Original Article

Juvenile foraging among the Hadza: Implications for human life history

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ABSTRACT

The longstanding view that children among foraging populations are largely dependent on the food collection efforts of others is an assumed and implicit characteristic of several models of human life history and family formation. The evolution of protracted juvenility in humans is often explained using the "embodied capital model" which argues that prolonged investment in growth and delayed reproduction evolved because a long training period is required to learn difficult foraging tasks and become a self-sufficient forager. The model suggests that if juvenile investment in growth and learning yields an increase in adult productivity, then selection will favor delayed maturity, long life span, and increased brain size. Here, we test the embodied capital model with naturalistic foraging and consumption data among juvenile Hadza hunter–gatherers of Tanzania to determine the extent to which children self-provision. We found that sex had a significant effect on both the type and the amount of food brought back to camp and consumed while out foraging; compared to their male counterparts, young female foragers consumed less while foraging and returned to camp with more food. A wide variation in caloric returns was seen across all foragers in the sample. When analyzing *only* food brought back to camp, age was not a significant predictor. When combining the amount of food back to camp and the amount consumed while out foraging, however, older children consistently collected more food. The data presented here suggest that although older children do appear to have greater overall foraging success, even very young children are capable of collecting a considerable amount of food. Our data, although lending support to the embodied capital model, suggest that although foraging efficiency increases with age, it remains difficult to determine if this efficiency is a byproduct of learning, strength, or perhaps individual motivation. In addition, our results indicate that juvenile self-provisioning may have played a key role in the evolution of food sharing and cooperation during hominin evolution.

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1. Introduction

In many models of human life history and the evolution of childhood, there exists an implicit acceptance of the notion that children rely heavily, if not exclusively, on provisioning by adults until they reach nutritional independence. There is an assumption that children are unable to substantially contribute to their own subsistence until fully mature (Kaplan, Hill, Lancaster, & Hurtado, 2000; Lee, 1979). Mounting empirical data collected from several populations and across subsistence regimes, however, suggest that extensive juvenile self-provisioning, even from very young ages, is widespread (Bliege-Bird & Bird, 2002; Bock, 2002; Draper & Cashdan, 1988; Hawkes, O'Connell, & Jones, 1995; Jones, Hawkes, & O'Connell,

1989; Jones & Marlowe, 2002; Kramer, 2002, 2005a,b; Robinson, Lee, & Kramer, 2008). Children among foraging populations are in a unique position of being both dependents and workers, simultaneously feeding themselves and relying on adults or older children to supplement their diet. Children are neither energy limited, because they may be provisioned from the surplus of food collected by adults, nor are they time limited, because there are few alternative ways for hunter–gatherer children to spend their time (Tucker & Young, 2005).

The extent to which young foragers collect their own food is dependent on both the type of foods available and the collection and processing constraints associated with participation in food collection tasks. In environments that are both safe (e.g. have low predator pressure and are located close to water) and contain foods that are easy to locate and procure close to camp, juveniles may spend a considerable amount of time each day collecting food (Bird & Bliege-Bird, 2005; Bliege-Bird & Bird, 2002; Crittenden, 2009; Jones et al.,

1989, Jones, Hawkes, & Draper, 1994; Kramer, 2005a, 2005b; Tucker & Young, 2005). Although young foragers may not consistently collect the entirety of their daily requirements, any investment helps to attenuate the high costs of raising offspring to nutritional independence. Investigating self-provisioning by children in foraging populations further informs our understanding of childhood and has implications for models of human life history.

One of the most striking characteristics of human life history is a protracted juvenile period of growth and development (Bogin, 1997; Leigh, 2001; Robson, van Schaik, & Hawkes, 2006). The embodied capital hypothesis argues that natural selection favors prolonged investment in growth and delayed reproduction because potential reduction in fertility (due to a late age at first birth) is superseded by the benefits of a long training period in which to learn difficult foraging tasks that may reduce adult mortality (Gurven & Kaplan, 2006; Kaplan et al., 2000). This model emphasizes the role of learning subsistence skills and argues that adult level foraging competence is limited by body size and accumulation of "brain-based capital"—skills and knowledge (Gurven & Kaplan, 2006).

