scientific reports

Check for updates

OPEN

BaYaka mothers balance childcare and subsistence tasks during collaborative foraging in Congo Basin

Amandine E. S. Visine[1], Adam H. Boyette[1], Yann Reische Ouamba[2], Sheina Lew-Levy[3], Mallika S. Sarma[4] & Haneul Jang[1,5]✉

Across cultures, mothers balance childcare with other labour. Hunter-gatherer mothers face a daily choice of whether to take infants on foraging trips or leave them with caregivers in the settlement, as well as deciding with whom to forage. Yet, it remains unclear how infant presence affects mothers' mobility and food returns during group foraging. Using GPS, heart rate measurements, and food return data from 348 foraging trips by 22 BaYaka mothers in the Republic of the Congo, we found that mothers go on longer-duration foraging trips when they take infants along, compared to when they leave them behind. Despite this, infant presence does not affect mothers' mobility, energy expenditure, or food returns. Mothers also go on longer-duration and longer-distance trips during group foraging, compared to foraging alone. However, they have decreased food returns in larger groups with more adults, possibly due to food competition. Nevertheless, BaYaka mothers maintain their energy expenditure and net food returns in general, regardless of infant presence or group dynamics, likely due to their individual foraging strategies and support from group members. Particularly, children in foraging groups increase mothers' food returns, aligning with women's reports of children assisting as caregivers. These findings provide insights into how BaYaka mothers accommodate childcare with subsistence activities during group foraging.

Keywords Trade-offs, Childcare, Group foraging, Hunter-gatherer mothers

Compared to other great apes, humans have unique life-history traits including higher fertility, shorter inter-birth intervals, earlier weaning and an extended childhood period[1–4]. Due to these traits, mothers face trade-offs in allocating their time and energy between childcare and other labour[5–12], as well as in their investment towards each child[13–17]. In hunter-gatherer societies, mothers often take infants along on daily foraging trips[5,9,18]. Although some types of labour—such as gathering activities—are more compatible with childcare than other labour—such as hunting[19,20], mothers with young children often have to adjust their foraging strategies by reducing foraging duration[9] or by engaging in low-risk, low-intensity activities[21–23]. This balance between childcare and subsistence tasks can be more challenging for mothers with breastfeeding infants than those with weaned children. For example, mothers with breastfeeding infants, in general, spend less time foraging and acquire less food compared to mothers with weaned children[9]. Despite their greater behavioural constraints, we lack detailed knowledge of how childcare responsibilities limit the nature or extent of mobility during daily subsistence activities of breastfeeding mothers, and how mothers balance these trade-offs. Considering the important role of women's subsistence activities in family provisioning, further exploration of this topic can provide valuable insights into the interplay between childcare and subsistence strategies, which may have played a key role in shaping human evolutionary success.

As humans are central place foragers—returning to a specific location after foraging trips to feed offspring and rest[24,25]—as well as cooperative breeders—receiving childcare support from other group members[26–29], mothers have the choice of either taking their infants on daily foraging trips or leaving them with caregivers in the settlement (e.g., camp or village)[5]. As weaned children become heavier to carry and less vulnerable when away

[1]Department of Human Behavior, Ecology and Culture, Max Planck Institute for Evolutionary Anthropology, Leipzig 04103, Germany. [2]Université Marien Ngouabi, Brazzaville, Republic of the Congo. [3]Department of Psychology, Durham University, Durham, UK. [4]Department of Anthropology, University of Pennsylvania, Philadelphia, PA, USA. [5]Institute for Advanced Study in Toulouse, Toulouse School of Economics, 1 Esplanade de l'Université, Toulouse cedex 06 31080, France. ✉email: haneul.jang@iast.fr

from their mother's care, mothers are more likely to leave them at the settlement[9]. In comparison, breastfeeding mothers cannot be away from their infants for too long, as infants need to be breastfed regularly[9]. Thus, these mothers are more likely to bring breastfeeding infants along on foraging trips, allowing them to breastfeed intermittently between foraging activities.

However, carrying infants is energetically expensive[30–32], particularly for mothers who are recovering from a lengthy pregnancy and are expending energy on breastfeeding[33]. This energetic burden of carrying and breastfeeding infants may restrict mothers' mobility–limiting their ability to travel further from the village or explore a larger range–and may also reduce maternal energy that could instead be put towards subsistence activities[9,18]. On the other hand, when mothers forage without their infants, they can be free from the burden of infant carrying and breastfeeding, potentially allowing them to conserve energy for foraging activities. Nevertheless, mothers may still be constrained from travelling further away and spending extended time on out-of-village subsistence activities, as they need to return to the village to breastfeed[9]. These constraints and opportunities create dilemmas for breastfeeding mothers in their daily decision-making about whether to bring infants on foraging trips or leave them in the settlement.

Under the pooled energy model, such dilemmas can be mitigated by childcare support from allomaternal caregivers[5,34,35]. Studies show that assistance from allomaternal caregivers in the settlement enables mothers to allocate more time to other tasks, reduce their energy expenditure, or maintain their baseline activity levels[5,10,28,29,35–38]. Mothers also receive childcare support during foraging trips[18]. Hunter-gatherer women typically forage in variable-sized, mixed-age groups, including both adults and children[25,39,40]. In these groups, members can provide direct childcare while mothers acquire food, or they can take on foraging tasks while mothers look after their infants. Supporting this, an empirical study shows that mothers with infants have increased foraging efficiency with a greater number of potential caregivers in foraging groups[18]. However, larger group sizes may lead to decreased marginal returns, potentially reducing individual food returns and, thus, requiring longer travel distances to find sufficient food[41–44]. Yet, there is a large gap in our understanding of how mothers balance childcare and food acquisition, considering both the constraints and benefits of bringing infants on foraging trips, as well as the dynamics of group foraging.

