-follow methodology. More specifically, we extend an existing model for binary cross-sectional data [see (*54*, *55*)] to adjust for the uneven sampling that characterized our repeated-observation design. Our model can be written succinctly as

$$Y_{[i,j,d]} \sim \text{Bernoulli}(\phi_{[i,j]})\,|_{i<j \wedge C_{[i,j,d]}=1 \wedge Z_{[i,j,d]}=1} \qquad (1)$$

$$\text{logit}(\phi_{[i,j]}) = \alpha_{[A(i),A(j)]} + X_{[i,j]}\beta \qquad (2)$$

where $Y_{[i,j,d]}$ is an indicator for if individuals i and j were observed coforaging together on day d, $\phi_{[i,j]}$ is the predicted probability that individuals i and j coforage together, $C_{[i,j,d]}$ is an indicator of whether individuals i and j were both in-camp on day d, $Z_{[i,j,d]}$ is a censoring mask for day d (defined in more detail later), α is a $K \times K$ matrix of within- and between-age-class intercept offset parameters, $A(i)$ is a function returning the age class of individual i, β is a vector of regression coefficients, and $X_{[i,j]}$ is a row vector of dyadic covariate data. In each model, the dyad-level effects capture whether individuals were more likely to form ties with those who (i) were genetically related to themselves, (ii) were of different genders, (iii) were both females, and (iv) lived within the same household. The dyadic gender categories were male-male, different-genders, and female-female: Male-male was set as the base case, and the other two categories were coded as binary indicator variables.

In the second model, we added an interaction term between relatedness, R, and age-class blocks—and removed relatedness from the $X_{[i,j]}$ row vector—rewriting Eq. 2 as

$$\text{logit}(\phi_{[i,j]}) = \alpha_{[A(i),A(j)]} + \kappa_{[A(i),A(j)]}R_{[i,j]} + X_{[i,j]}\beta \qquad (3)$$

This model allows us to examine in more detail how the probability of tie formation within and between different age classes may differ when considering kin and nonkin. To assess the difference in the probability of observing ties between kin and nonkin for each age class, we generated predictions from our interaction model and then computed a posterior contrast by subtracting the predicted values for nonkin from the predicted values for kin.

To account for the focal-follow sampling methodology, we use a masking tensor, Z. In Eq. 1, we only model outcomes if three conditions are fulfilled: (i) $i < j$, because the network is undirected, we only model the upper triangle of the adjacency matrix. (ii) $C_{[i,j,d]} = 1$, we only model outcomes where the dyad could have been observed coforaging, by virtue of being in the same camp on the same day. Last, (iii) $Z_{[i,j,d]} = 1$, we only model outcomes where the dyad could have been feasibly been observed on a given day d, conditional on the focal-follow respondent on that day d. In the main model, we call $Z_{[1:N,1:N,d]}$ a two-step mask, and define it as follows

$$Z_{[i,j,d]} = \begin{cases} 1, \text{ if } f(d) \in \{i,j\} \\ 1, \text{ if } Y_{[i,f(d),d]} = 1 \\ 1, \text{ if } Y_{[f(d),j,d]} = 1 \\ 0, \quad \text{Otherwise} \end{cases} \qquad (4)$$

Here, the function $f(d)$ returns the index of the person being focal-followed on day d. The mask $Z_{[i,j,d]}$ thus takes a value of 1 if the focal on a day d is part of an i-j dyad or if anybody coforaging with the the focal on day d is part of an i-j dyad. This mask is needed, because other dyads could be coforaging on day d (in nonfocal groups) but would not be detectable given the focal-follow method. The only dyads that can appear in the outcome data are dyads in which the focal, or somebody coforaging with the focal, appear. As a robustness check, we also tested a variety of other definitions of Z: including no masking, an only-focal mask, a no-focal mask, and a two-step no-focal mask. Our results appeared robust to these alternative models. See the Supplementary Materials for additional details and a visual depiction of the set of considered masks. All analyses were conducted using Stan (*76*) and R [v.4.1.0; (*77*)].