Here, we test the embodied capital hypothesis using naturalistic juvenile foraging data collected among the Hadza hunter–gatherers of Tanzania. Using detailed data on food returns and self-provisioning, we determine whether age and/or sex has an effect on the type and amount of food collected. In addition, we determine the extent to which, and at what age, Hadza children are able to collect enough food to meet or closely approach their own daily energetic requirements on the days that they forage. The current study builds on previous experimental work on a subset of juvenile foraging skills done by Jones and Marlowe (2002) and provides the first comprehensive naturalistic food collection and consumption data for young Hadza foragers.

2. Methods

2.1. Study population

The Hadza are hunter–gatherers who live in a savanna–woodland habitat in Northern Tanzania. Approximately 300 individuals, of a total population of 1000, practice a strictly hunting and gathering way of life. They live in camps roughly composed of 30 individuals, although camp composition is fluid and people often move in and out. Camps move approximately every 2 to 3 months in response to the seasonal availability of water and foods, as distinct wet and dry seasons associate with differential subsistence behaviors (Marlowe, 2006; Vincent, 1985; Woodburn, 1968).

Nursing infants accompany their mothers on daily foraging trips, however when a child is approximately 2–3 years old and being weaned, he/she is typically left in camp with others. Children may be left without adult supervision but typically remain under the charge of at least one elderly camp member or older juvenile caregiver. Young children are raised in a communal setting and often play in large mixed age/sex groups. Play includes games, singing, dancing, dolls made out of mud or cloth, target practice with bows and arrows, or digging tubers (Jones, 1993). Children are weaned on ground baobab powder, animal fat and/or broth, pre-masticated meat, and honey. Once weaned, children spend a considerable amount of time foraging and tend to focus on easy to collect plant foods that are located close to camp. In addition to foraging for their own consumption, they also provision their younger siblings or other children left in their charge.

Juveniles may accompany their mothers on foraging excursions or forage unaccompanied by adults in mixed age and sex parties of their peers. Young foragers tend to focus early collection on fruit and tubers, and although members of both sexes spend considerable time digging tubers while out with large female foraging parties up until the age of 10 or 12 years (Jones, Hawkes, & O'Connell, 1997a, Jones,

Hawkes, & OConnell, 1997b; Jones & Marlowe, 2002), young male foragers tend to abandon the group foraging parties at this age and begin solo hunting trips. While juvenile males begin to hone their hunting skills, juvenile female foragers continue to hone their skills at tuber collection. Tuber collection is a difficult process and can often entail retrieving tubers that are located several feet below the ground's surface in hard-packed soil. The digging returns of young female foragers increase through their teenage years (Jones & Marlowe, 2002) and by the time they are 18 or 19 years old, they are fully proficient at locating and extracting all species of tubers.

Young male children are given small bows and arrows from a very young age, typically as soon as they can walk independently. They are able to make their own functioning bow and arrows around the age of 8 or 10 years. Up until adolescence, boys tend to limit their hunting play to the confines of camp where they practice shooting small species of mice and birds with miniature bows and arrows. As they mature, the size and precision of their bows and arrows also matures and they begin to target larger prey such as hyrax and medium- to large-sized birds.

Early anecdotal reports of foraging by Hadza children suggested high productivity (Bleek, 1931; Jelliffe, Woodburn, Bennett, & Jelliffe, 1962; Tomita, 1966; Woodburn, 1968). More recently, Jones et al. (1989, 1994) have provided estimations of return rates (collection per hour) for three types of food—baobab, tubers, and berries. Their data show that children and adolescents are active foragers and are capable of collecting up to 50% of their daily energy requirement above the age of 5 years, depending on the season and availability of certain resources. Here, we expand on this previous research to include the full complement of Hadza children's foods, detailed foraging, food return, and consumption data from two separate geographic regions in Hadza land, and nutritional composition values for all foods in the Hadza juvenile diet. The current study is the first to report both the daily productivity of juvenile foragers and detailed consumption data from out-of-camp foraging trips in order to determine the extent to which young foragers are able to provision themselves, thereby offsetting the cost of their own care.