In this study, we aim to investigate how the presence of breastfeeding infants and group foraging influences the mobility, energy expenditure, and food acquisition of breastfeeding mothers among BaYaka foragers in the northern Republic of the Congo. The BaYaka are a contemporary hunter-gatherer population in the Congo Basin, practicing a broad range of subsistence activities. In the BaYaka community where we conducted our study, both BaYaka men and women actively engage in daily subsistence activities–such as hunting, gathering, fishing, and crop cultivation, and women also spend long time in intense physical activity[45]. Childcare is widely shared among the BaYaka, through kinship and reciprocity, alleviating mothers' burden[10,18,46,47]. BaYaka women habitually travel long distances for food acquisition in mixed-age and mixed-kinship groups[39], often taking their breastfeeding infants on foraging expeditions. During these trips, they receive childcare support from other members of the foraging groups–including older children[18]. While foraging, BaYaka women collect food and put the food items in their own baskets, although they share both collected and cooked food in the village.

Using GPS, heart rate, food returns, and group composition data from 348 foraging trips by 22 breastfeeding mothers in a BaYaka community (22 households with 180 individuals), we examine how the presence of breastfeeding infants and other group members during foraging trips affects four variables: total travel duration (the time differences between departure and return to the village), total travel distance (the sum of distances between successive GPS waypoints), net energy expenditure, and net food returns of the mothers. We compare these four variables between (1) foraging trips with and without breastfeeding infants, and (2) group foraging and solo foraging. We further investigate the effects of the age-class and sex of foraging group members, as well as their genetic relatedness to the focal mothers. To investigate who provides childcare during foraging trips, we also conducted self-report interviews with the focal mothers after each foraging trip. We predict that the presence of breastfeeding infants will constrain mothers mobility and reduce their net food returns, due to the energetic burden of childcare during foraging trips. However, we expect that allomaternal childcare support from foraging group members may mitigate these costs to the extent that increased group size—and the number of potential caregivers—does not result in decreased marginal returns for mothers' food yields. Understanding these dynamics can provide scope for the compatibility between childcare and subsistence tasks, which may have been an important key to human demographic and ecological expansion.

Results

Across the 348 trips, BaYaka women engaged in a variety of foraging activities targeting different resources: 304 trips of gathering (mushrooms, nuts, leaves, or fruits), 173 trips of extracting wild yams, and 96 trips of hunting and fishing. Among those 348 foraging trips, the 22 mothers took their infants with them 59.2 percent of the time (206 trips with infants in total). BaYaka mothers primarily foraged in groups, foraging alone in only 11.78% of the 348 trips (41 solo foraging compared to 307 group foraging). The foraging groups varied in size and composition (mean group size = 3.16, SD = 0.17, range: from 0 to 20, other than the focal mother and her infant; see Supplementary Table 1 for details). Among the 307 group foraging trips that included at least one other individual but not their infants, 31.92% involved only kin (98 trips), 34.53% involved only non-kin (106 trips), and the remaining trips were a mix of kin and non-kin (103 trips). Among the 307 group foraging trips, 39.74% involved only females (122 trips), and 14.98% involved only female kin (46 trips). 21.82% involved only adults (67 trips), and 27.36% included the focal woman and only children, both kin and non-kin (84 trips). Foraging trips only with her own children accounted for 16.61% of the total (51 out of 307 foraging trips). The focal mothers went with their husbands for 16.61% of the total foraging trips (51 out of 307 foraging trips), and when BaYaka women traveled with adult men, 90.25% of those trips were with their husbands. See Supplementary Table 3 for the number of trips with different group compositions, comparing those with and without infants.

Among the 188 trips in which BaYaka mothers took their infants along while foraging with other individuals, the mothers reported that they received direct childcare assistance from foraging group members during 69% of trips when collecting food sources (130 trips) and during 31% of trips while walking in the forest (59 trips). When foraging with their husbands and infants, the focal mothers reported that their husbands provided direct childcare in 97% of the trips (38 out of 39). Crucially, the mothers reported that children in early or middle childhood provided direct childcare during foraging trips in 63% of the cases (85 children out of 134 caregivers reported during the 188 trips).

In the subsections that follow, we outline the model results: First, we examine how the presence of infants and the presence of other individuals in foraging groups affect mothers' mobility and foraging outcomes—i.e., travel duration, total travel distance, energy expenditure, and food returns (See Supplementary Table 2 for descriptive statistics of these metrics), and second, we investigate how individual characteristics of group members—i.e., age class, sex, and genetic relatedness—affect these outcome variables. The additional model results, which include two other response variables—maximum distance from the village (the distance from the village center to the furthest GPS waypoint) and foraging range (the smallest area polygon encompassing all GPS waypoints) of the mothers—do not differ from what we found for total travel distance and, thus, are outlined in the Supplementary Information (Supplementary Figures 1–6). To present our results, we evaluate the median of the posterior distributions for each parameter and their associated 95% credible intervals (*CI*).

The effects of infant presence and other individuals on mothers' foraging trips

We tested the effects of infant presence (yes/no) and the presence of other individuals in the group (yes/no) on the mothers' total travel duration (hour), total travel distance (km), energy expenditure (kcal/min), and food returns (kcal). We found that the presence of infants in foraging groups increased mothers' travel duration, suggesting that BaYaka mothers went on longer foraging trips when they took their infants along, compared to when they left their infants in the village (Fig. 1a). However, the presence of infants in foraging groups did not have any effect on mothers' travel distance, energy expenditure or food returns (Fig. 1b–d).