Supplementary Materials

This PDF file includes:

Supplementary Text
Figs. S1 to S6

REFERENCES AND NOTES

1. S. Gallois, A. G. Henry, The cost of gathering among the Baka forager-horticulturalists from Southeastern Cameroon. *Front. Ecol. Evol.* **9**, 952 (2021).
2. H. Kaplan, K. Hill, J. Lancaster, A. M. Hurtado, A theory of human life history evolution: Diet, intelligence, and longevity. *Evol. Anthropol.* **9**, 156–185 (2000).
3. J. Koster, R. McElreath, K. Hill, D. Yu, G. Shepard Jr., N. van Vliet, M. Gurven, B. Trumble, R. B. Bird, D. Bird, B. Codding, L. Coad, L. Pacheco-Cobos, B. Winterhalder, K. Lupo, D. Schmitt, P. Sillitoe, M. Franzen, M. Alvard, V. Venkataraman, T. Kraft, K. Endicott, S. Beckerman, S. A. Marks, T. Headland, M. Pangau-Adam, A. Siren, K. Kramer, R. Greaves, V. Reyes-García, M. Guèze, R. Duda, Á. Fernández-Llamazares, S. Gallois, L. Napitupulu, R. Ellen, J. Ziker, M. R. Nielsen, E. Ready, C. Healey, C. Ross, The life history of human foraging: Cross-cultural and individual variation. *Sci. Adv.* **6**, eaax9070 (2020).
4. T. S. Kraft, V. V. Venkataraman, I. J. Wallace, A. N. Crittenden, N. B. Holowka, J. Stieglitz, J. Harris, D. A. Raichlen, B. Wood, M. Gurven, H. Pontzer, The energetics of uniquely human subsistence strategies. *Science* **374**, eabf0130 (2021).
5. F. W. Marlowe, Hunter-gatherers and human evolution. *Evol. Anthropol.* **14**, 54–67 (2005).
6. M. Tomasello, A. P. Melis, C. Tennie, E. Wyman, E. Herrmann, Two key steps in the evolution of human cooperation: The interdependence hypothesis. *Curr. Anthropol.* **53**, 673–692 (2012).
7. K. Hill, Altruistic cooperation during foraging by the Ache, and the evolved human predisposition to cooperate. *Hum. Nat.* **13**, 105–128 (2002).
8. M. A. Janssen, K. Hill, Benefits of grouping and cooperative hunting among Ache hunter–gatherers: Insights from an agent-based foraging model. *Hum. Ecol.* **42**, 823–835 (2014).
9. B. Winterhalder, Diet choice, risk, and food sharing in a stochastic environment. *J. Anthropol. Archaeol.* **5**, 369–392 (1986).
10. M. Gurven, To give and to give not: The behavioral ecology of human food transfers. *Behav. Brain Sci.* **27**, 543–559 (2004).
11. M. Dyble, J. Thompson, D. Smith, G. D. Salali, N. Chaudhary, A. E. Page, L. Vinicuis, R. Mace, A. B. Migliano, Networks of food sharing reveal the functional significance of multilevel sociality in two hunter-gatherer groups. *Curr. Biol.* **26**, 2017–2021 (2016).
12. M. S. Alvard, Kinship, lineage, and an evolutionary perspective on cooperative hunting groups in Indonesia. *Hum. Nat.* **14**, 129–163 (2003).
13. M. Gurven, C. Von Rueden, Hunting, social status and biological fitness. *Soc. Biol.* **53**, 81–99 (2006).
14. M. Gurven, K. Hill, Why do men hunt? A reevaluation of man the hunter and the sexual division of labor. *Curr. Anthropol.* **50**, 51–74 (2009).
15. M. S. Alvard, D. A. Nolin, Rousseau's whale hunt?: Coordination among big-game hunters. *Curr. Anthropol.* **43**, 533–559 (2002).
16. K. Hawkes, J. F. O'Connell, N. G. Blurton Jones, Hunting and nuclear families: Some lessons from the Hadza about mens work. *Curr. Anthropol.* **42**, 681–709 (2001).
17. D. Redhead, C. R. von Rueden, Coalitions and conflict: A longitudinal analysis of men's politics. *Evol. Hum. Sci.* **3**, e31 (2021).
18. M. S. Alvard, Carcass ownership and meat distribution by big-game cooperative hunters. *Res. Econ. Anthropol.* **21**, 99–131 (2002).
19. K. Hill, A. M. Hurtado, Cooperative breeding in South American hunter-gatherers. *Proc. Biol. Sci.* **276**, 3863–3870 (2009).