2.2. Analytical methods

Foraging data were collected in two Hadza camps, Gangidape and Siponga (located approximately 40 km away from one another), over four non-sequential months in 2005. Data were collected in Gangidape, located in the Tli'ika region, during the late wet season from April through May and in Siponga, located in the Yaeda Valley, during the late dry season from October through November. Resource availability and general patterns of rainfall during these particular months map onto the greater resource availability throughout the wet and dry seasons of 2005 (Crittenden, 2009) and general seasonal trends in this region of Lake Eyasi over the past two decades (Marlowe, 2006). The data collected in these camps therefore represent accurate snapshots of juvenile diet composition.

Foraging returns were recorded for every day that food was brought back to camp during the study period. Of the 70 total days of residence in the combined camps, at least one juvenile forager returned to camp with food on 65 of the days. No forager in the sample collected food on a daily basis (see Table 1 for the total number of days foraged for each individual in the sample). All food brought back to camp was measured using a hanging spring scale. Focal follows were conducted during 14 out-of-camp food collection trips by young foragers ranging in age from 5 to 14 years. Time out of camp, time spent foraging, distance traveled, and amount of food collected and consumed were recorded.

Ages were determined using long-term census data collected by Nicholas Blurton Jones (from 1982–1994) and Frank Marlowe (from 1995–present). For the few very young children who did not appear in the census data, ages were estimated using comparisons of relative

Table 1
Average daily returns for individual foragers.

Forager	Age	Sex: 1 = male 2 = female	Average kcal collected per foraging day	Daily energy requirement	No. of days foraged
1	3	1	480	1324–1485	4
2	5	2	253	1379–1557	4
3	5	2	9	1379–1557	1
4	5	2	958	1379–1557	4
5	5	2	588	1379–1557	10
6	6	2	125	1451–1642	3
7	6	2	113	1451–1642	6
8	6	2	27	1451–1642	1
9	6	2	1035	1451–1642	18
10	6	1	987	1535–1742	4
11	7	2	1345	1515–1719	7
12	8	2	136	1593–1810	11
13	8	2	737	1593–1810	23
14	9	1	37	1787–2043	1
15	9	2	267	1660–1890	31
16	9	2	587	1660–1890	28
17	10	1	1363	1875–2149	10
18	10	1	632	1875–2149	23
19	10	2	560	1729–1972	31
20	10	1	415	1875–2149	36
21	10	2	1139	1729–1972	40
22	11	1	598	1985–2279	13
23	11	1	190	1985–2279	45
24	12	1	901	2113–2428	17
25	12	1	11	2113–2428	1
26	13	1	93	2276–2618	1
27	13	1	151	2276–2618	19
28	14	1	677	2459–2829	28
29	14	2	363	2036–2334	12
30	15	2	418	2057–2362	3
31	16	2	369	2059–2368	5
32	16	2	324	2059–2368	14
33	17	1	952	2796–3226	13
34	17	2	472	2042–2053	12

Values extracted from Institute of Medicine of the National Academies (2002). The recommended daily allowances are extracted from this text because estimates of energy needs are based on weight and sex.

age and the length of time between a woman's last recorded interview (Marlowe's census) and the interviews recorded for the current study (Crittenden's census).

The energy values for all plant foods including baobab, berries, honey, legumes, nuts, and tubers were determined using standard analytical methods for wild foods (Conklin-Brittain, Knott, & Wrangham, 2006; Crittenden, 2009). The energy values for birds and small game meat were determined based on published values (Clum, Fitzpatrick, & Dierenfeld, 1996; Prange, Anderson, & Rahn, 1979; USDA, 2008).

The programming language R was used for all statistical analyses. For comparisons between age and foraging return, the data were analyzed in two ways in order to capture both overall age patterns and individual variation in foraging return. First, all foraging trips were combined, age was analyzed as a continuous variable, and a Pearson product–moment correlation coefficient was computed to determine if age affected overall foraging return, distance traveled, and/or levels of consumption. Second, we calculated the mean return rate of individual foragers and used a linear regression to determine if foraging return increased with age. For analyses comparing sex differences in foraging return, distance traveled, or amount consumed, the mean values per foraging trip for males and females were compared using a Wilcoxon rank sum test. In order to determine if age and/or sex affected the type of food collected, a Pearson's chi-square test was used.