Moreover, BaYaka mothers went on longer and farther foraging trips, when accompanied by other group members, compared to when foraging alone (Fig. 1a, b). However, the presence of other individuals during foraging activities did not effect mothers' energy expenditure or net food returns (Fig. 1c, d)

The effects of age-class, sex, and kinship of group members on mothers' foraging trips

We further aimed to understand how the age-class (adults/children), sex (females/males) of group members, and their kinship relationship with the focal mothers (kin/non-kin) affect mothers' travel duration, total travel distance, energy expenditure, and food returns. We defined kin as individuals with a genetic relatedness (r) between 0.125 and 0.5. For this, we built three sub-models focusing separately on (1) age-class, (2) sex, and (3) kinship relation, each examining their effects on the four outcome variables—travel duration, total distance, energy expenditure, and food returns. We initially included the interactive effects of infant presence along with

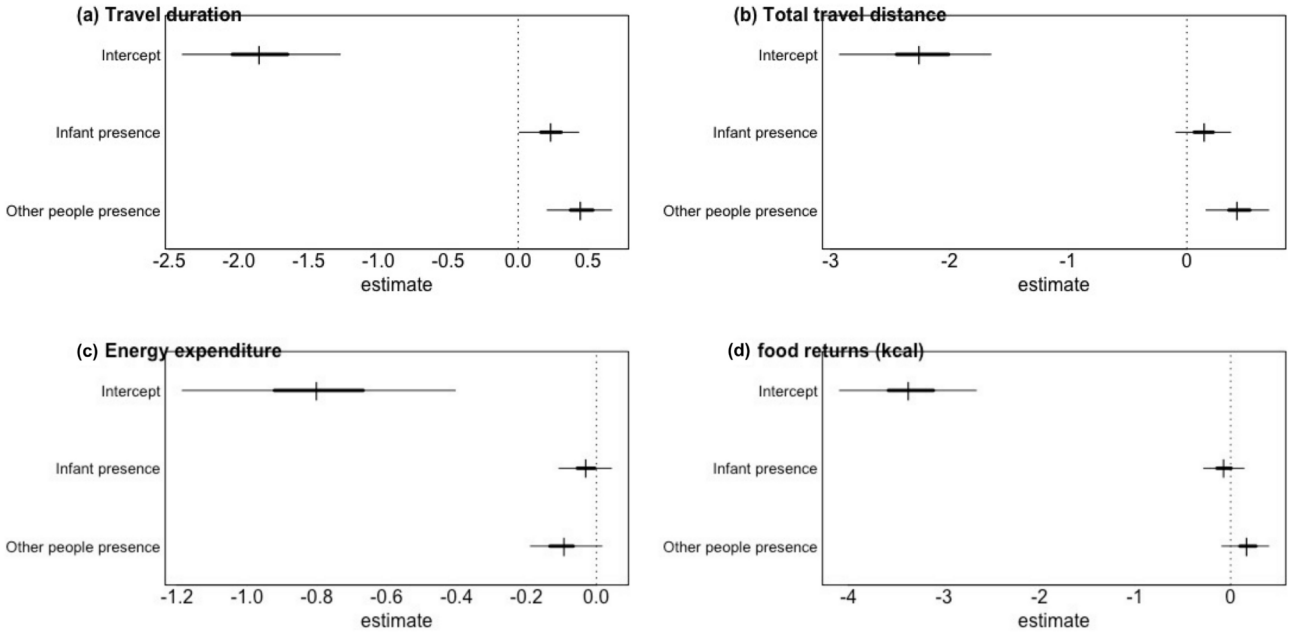

Fig. 1. Forest plots showing estimated changes in (**a**) total travel duration (hour), (**b**) total travel distance (km), (**c**) energy expenditure (kcal/min) and (**d**) food returns (kcal) of focal mothers during foraging trips, based on the presence of the infant (yes/no) and the presence of other group members (yes/no). Results display the median of the posterior distributions for each parameter, along with the 50 percent (inner) and 90 percent (outer) credible intervals (*CI*).

these categories, however, we did not find any substantial effects of these interactions (see Supplementary Figs. 1, 2 and 3, illustrating the models with interactions). Therefore, we removed the interactions from each model and focused on the direct effects of each parameter, which we explain below in the order of age-class (adults/children), sex (females/males), and kinship (kin/non-kin).

First, we found that the number of adults (defined as 20 years and over) in the groups increased mothers' travel duration and travel distance (Fig. 2a, b, first column), but decreased mothers' net food returns (Fig. 2d, first column). In contrast, the number of children (between 4 and 19 years) in foraging groups did not have any substantial effects on mothers' travel duration, total travel distance, or maternal energy expenditure (Fig. 2a–c, second column), but increased mothers' net food returns (Fig. 2d, second column). Neither the number of adults nor children had effects on maternal energy expenditure (Fig. 2c, first and second columns). Second, the number of females—including both girls and women—in foraging groups increased mothers' travel duration and travel distance (Fig. 2a, b, third column), but neither maternal energy expenditure nor net food returns (Fig. 2c, d, third column). We did not find any effect of the number of males in foraging groups on any of the four variables (Fig. 2a–d, fourth column). Third, the number of both kin and non-kin in foraging groups increased BaYaka mothers' travel duration and travel distance (Fig. 2a, b, fifth and sixth columns), but neither maternal energy expenditure nor food returns (Fig. 2c, d, fifth and sixth columns).

