DOES THE OCCURRENCE AND DURATION OF HEALTH INSULTS AMONG SHIWIAR FORAGER-HORTICULTURALISTS INDICATE THAT HEALTH CARE PROVISIONING REDUCES JUVENILE MORTALITY?

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ABSTRACT

Humans lifespan is characterized by delayed maturation. Delayed maturation may arise when juvenile mortality is reduced. Recent research suggests that juvenile mortality reduction could be achieved via provisioning to weaned juveniles, particularly during health crises. Here I test this idea with data on the causes, distribution, and duration of injuries and illnesses suffered by Shiwiar forager-horticulturalists during the juvenile period. Health insults for which prolonged care is necessary for survival are a recurrent feature of the juvenile lifespan. About half the individuals for whom data on disability duration were gathered suffered health insults likely to be lethal without extended aid; over 80% were born after a parent suffered such an event; and

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over 90% were born after a direct ancestor in the two ascending generations suffered such an event. The data indicate that health-care provisioning reduces juvenile mortality, and that provisioning of sick and injured juveniles has important fitness consequences in this population.

INTRODUCTION

Evolutionary life history theory examines how natural selection produces age-related resource allocation between somatic (growth and maintenance) and reproductive (mating and parental) effort (Charnov & Schaffer, 1973; Hill & Hurtado, 1996; Kaplan et al., 2000; MacArthur & Wilson, 1967; Schaffer, 1974; Williams, 1966). Most species delay maturity and hence reproduction for a length of time during which growth and development takes place. The evolution of delayed maturity is a central question for life history theory because, all else equal, delayed maturity decreases the probability that juveniles will live to reproductive age (Charnov, 1991; Hill & Hurtado, 1996; Kaplan et al., 2000; Pagel & Harvey, 1993).

Primates in general have delayed reproduction (Pagel & Harvey, 1993; Pereira, 1993), but even controlling for body size, humans have later reproduction and longer lifespans than other primates do, including our closest living relatives the common chimpanzee *Pan troglodyte* (e.g. Hill et al., 2001; Kaplan et al., 2000). For instance, in natural fertility foraging societies human females begin reproduction at about 17–20 years of age (Hawkes et al., 1998; Hill & Hurtado, 1996; Kaplan et al., 2000), whereas chimpanzee females begin reproducing at 13–15 years (Boesch & Boesch, 2000; Nishida et al., 1990; Pusey, 1990). While 42% of precontact Aché foragers reached 50 years of age, only about 9% of wild chimpanzees live to be 50 years old (Hill et al., 2001). This difference is not just the outcome of higher chimpanzee mortality. Chimpanzees senesce more rapidly than do humans, indicating that the difference in lifespan is the result of selection acting differentially on the life history of each species (Hill et al., 2001).

Human life history also includes subsistence and other support of females and their offspring by post-reproductive and other females (e.g. Hawkes et al., 1998, 2000; Hrdy, 1999, n.d.), while males contribute resources to mates, other adults, and juveniles (Hawkes et al., 2001; Hewlett, 1992; Hill & Hurtado, 1996; Kaplan et al., 2000; Marlowe, 1999, 2001; Winterhalder, 1996). Humans also exhibit exceptional intelligence, complex social skills, and a large capacity for developmental learning (e.g. Bogin, 1999; Byrne, 1997; Flinn et al., manuscript; Geary & Flinn, 2001; Hill & Kaplan, 1999; Kaplan et al., 2000; Tooby & DeVore, 1987). Kaplan et al. (2000) and others have argued that human adult foraging competence requires a long period of skill and knowledge acquisition (e.g. Bock, 2002; Hill & Kaplan, 1999; Walker et al., 2001). Although this claim is currently debated and the degree to which juvenile foragers contribute to their own subsistence varies (e.g. Bird & Bliege Bird, 2002; Bliege Bird & Bird, 2002; Blurton Jones & Marlowe, 2002; Blurton Jones et al., 1994; Sugiyama & Chacon, n.d.; Tucker et al., n.d.), humans are nevertheless distinguished by a long period of juvenile dependence (e.g. Bliege Bird & Bird, 2002; Bogin, 1999; Hawkes et al., 2001; Hewlett, 1992; Hill & Kaplan, 1999; Kaplan et al., 2000).