3. Results

A total of 43 individuals ($n_1 = 18$ males, $n_2 = 25$ females) ranging in age from 1 to 17 years resided in the two camps reported in this
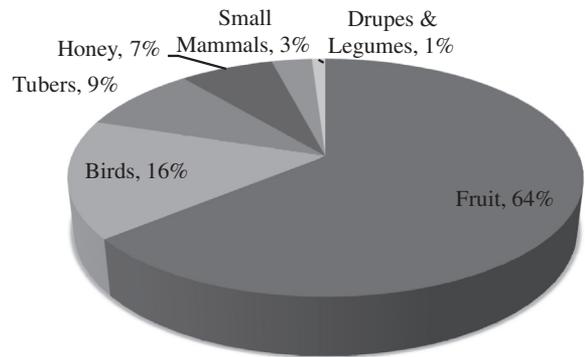

Fig. 1. Juvenile foods collected.

study. The study sample included a total of 34 juveniles ($n_1 = 14$ males, $n_2 = 20$ females) ranging in age from 3 to 17 years who foraged at least once. The duration of trips ranged from 40 min to 5 h; distance traveled ranged from 300 m to approximately 7 km. Of the total kilocalories young foragers brought back to camp in both regions, the majority (64%) comprised fruit, including baobab, figs, and berries. Fruit was followed by birds (19%), tubers (9%) and honey (7%). The lowest contributions came from small game meat (3%) and drupes and legumes (1%) (Fig. 1).

3.1. Sex effects

In order to determine if sex had an effect on foraging return, the mean values of the amounts of food returning to camp for both males and females per foraging trip were compared. Although the mean returns *per trip* were similar, 201 kcal for males ($n = 14$ individuals) and 281 kcal for females ($n = 20$ individuals), female foragers consistently brought back significantly more kilocalories to camp when analyzing all foraging trips combined (Wilcoxon rank sum $p = .003$, $n_1 = 107,323$ kcal, 214 forays for males, $n_2 = 166,556$ kcal, 266 forays for females).

Sex did not affect distance traveled (Wilcoxon rank sum test $p = .491$, $\text{mu\_hat}_1 = 2.3$ km for males, $\text{mu\_hat}_2 = 1.8$ km for females), however males consumed significantly more calories while foraging when compared to females (Wilcoxon rank sum test $p = .008$, $\text{mu\_hat}_1 = 2,267$ kcal for males, $\text{mu\_hat}_2 = 617$ kcal for females)
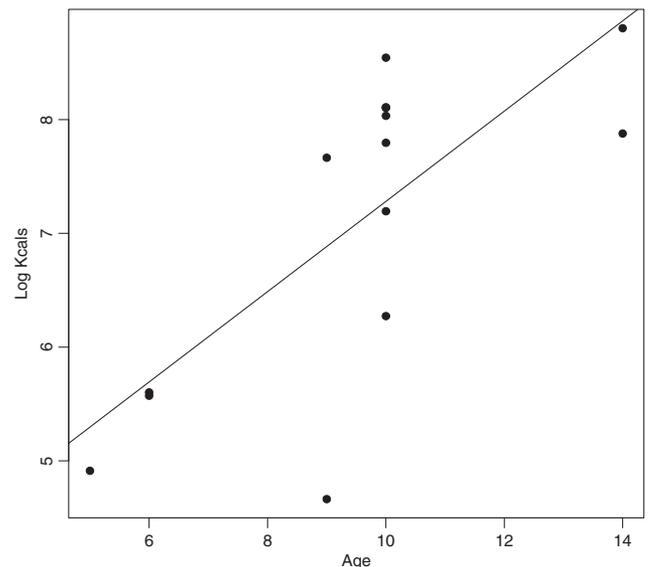

Fig. 2. Kilocalories collected during focal follow foraging trips (amount consumed plus amount collected) ($n_1 = 6$ males, $n_2 = 7$ females).
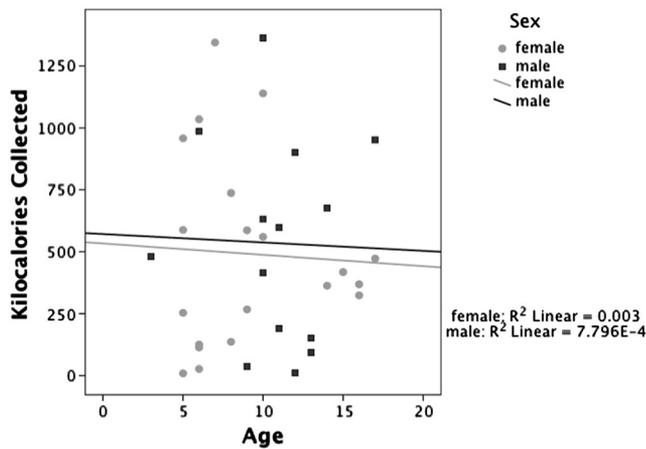
Fig. 3. Individual foraging returns across all foraging trips ($n_1 = 14$ males, $n_2 = 20$ females).