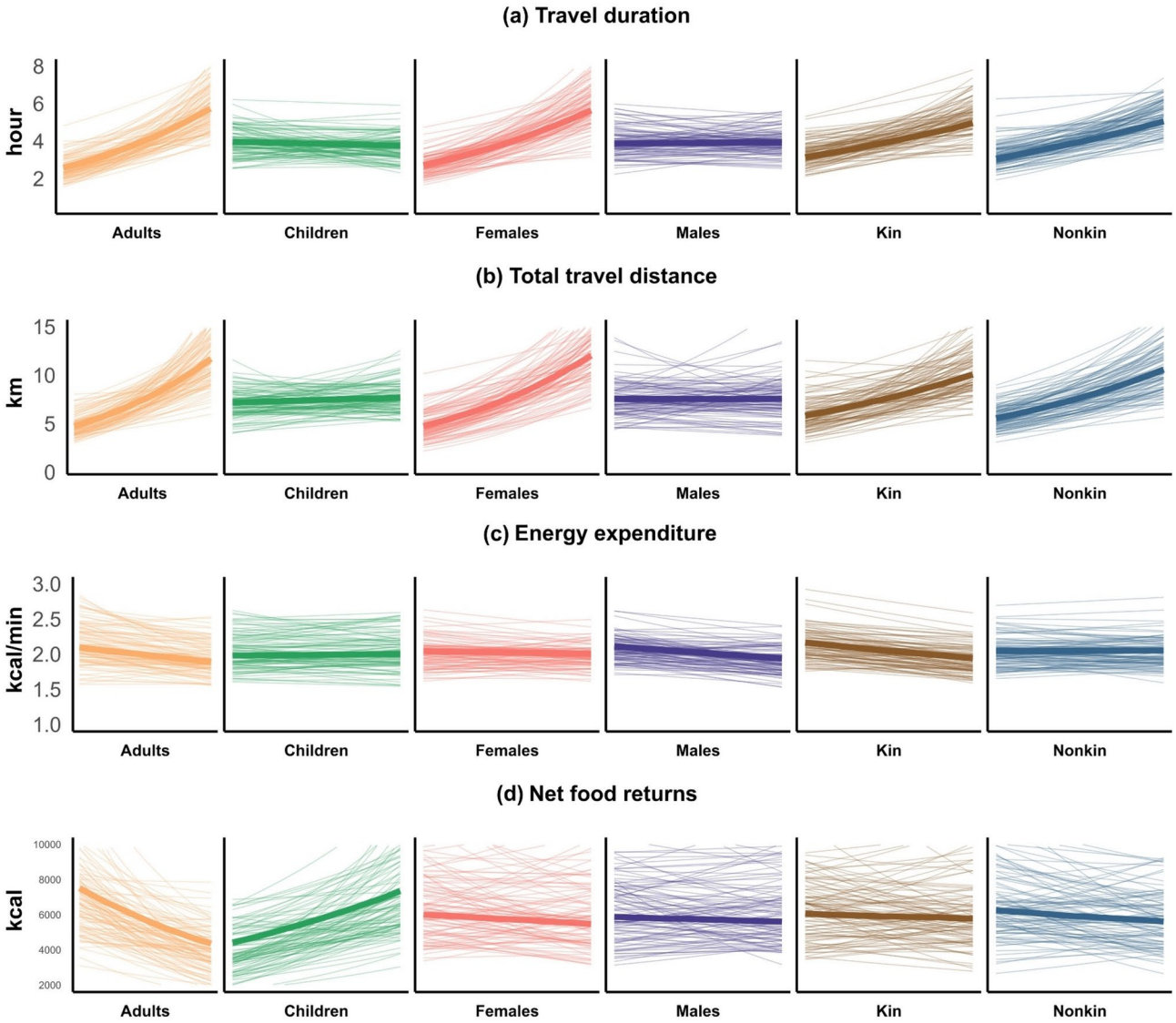

Fig. 2. Predictive graphs from posterior samples of multilevel regression models after removing interaction terms. We present 12 models in total, with three models for each of the four response variables: (**a**) travel duration (hour), (**b**) total travel distance (km), (**c**) energy expenditure (kcal/min) and (**d**) net food return (kcal). Each set of three models examines the effects of the number of group members in different categories: (1) Age-class model: adults versus children, (2) Sex model: females versus males, and (3) Kinship model: kin versus nonkin. These effects are tested in separate models rather than being combined in a single model.

To further investigate which individuals may drive these effects, we ran additional post-hoc models by breaking down the initial three categories—age-class (adults/children), sex (females/males), and kinship (kin/non-kin)—into sub-categories. In the first post-hoc model, we examined the effects of the number of 'kin adults', 'non-kin adults', 'kin children' and 'non-kin children'. We found that the number of non-kin adults in the group, but not kin adults, was associated with increased travel duration and travel distance of the focal mothers, while decreasing their net food returns (See Supplementary Table 4). In the second model, which investigates the effects of 'female adults', 'male adults', 'female children', and 'male children', we found that female adults, female children, and male adults were associated with increased travel duration and travel distance of the focal mothers (See Supplementary Table 5).

Discussion

BaYaka mothers go on longer foraging trips when taking infants along compared to when they leave infants in the village. This can be explained by several factors: First, mothers may walk more slowly while carrying infants and spend additional time caring for them. Second, to compensate for the time spent on childcare during foraging, mothers may need to extend the overall duration of their foraging trips to maintain their net food returns. Third, as mothers can breastfeed intermittently during foraging without needing to return to the village, they are able to undertake longer foraging trips. Thus, this strategy of going on longer foraging trips may help mothers meet both the need to collect sufficient food and the need for childcare.

However, the presence of infants in foraging groups does not affect mothers' travel distance, energy expenditure, or food returns. Longer travel duration without increased travel distance supports our earlier explanation that mothers walk more slowly while carrying infants. Walking slowly further allows mothers to conserve energy, as we found no differences in maternal energy expenditure when they were with or without infants. Moreover, BaYaka mothers maintained their net food returns when with infants, without expending additional energy or travelling long distances. These findings indicate that mothers successfully collect sufficient food–likely by spending more time at a foraging patch rather than exploring larger ranges (similar to observations in Hiwi mothers[9]). Therefore, our results demonstrate that BaYaka mothers effectively accommodate childcare during foraging trips without substantial losses in energy or food returns. Future studies should further compare the travel speed of BaYaka mothers when carrying infants versus when not, as well as investigate their detailed behavioural strategies, particularly whether mothers spend more time at foraging patches rich in food resources.

Regardless of infant presence in foraging groups, BaYaka mothers travelled longer distances when foraging in groups, compared to foraging alone. On the one hand, this can be explained by the childcare support provided by foraging group members. BaYaka mothers indeed reported that they frequently received childcare assistance from foraging group members, who helped by carrying infants and/or baskets (Fig. 3). This support alleviates the physical burden on the mothers, enabling them to travel longer distances without increasing their overall energy expenditure levels (as in[37]). On the other hand, the increased mobility of mothers may also result from the necessity to travel farther to find sufficient food for larger groups. Notably, BaYaka mothers walked longer distances when more non-kin adults—rather than kin adults—were present in foraging groups, suggesting potential food competition among group members.