20. K. L. Kramer, A. Veile, Infant allocare in traditional societies. *Physiol. Behav.* **193**, 117–126 (2018).
21. K. Starkweather, A. Reynolds, F. Zohora, N. Alam, Shodagor women cooperate across domains of work and childcare to solve an adaptive problem. *Philos. Trans. R. Soc. B* **378**, 20210433 (2023).
22. A. E. Page, A. B. Migliano, M. Dyble, D. Major-Smith, S. Viguier, A. Hassan, Sedentarization and maternal childcare networks: Role of risk, gender and demography. *Philos. Trans. R. Soc. B* **378**, 20210435 (2023).
23. R. B. Bird, B. Scelza, D. W. Bird, E. A. Smith, The hierarchy of virtue: Mutualism, altruism and signaling in Martu women's cooperative hunting. *Evol. Hum. Behav.* **33**, 64–78 (2012).
24. R. B. Bird, E. A. Power, Prosocial signaling and cooperation among Martu hunters. *Evol. Hum. Behav.* **36**, 389–397 (2015).
25. P. Barclay, R. Bliege Bird, G. Roberts, S. Számadó, Cooperating to show that you care: Costly helping as an honest signal of fitness interdependence. *Philos. Trans. R. Soc. B* **376**, 20200292 (2021).
26. E. A. Power, E. Ready, Cooperation beyond consanguinity: Post-marital residence, delineations of kin and social support among South Indian Tamils. *Philos. Trans. R. Soc. B* **374**, 20180070 (2019).
27. J. P. Ziker, K. S. Fulk, Paying it forward or giving back? Womens sharing networks in Siberia. *Cross-Cult. Res.* **53**, 272–290 (2019).
28. T. S. Kraft, D. K. Cummings, V. V. Venkataraman, S. Alami, B. Beheim, P. Hooper, E. Seabright, B. C. Trumble, J. Stieglitz, H. Kaplan, K. L. Endicott, K. M. Endicott, M. Gurven, Female cooperative labour networks in hunter–gatherers and horticulturalists. *Philos. Trans. R. Soc. B* **378**, 20210431 (2023).
29. B. F. Codding, R. B. Bird, D. W. Bird, Provisioning offspring and others: Risk energy trade-offs and gender differences in hunter–gatherer foraging strategies. *Proc. Biol. Sci.* **278**, 2502–2509 (2011).
30. K. Hawkes, J. F. O'Connell, N. G. Blurton Jones, Hadza women's time allocation, offspring provisioning, and the evolution of long postmenopausal life spans. *Curr. Anthropol.* **38**, 551–577 (1997).
31. H. Jang, K. R. Janmaat, V. Kandza, A. H. Boyette, Girls in early childhood increase food returns of nursing women during subsistence activities of the BaYaka in the Republic of Congo. *Proc. R. Soc. B* **289**, 20221407 (2022).
32. B. Scelza, R. Bliege Bird, Group structure and female cooperative networks in Australias Western Desert. *Hum. Nat.* **19**, 231–248 (2008).
33. A. E. Page, M. G. Thomas, D. Smith, M. Dyble, S. Viguier, N. Chaudhary, G. D. Salali, J. Thompson, R. Mace, A. B. Migliano, Testing adaptive hypotheses of alloparenting in Agta foragers. *Nat. Hum. Behav.* **3**, 1154–1163 (2019).
34. B. M. Wood, J. A. Harris, D. A. Raichlen, H. Pontzer, K. Sayre, A. Sancilio, C. Berbesque, A. N. Crittenden, A. Mabulla, R. McElreath, E. Cashdan, J. H. Jones, Gendered movement ecology and landscape use in Hadza hunter-gatherers. *Nat. Hum. Behav.* **5**, 436–446 (2021).
35. D. Redhead, A. D. Ragione, C. T. Ross, Friendship and partner choice in rural Colombia. *Evol. Hum. Behav.* **44**, 430–441 (2023).
36. P. L. Hooper, M. Gurven, J. Winking, H. S. Kaplan, Inclusive fitness and differential productivity across the life course determine intergenerational transfers in a small-scale human society. *Proc. R. Soc. B.* **282**, 20142808 (2015).
37. K. L. Kramer, P. T. Ellison, Pooled energy budgets: Resituating human energy-allocation trade-offs. *Evol. Anthropol.* **19**, 136–147 (2010).