(Fig. 2). Sex also significantly affected the type of food collected (Pearson's $\chi^2 = 223.95$, $df = 8$, $p < .001$, $n = 480$ food returns). Although baobab made the largest energetic contribution to the foraging returns of both male and female foragers, the remaining categories of food collected were different. In decreasing order, the secondary foods collected by female foragers were figs, tubers, berries, birds, drupes, and legumes. Male foragers secondarily focused on birds, followed by honey, small mammals, and a small amount of tubers.

3.2. Age effects

Age was a determinant in the types of food targeted (Pearson's $\chi^2 = 146.36$, $df = 24$, $p < .001$, $n = 480$ food returns). Baobab, berries, and figs were targeted by all ages, yet younger foragers tended to focus almost exclusively on these foods while older foragers also incorporated birds, honey, tubers, drupes, and legumes. In order to determine if age was a significant predictor of how much food (kcal) was brought back to camp, the food return data were analyzed in two ways in order to capture both individual variation among foragers and variation between foraging trips. First, when combining all days of foraging returns (kcal) for each forager and analyzing age as a continuous variable, there was no correlation between increase in age and greater foraging return (Pearson's $r = -0.05$, $p = .29$, $n = 65$ days of food collection). Second, when analyzing mean individual foraging returns across all trips, age was not a significant predictor of amount of food collected ($p = .872$, $df = 33$, $R_2 = -0.030$, $n = 34$ individuals) (Fig. 3). Thus, when analyzing only the amount of food brought back to camp, age had no effect on total foraging yield.

We also analyzed the focal follow foraging data for the subset of 13 foragers ($n_1 = 6$ males, $n_2 = 7$ females) for whom we had detailed consumption data. Age had no effect on distance traveled while out of camp on a foraging excursion ($r = 0.26$, $p = 0.37$, by permutation test). When we totaled the amount of food consumed while foraging and the amount of food brought back to camp, older children collected significantly more kilocalories (Pearson's $r = 0.74$, $p = .001$, $n = 13$ focal out of camp follows) (Fig. 4). Thus, age was *not* a significant predictor of either how far a young forager traveled or how much food they brought back to camp to share, yet *was* a significant predictor in terms of the total amount of food collected.

3.3. Estimated energy production

Food returns can be used to estimate the degree to which juvenile foragers are able to provision themselves. The age- and sex-specific daily energy requirements for each forager are not known, however estimates can be obtained using published values of energy requirements (Institute of Medicine of the National Academies, 2002) based on the age and weight of each individual. Table 1 lists the average yield per foraging day for each individual forager in the sample and the estimated range of daily energy needs, which is based on a variation of ± 400 kcal at any given age and variation in work load (Garrow, 1978). If the lower range of daily energy requirements is used as the estimate, the average daily collections of seven individuals (numbered 1, 16, 18, 19, 22, 28, 33) met 25%–50% of their daily needs on the days foraged, and five individuals (numbered 4, 5, 10, 13, 24) met 51%–75% of their daily needs on the days foraged. Four of the foragers in the sample (numbered 9, 11, 17, 21) had average daily collection rates that met or closely approached the lower range of daily energy requirements.

4. Discussion

We demonstrate that children, despite a high degree of individual variation, are able to collect a sizeable percentage of their daily energetic requirements from a young age and that age and sex significantly influence the type and amount of food collected. The naturalistic data presented here are the first to detail consumption and collection data for all foods targeted by juveniles across both the wet and dry seasons. Our results confirm earlier predictions of Hadza child productivity that were based on experimental games testing age effects on foraging proficiency (Jones & Marlowe, 2002).