In contrast to adults, the presence of children in foraging groups increased mothers' net food returns. This finding aligns with a previous study indicating that BaYaka children, rather than adults, improve mothers' foraging efficiency, especially when mothers have infants with them during foraging trips[18]. It is further supported by our self-report data, where the focal mothers indicated receiving help for infant care from children in foraging groups. Furthermore, the presence of children in foraging groups does not hinder mothers' mobility–suggesting that even young children can achieve an adult-level walking capacity[48]. These findings provide valuable insights into the role of children in women's subsistence activities, framing them as active participants rather than obstacles to adults' foraging efforts. Future studies should focus on observing children's behaviours in women's foraging groups, using methods such as focal follow sampling.

In sum, our findings highlight the compatibility between childcare and subsistence work among BaYaka mothers. Carrying a breastfeeding infant during foraging trips requires greater effort from mothers to maintain the same net food intake. In addition, foraging in a group requires mothers to exert additional effort to secure sufficient food due to potential competition. Our results demonstrate that, despite these challenges, BaYaka mothers effectively balance childcare with subsistence work during collaborative foraging, maintaining both their energy expenditure and net food returns. To better understand their detailed behavioural strategies, future studies should examine the actual time spent carrying infants versus foraging, by mothers and other group members, through focal follow sampling. Furthermore, even when BaYaka mothers go on foraging trips without their own infants, they may still provide childcare to other women in the foraging groups by carrying other infants. Hence, to better examine the costs associated with infant presence at a group level, future studies should investigate how both the presence and total number of infants affect the energy expenditure and food returns of all group members in a foraging group. This approach will allow us to understand the costs of childcare at a group level, going beyond the individual perspectives of mothers, as well as to investigate the group-level strategies for balancing the trade-offs between childcare and subsistence tasks under the pooled energy model[34]. This line of research will elucidate how human mothers mitigate these trade-offs between childcare and other labour through individual-level and group-level strategies, which is crucial for understanding human demographic success and range expansion.

Fig. 3. During a foraging trip, a BaYaka mother (front) carries her basket, and her 12-years old daughter (back) carries an infant, her youngest sibling. (Picture taken by H.J., who obtained informed consent from both the mother and her daughter to use this image in an online open-access publication).

Methods

Ethics and consent procedures

Permissions to conduct this research in the Republic of the Congo were obtained from the Institut de Recherche en Sciences Exactes et Naturelles (IRSEN) and the Institut National de Recherche en Sciences Sociales et Humaines (INRSSH) in Brazzaville. Our study procedures and methods were carried out in accordance with the national laws, the relevant guidelines and regulations of the Republic of the Congo. The study protocol was approved by the Institut National de Recherche en Sciences Sociales et Humaines (Approval No: 007/MESRSIT/INRSSH-DG) as well as by the Max Planck Society's Ethics Council in Germany (Approval No: 2022_7). Before the data collection, H.J. presented an overview of the project-the research aims and methods-in a public meeting with all residents in the village, and obtained informed consent from the study community. In the following days, H.J. visited each household and obtained informed consent from the focal mothers and their family members. All of the focal mothers agreed to participate in daily interviews about their foraging trips and to wear GPS

watches during their foraging trips as part of the study. All interview data, GPS data and individual information have been anonymised.

Data collection

The study was conducted between August and October 2022 in a BaYaka village in the forest of the Likouala department in the northern Republic of the Congo. In the beginning of the study period, H.J. conducted the household survey for each house in the village and collected demographic and household-level data for each family unit. All of 23 households in the study village were surveyed, and the village census counted 180 individuals. All 22 nursing mothers in the village, each with an infant aged between 3 months and 3.5 years, who actively participate in daily foraging trips were selected as focal mothers for our study. H.J. and Y.R.O. collected anthropometric data of all the focal mothers, namely height and weight, and estimated their ages and age classes based on the number of their children and siblings. Over the course of the six-week study period, we distributed 20 Forerunner 55 watches (Garmin, Olathe, United States) to the focal mothers every morning and collected them again in the evening on the same day. The GPS watches recorded GPS coordinates and heart rate measurements (in bpm) every second. We conducted daily interviews with all the focal mothers both when they left the village and when they returned from their trips. We recorded the time of departure and return, trip types (e.g., foraging, crop cultivation, fetching water and firewood, social visits, etc.), the presence of their nursing infants in foraging groups, and the identities of all the foraging group members. We observed the group composition when the mothers left and returned to the village, and we also asked the focal mothers to provide the names of all accompanying individuals for confirmation. The sex and age class of individuals in the groups, along with their relatedness to the focal mothers, were recorded. Upon their return to the village with food, we documented the types of collected food items and measured the weight of each item. After each foraging trip in which the focal mothers brought their breastfeeding infants, we asked them who provided childcare (1) while they were collecting food and (2) while they were walking in the forest. In total, we recorded 348 person-days of GPS tracking, heart rate, and food return data from the 22 focal mothers.