38. J. Bock, Learning, life history, and productivity : Children's lives in the Okavango Delta, Botswana. *Hum. Nat.* **13**, 161–197 (2002).
39. L. L. Cavalli-Sforza, M. W. Feldman, K.-H. Chen, S. M. Dornbusch, Theory and observation in cultural transmission. *Science* **218**, 19–27 (1982).
40. V. Reyes-García, S. Gallois, K. Demps, "A multistage learning model for cultural transmission: Evidence from three indigenous societies" in *Social Learning and Innovation in Contemporary Hunter-Gatherers*, H. Terashima, B. S. Hewlett, Eds. (Springer, 2016), pp. 47–60.
41. M. D. Gurven, R. J. Davison, T. S. Kraft, The optimal timing of teaching and learning across the life course. *Philos. Trans. R. Soc. B* **375**, 20190500 (2020).
42. B. S. Hewlett, L. L. Cavalli-Sforza, Cultural transmission among Aka pygmies. *Am. Anthropol.* **88**, 922–934 (1986).
43. S. Lew-Levy, W. van den Bos, K. Corriveau, N. Dutra, E. Flynn, E. O'Sullivan, S. Pope-Caldwell, B. Rawlings, M. Smolla, J. Xu, L. Wood, Peer learning and cultural evolution. *Child Dev. Perspect.* **17**, 97–105 (2023).
44. B. Hewlett, Social learning and innovation in adolescence: A comparative study of Aka and Chabu hunter-gatherers of Central and Eastern Africa. *Hum. Nat.* **32**, 239–278 (2021).
45. S. Lew-Levy, R. Reckin, N. Lavi, J. Cristóbal-Azkarate, K. Ellis-Davies, How do hunter-gatherer children learn subsistence skills? *Hum. Nat.* **28**, 367–394 (2017).
46. M. Smolla, E. Akçay, Cultural selection shapes network *structure*. *Sci. Adv.* **5**, eaaw0609 (2019).
47. M. Smolla, E. Akçay, Pathways to cultural adaptation: The coevolution of cumulative culture and social networks. *Evol. Hum. Sci.* **5**, e26 (2023).
48. A. Kandler, L. Fogarty, F. Karsdorp, The interplay between age structure and cultural transmission. *PLOS Comput. Biol.* **19**, e1011297 (2023).
49. J. Lewis, "Forest hunter-gatherers and their world: A study of the mbendjele yaka pygmies of congo-brazzaville and their secular and religious activities and representations," thesis, University of London (2002).
50. K. Kitanishi, Seasonal changes in the subsistence activities and food intake of the Aka hunter-gatherers in northeastern Congo. *Afr. Study Monogr.* **16**, 73–118 (1995).
51. J. Lewis, "Egalitarian social organization: The case of the Mbendhele BaYaka" in *Hunter-Gatherers of the Congo Basin: Cultures, Histories, and Biology of African Pygmies*, B. S. Hewlett, Ed. (Transaction, 2014), pp. 219–243.
52. A. H. Boyette, S. Lew-Levy, Socialization, autonomy, and cooperation: Insights from task assignment among the egalitarian BaYaka. *Ethos* **48**, 400–418 (2020).
53. J. Veen, H. Jang, D. Raubenheimer, B. O. C. M. van Pinxteren, V. Kandza, P. G. Meirmans, N. M. van Dam, S. Dunker, P. Hoffmann, A. Worrich, K. R. L. Janmaat, Development of embodied capital: Diet composition, foraging skills, and botanical knowledge of forager children in the Congo Basin. *Front. Ecol. Evol.* **11**, 10.3389/fevo.2023.935987, (2023).
54. D. Redhead, R. McElreath, C. T. Ross, Reliable network inference from unreliable data: A tutorial on latent network modeling using STRAND. *Psychol. Methods* 10.1037/met0000519, (2023).
55. C. T. Ross, R. McElreath, D. Redhead, Modelling animal network data in R using STRAND. *J. Anim. Ecol.* 10.1111/1365-2656.14021, (2023).
56. P. W. Holland, K. B. Laskey, S. Leinhardt, Stochastic blockmodels: First steps. *Soc. Netw.* **5**, 109–137 (1983).
57. B. Bogin, *Patterns of Human Growth* (Cambridge Univ. Press, 2020), vol. 88.