4.1. Sex differences and the division of labor

We found strong sex differences that may be linked with adult patterns of division of labor. Both sexes travel approximately the
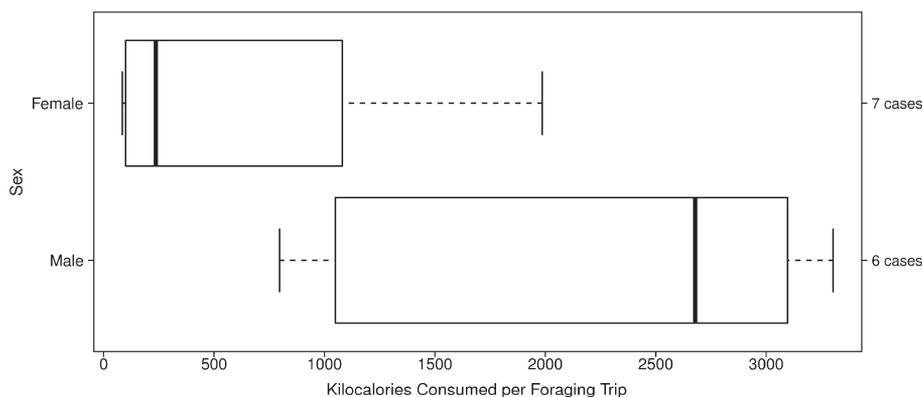

Fig. 4. Sex differences in consumption while out foraging ($n_1 = 6$ males, $n_2 = 7$ females).

same distance while out foraging, yet young female foragers consistently bring back significantly more food to camp—which is similar to Hadza adults for the majority of the year (see Marlowe, 2003 for the discussion of the conditions under which men are incentivized to bring home more food to share). We also found striking sex differences in out-of-camp consumption. Male foragers, although bringing back fewer kilocalories to camp when compared to their female counterparts, consumed significantly more food while out foraging. Sex differences in consumption may be associated with sex differences in foraging strategies and/or household responsibilities.

Armed with a bow, arrows, and sometimes a small axe, young male foragers leave camp targeting small game and honey. Honey collection and the hunting of small and medium sized game involve high energetic costs; locating, climbing, and chopping into trees to access honey require increases in energy requirements that can be met with the energy provided by the simple sugars of liquid honey. Tracking animals may also increase energy requirements. Interestingly, the timing of solo foraging trips by male juveniles occurs around the age of 10 to 12 years, corresponding with the commencement of the adolescent growth spurt. Although the Hadza only exhibit weak indications of an adolescent growth spurt, it is more apparent in males than in females (Jones, 2006). Young male Hadza foragers may be feeding the excess requirements of their own growth when eating large quantities of food outside of camp. In addition to collecting food for others, young female foragers also spend large amounts of time in camp caring for younger children and tend to be in charge of household chores like water collection (Crittenden & Marlowe, 2008). This follows the pattern among other foraging groups suggesting that there is greater economic demand on the time of female juveniles when compared to males (Ivey, Morelli, & Tronick, 2005; McIntyre & Edwards, 2009).

4.2. Embodied capital and age variance in energy production

The age of the child affected neither the distance traveled while out foraging nor the amount of food brought back to camp. When combining the amount consumed while foraging and the amount returning to camp, however, older children consistently collected greater amounts of food. These data, although lending support to the embodied capital hypothesis that predicts that an increase in age correlates with an increase in foraging proficiency, provide an interesting divergence from expected outcomes using the formal model. We suggest two important caveats to interpreting our data as direct support for the embodied capital model. First, a small number of foragers in the sample collected enough food to meet or exceed their own daily requirements on the days in which they foraged, which is counterintuitive to the embodied capital model that argues that children do not become net producers until late into their teen years (Gurven & Kaplan, 2006). Second, based on the type of data presented here, it remains difficult to determine if this efficiency is a byproduct of learning, strength, or perhaps individual motivation.

An individual's daily returns can greatly fluctuate depending on food type and individual motivation to forage. The wide variation in overall return that characterizes our data suggests that in addition to differences in yield based on age or sex, the skill of the forager and the circumstances facing each individual are also mitigating factors influencing foraging success. Such wide variation in individual collection is consistent with published values on children's foraging on the Island of Mer (Bird & Bliege-Bird, 2005; Bliege-Bird & Bird, 2002), among the Martu of Australia (Bird & Bliege-Bird, 2005), and the Mikea of Madagascar (Tucker & Young, 2005).