Data processing

We first cleaned the GPS tracks by removing points that indicated unrealistic walking speeds exceeding 30 km/h[49], as these were likely due to errors in satellite recording. Using the GPS coordinates of all the houses in the village, we defined the village's geographical center and area. We then extracted GPS tracks that were located outside this area to calculate metrics for out-of-village foraging trips. For each foraging trip, we calculated *total travel duration (hours)*, *total travel distance (kilometres)*, *net energy expenditure (kcal/minute)*, and *net caloric food returns (kcal)*. The total travel duration of the trips (hours) was calculated by subtracting the departure time from the arrival time. We determined thetotal travel distance (kilometres) by summing the distances between each successive GPS waypoint along the foraging trip tracks. For the net energy expenditure, we applied the method outlined by Hiilloskorpi et al.[50], which has been specifically adapted for the BaYaka population. This method allows us to calculate energy expenditure using two distinct formulas: one for intense activities (defined as a heart rate above 90 bpm) and another for light activities (heart rate below 90 bpm)[45]. We first calculated basal metabolic rate (BMR) for each focal woman, and then converted heart rate (bpm) into energy expenditure (kcal/min), accounting for individual body weight (kg). Finally, to calculate the net caloric return of the foraging trip, we multiplied the mass (grams) of each food item collected during the trip by its nutritional value (kcal/g) from the dataset provided by Benoît et al.[51], and then summed the caloric value (kcal) of all the collected food items. All data were processed using R (version 4.3.0) on Rstudio Pro (server version 2023.03.0).

Statistical analyses

We used Bayesian multilevel regression models within the Stan computational framework (http://mc-stan.org/), accessed with the function 'brm' from the brms package v. 2.16.3[52] in R v. 4.1.0 (R Core Team 2020). The unit of analysis in the statistical models was a subsistence trip of a focal woman, and we used four trip metrics of each foraging trip as response variables: *total travel duration (hours)*, *total travel distance (kilometres)*, *net energy expenditure (kcal/minute)*, and *net caloric food returns (kcal)*. To assess variation across focal women, days, and food items, we first fitted baseline models for each response variable. These models accounted for the multilevel structure of the data and included only random effects associated with focal women IDs (N = 22), day IDs (N = 35), and targeted food types (N = 15 different combinations of seven unique food items, including animals, mushrooms, leaves, nuts, tubers and fruits). Baseline models did not include any predictor variables (i.e., fixed effects). We examined the standard deviations of the log-odds for response outcomes across focal women, days, and food types, calculating intra-class correlation coefficients to determine the proportion of variance explained by each level (focal women ID, day ID, and food types)[53]. We then fitted models incorporating both the fixed effects and the random effects mentioned above. To account for variation in infant presence and foraging group composition among focal women, we included random slopes for the fixed effects within the random intercepts of focal woman IDs[54,55].

First, we developed models with two fixed effects: the presence of the women's infants (yes/no) and the presence of other individuals (yes/no) within foraging groups. To address both between- and within-individual effects for the focal women, we included individual-level (focal woman-level) and trip-level fixed effects. For the individual-level predictors, we calculated each focal woman's average probability of taking her infant on foraging trips and her average probability of foraging with other individuals. At the trip level, we included the presence of a focal woman's infant (yes/no) and the presence of other individuals (yes/no) during each specific trip. In the food returns model, we also included a predictor that accounted for the non-linear relationship between travel duration and food returns, based on our assumption that the duration of food collection could influence the amount of food returned.

Second, we constructed models to examine the effects of group members' characteristics, including age class (adults versus children), sex (females versus males), and kinship relation to the focal women (kin versus non-kin). Initially, we included two-way interactive effects between the presence of infants in groups (yes/no) and the number of individuals in each category. In the age-class model, we included two interactions: (1) the presence of infants and the number of adults, and (2) the presence of infants and the number of older children within the foraging groups. In the sex model, we examined interactions between infant presence and (1) the number of females and (2) the number of males present in the groups. For the kinship model, we included interactions between infant presence and (1) the number of kin ($0.125 \leq r \leq 0.5$) and (2) the number of non-kin members in the group. We modeled nonlinear function using a spline for these interactions between infant presence and the number of individuals in each category during each trip. The interactions were included as trip-level predictors. After we did not find any effect of those two-way interactions, we removed the interaction terms, and ran the models with individual predictors to explore the independent effects of each variable. We further conducted post-hoc analyses by further breaking down the initial categories—age-classes (adults/children), sex (females/males), and kinship (kin/non-kin)—into sub-categories. For age-class and kinship, we divided individuals into four sub-categories: kin adults, non-kin adults, kin children, and non-kin children. For age-class and sex, we divided individuals into female adults, male adults, female children, and male children. All quantitative predictors were standardised to a mean of zero and a standard deviation of one before fitting models[56]. We fitted all models using a log-normal error distribution and applied weakly informative normal priors to prevent overfitting[57]. Posterior distributions for the effects of predictors were obtained from four independent MCMC chains. Our models capture the uncertainty inherent in the data and assumptions. We compared each of the main models to the baseline model using information criteria and calculated model weights with the model_weights function from the brms package. The comparison showed that models with fixed effects were favored over the baseline models.

Data availibility

All relevant data and code for reproducing the analyses and figures are available at the following GitHub repository: https://github.com/haneuljangkr/bayaka-tradeoffs-childcare-foraging

Received: 3 February 2024; Accepted: 7 October 2024
Published online: 22 October 2024