58. J. C. Berbesque, B. M. Wood, A. N. Crittenden, A. Mabulla, F. W. Marlowe, Eat first, share later: Hadza hunter–gatherer men consume more while foraging than in central places. *Evol. Hum. Behav.* **37**, 281–286 (2016).
59. S. Wright, Coefficients of inbreeding and relationship. *Am. Nat.* **56**, 330–338 (1922).
60. S. Lew-Levy, S. M. Kissler, A. H. Boyette, A. N. Crittenden, I. A. Mabulla, B. S. Hewlett, Who teaches children to forage? Exploring the primacy of child-to-child teaching among Hadza and BaYaka Hunter-Gatherers of Tanzania and Congo. *Evol. Hum. Behav.* **41**, 12–22 (2020).
61. A. H. Boyette, B. S. Hewlett, Autonomy, equality, and teaching among Aka foragers and Ngandu farmers of the Congo Basin. *Hum. Nat.* **28**, 289–322 (2017).
62. S. Gallois, R. Duda, B. Hewlett, V. Reyes-García, Childrens daily activities and knowledge acquisition: A case study among the Baka from southeastern Cameroon. *J. Ethnobiol. Ethnomed.* **11**, 86 (2015).
63. A. E. Maynard, Cultural teaching: The development of teaching skills in Maya sibling interactions. *Child Dev.* **73**, 969–982 (2002).
64. M. A. Kline, TEACH: An ethogram-based method to observe and record teaching behavior. *Field Methods* **29**, 205–220 (2017).
65. L. Vygotsky, *Mind in Society: Interaction between Learning and Development* (WH Freeman and Company, 1978).
66. W. D. Hamilton, The genetical evolution of social behaviour. II. *J. Theor. Biol.* **7**, 17–52 (1964).
67. M. J. Goodman, P. B. Griffin, A. A. Estioko-Griffin, J. S. Grove, The compatibility of hunting and mothering among the Agta hunter-gatherers of the Philippines. *Sex Roles* **12**, 1199–1209 (1985).
68. K. L. Kramer, Female cooperation: Evolutionary, cross-cultural and ethnographic evidence. *Philos. Trans. R. Soc. B* **378**, 20210425 (2023).
69. F. W. Marlowe, Hunting and gathering: The human sexual division of foraging labor. *Cross-Cult. Res.* **41**, 170–195 (2007).
70. S. Lew-Levy, A. H. Boyette, A. N. Crittenden, B. S. Hewlett, M. E. Lamb, Gender-typed and gender-segregated play among Tanzanian Hadza and Congolese BaYaka hunter-gatherer children and adolescents. *Child Dev.* **91**, 1284–1301 (2020).
71. S. Lew-Levy, N. Lavi, R. Reckin, J. Cristóbal-Azkarate, K. Ellis-Davies, How do hunter-gatherer children learn social and gender norms? A meta-ethnographic review. *Cross-Cult. Res.* **52**, 213–255 (2018).
72. J. F.-L. De Pablo, V. Romano, M. Derex, E. Gjesfjeld, C. Gravel-Miguel, M. J. Hamilton, A. B. Migliano, F. Riede, S. Lozano, Understanding hunter–gatherer cultural evolution needs network thinking. *Trends Ecol. Evol.* **37**, 632–636 (2022).
73. H. Jang, C. Boesch, R. Mundry, S. D. Ban, K. R. Janmaat, Travel linearity and speed of human foragers and chimpanzees during their daily search for food in tropical rainforests. *Sci. Rep.* **9**, 11066 (2019).
74. D. Deffner, A. Kandler, L. Fogarty, Effective population size for culturally evolving traits. *PLOS Comput. Biol.* **18**, e1009430 (2022).
75. A. B. Migliano, A. E. Page, J. Gómez-Gardeñes, G. D. Salali, S. Viguier, M. Dyble, J. Thompson, N. Chaudhary, D. Smith, J. Strods, R. Mace, M. G. Thomas, V. Latora, L. Vinicius, Characterization of hunter-gatherer networks and implications for cumulative culture. *Nat. Hum. Behav.* **1**, 0043 (2017).
76. Stan Development Team, *Stan Modeling Language Users Guide and Reference Manual*, version 2.18.0 (2018).

77. R Core Team, *R: A Language and Environment for Statistical Computing* (R Foundation for Statistical Computing, 2022).

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