A handful of foragers in our sample appear to be far more productive than their age mates. On three foraging days of fig collection by one 10-year-old female (Table 1, forager 21), her daily returns regularly exceeded 10,000 kcal. Her younger sister, aged 6 (Table 1, forager 9),

also had uncharacteristically high returns and was capable of bringing back close to 7000 kcal a day when collecting figs. These sisters represent a unique case in which both parents are unable to routinely collect enough food to successfully provision their household; their father has a severe debilitating injury from falling into a fire as a young man and their mother is developmentally disabled. The two sisters were not only able to provision themselves, but also shared their foraging yield with their younger brother, parents, and occasionally grandparents. Their younger brother, aged 3 (Table 1, forager 1) is the youngest forager in the sample. The high yields of the young foragers in this family may be linked to their motivation to collect food.

Future research will explore the factors influencing Hadza juvenile motivation to forage and determine if such wide variation in individual returns is linked to ecological and/or social circumstances (e.g. seasonality, birth order, family composition, parents' ability to forage, etc.). Future work must also test optimal foraging theory among young Hadza hunter–gatherers, as no studies of economic competition among children in a naturalistic foraging context exist (Disma, Sokolowski, & Tonneau, 2011). It remains to be determined whether differences in type of food targeted are based on the child's strength and size (i.e. ability to target particular food items with more success, such as collecting low-hanging fruits or those that can be found on the ground), or whether the correlation between increase in foraging skill and age is a direct result of practice. Future work will also measure learning curves for specific subsistence skills, rather than inferring efficiency based on observed age differences, allowing us to test Bock's (2002) a hypothesis that there are sensitive periods of learning where skills are acquired more efficiently.

4.3. Embodied capital and cooperative breeding in human evolution

Juveniles are both dependents and providers. This "two-fold" nature of human juvenility is an often overlooked, yet critical, dimension of human life history and the evolution of cooperative breeding (Kramer, 2011). The majority of life history models evaluating juvenile contributions measure net economic value, yet young foragers are concurrently collecting, exchanging, and receiving resources before they become a net producer (Kramer, 2011). Hadza juvenile foragers are no exception; although not collecting the entirety of their daily caloric requirements, they are making substantial contributions by way of self-provisioning. The caloric contributions provided by juveniles underwrite the cost of their care and may contribute to a mother's ability to successfully raise multiple dependents, thus supporting the notion of humans as cooperative breeders.

Our data support the recent claim made by Schuppli, Isler, and van Schaik (2012) in their recent cross species analysis of the embodied capital hypothesis, that the provisioning of immature individuals combined with food sharing may have allowed for increased brain growth in hominin evolution and improved the survival of children as well as adults, therefore enabling the evolution of longer lifespans. We extend this argument to include self-provisioning by juvenile foragers, which may have been a key component of the derived *Homo* complex. The cooperative breeding system is flexible and incorporating views of cooperative care that underscore the importance of investment from a large constellation of helpers, including self-provisioning juveniles, allows us to successfully highlight variation in food-sharing patterns.

work and dedication; and COSTECH for research permission. We are greatly indebted to the Hadza families who welcomed us into their lives and to the children who make this type of research so enjoyable.

Appendix

In order to determine the energy values for all plant foods, the inedible portions of each food (seed, husk, stem, etc.) were subtracted from the wet weight. The energy value of the remaining portion was determined using standard analytical methods for wild foods (Conklin-Brittain et al., 2006; Crittenden, 2009). For honey, the moisture content reported in Murray et al. 2001 was used to determine energy value. The honey values are most likely an underestimation of energy because larvae were not analyzed. The Hadza collect the honey of stinging (*Apis mellifera*) and stingless bees (*Meliponinae*), consuming the larvae of both. The energy values for small game meat (e.g. birds and rodents) were calculated on an individual basis for each species using published values. In three of four cases, no data on the chemical composition of the particular animal in question exist; therefore, published composition values for related species were used in all four cases. For all remaining plant foods, data were extracted from Crittenden, 2009.

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