References

1. Charnov, E. L. & Berrigan, D. Why do female primates have such long lifespans and so few babies? or Life in the slow lane. *Evol. Anthropol. Issues News Rev.* **1**(6), 191–194 (1993).
2. Bogin, B. Evolutionary perspective on human growth. *Annu. Rev. Anthropol.* **28**(1), 109–153 (1999).
3. Blurton-Jones, N. G. & Marlowe, F. W. Selection for delayed maturity. *Hum. Nat.* **13**(2), 199–238 (2002).
4. Kaplan, H., Hill, K., Lancaster, J. & Hurtado, A. M. A theory of human life history evolution: Diet, intelligence, and longevity. *Evol. Anthropol. Issues, News Rev.* **9**(4), 156–185 (2000).
5. Meehan, C. L. Maternal time allocation in two cooperative childrearing societies. *Hum. Nat.* **20**(4), 375–393 (2009).
6. Brown, J. K. A note on the division of labor by sex 1. *Am. Anthropol.* **72**(5), 1073–1078 (1970).
7. Gurven, M., Kaplan, H. & Gutierrez, M. How long does it take to become a proficient hunter? Implications for the evolution of extended development and long life span. *J. Hum. Evol.* **51**(5), 454–470 (2006).
8. Hawkes, K., O'Connell, J. F. & Blurton-Jones, N. G. Hadza women's time allocation, offspring provisioning, and the evolution of long postmenopausal life spans. *Curr. Anthropol.* **38**(4), 551–577 (1997).
9. Hurtado, A. M., Hill, K., Hurtado, I. & Kaplan, H. Trade-Offs between female food acquisition and child care among hiwi and ache foragers. *Hum. Nat.* **3**(3), 185–216 (1992).
10. Ivey, P. K. Cooperative reproduction in Ituri forest Hunter-Gatherers: Who cares for Efe infants?. *Curr. Anthropol.* **41**(5), 856–866 (2000).
11. Peacock, N. R. Time allocation, work and fertility among Efe Pygmy women of Northeast Zaire (Africa, Mbuti, Ituri). ISBN: 9798641993386. PhD thesis (1985).
12. Blaffer Hrdy, S. & Hawkes, K. Mother nature: A history of mothers, infants and natural selection. *Nature* **402**(6758), 120–120 (1999).
13. Borgerhoff Mulder, M. Optimizing offspring: The quantity-quality tradeoff in agropastoral Kipsigis. *Evol. Hum. Behav.* **21**(6), 391–410 (2000).
14. Clutton-Brock, T. H. *The Evolution of Parental Care*. Google-Books-ID: RV65DwAAQBAJ (Princeton University Press, 1991).
15. Kaplan, H., Hill, K., Hurtado, A. M. & Lancaster, J. The embodied capital theory of human evolution. *Reprod. Ecol. Hum. Evol.* **2001**, 293–317 (2001).
16. Lawson, D. W. & Mace, R. Trade-offs in modern parenting: A longitudinal study of sibling competition for parental care. *Evol. Hum. Behav.* **30**(3), 170–183 (2009).
17. Trivers, R. L. Parental investment and sexual selection. In *Sexual Selection and the Descent of Man* 136–179 (Routledge, 2017).
18. Jang, H., Janmaat, K. R. L., Kandza, V. & Boyette, A. H. 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: Biol. Sci.* **289**(1987), 20221407 (2022).
19. Gurven, M. & Kaplan, H. Determinants of time allocation across the lifespan: A theoretical model and an application to the Machiguenga and Piro of Peru. *Hum. Nat.* **17**, 1–49 (2006).
20. Lew-Levy, S., Crittenden, A. N., Boyette, A. H., Mabulla, I. A., Hewlett, B. S. & Lamb, M. E. Inter-and intra-cultural variation in learning-through-participation among Hadza and BaYaka forager children and adolescents from Tanzania and the Republic of Congo. *J. Psychol. Afr.* **29**(4), 309–318 (2019).
21. Bird, R. Cooperation and conflict: The behavioral ecology of the sexual division of labor. *Evol. Anthropol. Issues, News Rev.* **8**(2), 65–75 (1999).
22. Piperata, B. A. Forty days and forty nights: A biocultural perspective on postpartum practices in the Amazon. *Soc. Sci. Med.* **67**(7), 1094–1103 (2008).
23. Hurtado, A. M., Hawkes, K., Hill, K. & Kaplan, H. Female subsistence strategies among Ache hunter-gatherers of eastern Paraguay. *Hum. Ecol.* **13**, 1–28 (1985).
24. Binford, L. R. Willow smoke and dogs' tails: Hunter-gatherer settlement systems and archaeological site formation. *Am. Antiq.* **45**(1), 4–20 (1980).
25. Kelly, R. L. *The Lifeways of Hunter-Gatherers: The Foraging Spectrum* (Cambridge University Press, 2013).

26. Hawkes, K., O'Connell, J. F., Blurton Jones, N. G., Alvarez, H. & Charnov, E. L. Grandmothering, menopause, and the evolution of human life histories. *Proc. Natl. Acad. Sci.* **95**(3), 1336–1339 (1998).
27. Hrdy, S. B. *Mothers and Others: The Evolutionary Origins of Mutual Understanding* (Harvard University Press, 2009).
28. Page Abigail, E. et al. Children are important too: Juvenile playgroups and maternal childcare in a foraging population, the Agta. *Philos. Trans. R. Soc. B* **376**(1827), 20200026 (2021).
29. Kramer, K. L. Cooperative breeding and its significance to the demographic success of humans. *Annu. Rev. Anthropol.* **39**(1), 417–436 (2010).
30. Kramer, P. A. The costs of human locomotion: Maternal investment in child transport. *Am. J. Phys. Anthropol.* **107**(1), 71–85 (1998).
31. Wall-Scheffler, C. M., Geiger, K. & Steudel-Numbers, K. L. Infant carrying: The role of increased locomotory costs in early tool development. *Am. J. Phys. Anthropol.* **133**(2), 841–846 (2007).
32. Watson, J. C., Payne, R. C., Chamberlain, A. T., Jones, R. K. & Sellers, W. I. The energetic costs of load-carrying and the evolution of bipedalism. *J. Hum. Evol.* **54**(5), 675–683 (2008).
33. Butte, N. F. & King, J. C. Energy requirements during pregnancy and lactation. *Public Health Nutr.* **8**(7), 1010–1027 (2005).
34. Kramer, K. L. & Ellison, P. T. Pooled energy budgets: Resituating human energy-allocation trade-offs. *Evol. Anthropol. Issues, News Rev.* **19**(4), 136–147 (2010).
35. Gettler, L. T. Direct male care and hominin evolution: Why male-child interaction is more than a nice social idea. *Am. Anthropol.* **112**(1), 7–21 (2010).
36. Meehan, C. L. & Quinlan, R. & Malcom, C.D. Cooperative breeding and maternal energy expenditure among aka foragers. *Am. J. Hum. Biol.* **25**(1), 42–57 (2013).
37. Madimenos, F. C., Snodgrass, J. J., Blackwell, A. D., Liebert, M. A. & Sugiyama, L. S. Physical activity in an indigenous Ecuadorian forager-horticulturalist population as measured using accelerometry. *Am. J. Hum. Biol.* **23**(4), 488–497 (2011).
38. Kramer, K. L. Children's help and the pace of reproduction: Cooperative breeding in humans. *Evol. Anthropol. Issues, News, Rev.* **14**(6), 224–237 (2005).
39. Jang, H. et al. Women's subsistence networks scaffold cultural transmission among BaYaka foragers in the Congo Basin. *Sci. Adv.* **10**(2), eadj2543 (2024).
40. Bird, D. W., Bird, R. B., Codding, B. F. & Zeanah, D. W. Variability in the organization and size of hunter-gatherer groups: Foragers do not live in small-scale societies. *J. Hum. Evol.* **131**, 96–108 (2019).
41. Giraldeau, L.-A. The stable group and the determinants of foraging group size. *Ecol. Soc. Behav.* **1988**, 33–53 (1988).
42. Wrangham, R. W., Gittleman, J. L. & Chapman, C. A. Constraints on group size in primates and carnivores: Population density and day-range as assays of exploitation competition. *Behav. Ecol. Sociobiol.* **32**, 199–209 (1993).
43. Smith, E. A. et al. Anthropological applications of optimal foraging theory: A critical review [and comments and reply]. *Curr. Anthropol.* **24**(5), 625–651 (1983).
44. Smith, E. A. Inuit foraging groups: Some simple models incorporating conflicts of interest, relatedness, and central-place sharing. *Ethol. Sociobiol.* **6**(1), 27–47 (1985).
45. Sarma, M. S. et al. Sex differences in daily activity intensity and energy expenditure and their relationship to cortisol among BaYaka foragers from the Congo Basin. *Am. J. Phys. Anthropol.* **172**(3), 423–437 (2020).
46. Hackman, J. & Kramer, K. L. Kin networks and opportunities for reproductive cooperation and conflict among hunter-gatherers. *Philos. Trans. R. Soc. B: Biol. Sci.* **378**(1868), 20210434 (2022).
47. Chaudhary, N., Salali, G. D. & Swanepoel, A. Sensitive responsiveness and multiple caregiving networks among Mbendjele BaYaka hunter-gatherers: Potential implications for psychological development and well-being. *Dev. Psychol.* **2023**, 56 (2023).
48. Mateos, A., Zorrilla-Revilla, G. & Rodrıguez, J. At their own pace: Optimal walking speed in children and adolescents. *Am. J. Biol. Anthropol.* **178**(4), 593–604 (2022).
49. Carrier, D. R. et al. The energetic paradox of human running and hominid evolution [and comments and reply]. *Curr. Anthropol.* **25**(4), 483–495 (1984).
50. Hiilloskorpi, H. K., Pasanen, M. E., Fogelholm, M. G., Laukkanen, R. M. & Mänttäri, A. T. Use of heart rate to predict energy expenditure from low to high activity levels. *Int. J. Sports Med.* **24**(5), 332–336 (2003).
51. Benoit, L., Lew-Levy, L., Ouamba, Y. R. & Crittenden, A. N. A dataset of energetic value estimates of wild and domesticated food items consumed by Congolese BaYaka foragers. *J. Ecol. Anthropol.* **2033**, 569 (2023).
52. Bürkner, P.-C. brms: An R package for Bayesian multilevel models using stan. *J. Stat. Softw.* **80**, 1–28 (2017).
53. Nakagawa, S., Johnson, P. C. D. & Schielzeth, H. The coefficient of determination R 2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. *J. R. Soc. Interface* **14**(134), 20170213 (2017).
54. Barr, D. J. Random effects structure for testing interactions in linear mixed-effects models. *Front. Psychol.* **4**, 328 (2013).
55. Forstmeier, W. & Schielzeth, H. Cryptic multiple hypotheses testing in linear models: Overestimated effect sizes and the winner's curse. *Behav. Ecol. Sociobiol.* **65**, 47–55 (2011).
56. Schielzeth, H. Simple means to improve the interpretability of regression coefficients. *Methods Ecol. Evol.* **1**(2), 103–113 (2010).
57. McElreath, R. & Smaldino, P. E. Replication, communication, and the population dynamics of scientific discovery. *PLoS ONE* **10**, 8 (2015).

Acknowledgements

We thank the Ministère de la Recherche Scientifique et de l'Innovation Technologique, Institut de Recherche en Sciences Exactes et Naturelles (IRSEN) and Institut National de Recherche en Sciences Sociales et Humaines (INRSSH) for their permission to conduct our research. We gratefully acknowledge Prof. G. Tchimbakala at IRSEN, Prof. G. Moussavou at INRSSH and V. Kandza for logistic support for this study. We thank E. Ringen for helpful advice for the statistical analyses. We are especially grateful to the BaYaka mothers and their families for allowing us to follow them on their daily subsistence expeditions.

Author contributions

H.J. conceived the research; H.J. designed the data collection protocol in collaboration with A.H.B., S.L-L. and M.S.S.; H.J. and Y.R.O. collected the data; A.V. cleaned and prepared the data for statistical analyses under the supervision of H.J.; A.V. and H.J. conducted statistical analyses and interpreted the results; A.V. and H.J. wrote the paper; all authors reviewed and edited the paper.

Funding

The field research was funded by the Max Planck Society. A.V., A.H.B. and H.J. receive funding from Max Planck Institute for Evolutionary Anthropology. M.S.S. is supported by the National Institute on Deafness and Other Communication Disorders of the National Institute of Health under Award Number 5T32DC000023-33. H.J. ac-

knowledges IAST funding from the French National Research Agency (ANR) under grant ANR-17-EURE-0010 (Investissements d'Avenir program).

Competing interests
The authors declare no competing interests.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-024-75467-1.

Correspondence and requests for materials should be addressed to H.J.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.