Three basic inter-related factors are used to explain delayed maturity and long lifespan: demographic factors, skill and/or knowledge acquisition, and invariant patterns of growth (Pagel & Harvey, 1993). The demographic perspective emphasizes that reproductive age and lifespan are largely the function of extrinsic mortality rates. Species with high juvenile mortality tend to mature faster and be shorter-lived, because they cannot afford the high risk of dying before reproducing (e.g. Horn, 1978; Rose, 1983; Williams, 1957). Species with lower juvenile mortality can afford to mature later.

In addition, all else equal, delayed maturity can evolve if the pre-reproductive mortality risk it entails is offset by fitness-enhancing benefits acquired during the juvenile period. Longer adult lifespan allows more time for these payoffs to be realized. Thus, a second factor in explanations of long juvenile lifespan is that it is a time during which juveniles acquire “embodied capital,” not only via growth, but also via knowledge or skills – social, parental, fighting, or foraging skills – that enhance later fertility and/or reduce mortality (e.g. Harvey & Zammuto, 1983; Kaplan et al., 2000; Pereira & Altmann, 1985; Promislow & Harvey, 1990; Sutherland et al., 1986). Rates of adult mortality are therefore expected to covary with fertility and age at maturity such that investments in the juvenile period – defined here as the period between weaning and first reproduction (Pagel & Harvey, 1993) – are compensated by higher lifetime fitness. Low adult mortality allows a longer lifespan, and consequently an increased age at maturity, decreased fecundity, and higher parental investment. Conversely, high adult mortality is expected to be compensated for by increased fecundity and/or rapid maturation (Pereira, 1993; Sutherland et al., 1986).

The final factor in explanations of long lifespan and delayed maturity focuses on invariant patterns of growth. The larger an animal’s adult body size, the greater its ability to produce energy, but the later the animal will begin reproduction because of the time it takes to grow to adult size (e.g. Bonner, 1965; Charnov, 1993; Charnov & Berrigan, 1993; Lindstedt & Swain, 1988). This approach assumes a tradeoff between resources spent growing and resources spent reproducing. Within a lifespan, the longer it takes to reach reproductive age, the shorter the period in which reproduction can take place (Charnov, 1993). This brings us back to rates of extrinsic mortality, which set the length of lifespan and the probability of reaching reproductive age. Human maturational timing has been argued to be consistent with the pattern expected based on the length of the human lifespan (e.g. Alvarez, 2000; Hawkes et al., 1998), and in this view evolution of delayed maturation requires "no special explanation" (Blurton Jones & Marlowe, 2002, p. 201). It is a byproduct of long lifespan. However, across primates, there is unexplained variance in life history traits even when the effects of body size are controlled (e.g. Harvey & Clutton-Brock, 1985; Harvey & Zammuto, 1985; Lindstedt & Swain, 1988; Pereiara, 1993; Watts & Pusey, 1993). Further, explanation of long human lifespan is still needed. Several theories seek to explain important features of this uniquely human pattern (e.g. Bogin, 1999; Flinn et al., manuscript; Hawkes et al., 1998; Kaplan et al., 2000), here I focus on just one of those theories.

Kaplan et al. (2000) integrate insights from previous models, but note that theirs diverges from others in key ways. They propose that our extended juvenile dependency and lifespan are the product of the co-evolution of: (1) the dietary transition to high-quality, difficult-to-acquire foods (primarily game); (2) increased investment in the learning of complex subsistence strategies to exploit such foods; (3) increased food sharing and provisioning of conspecifics; and (4) the extension of this food provisioning to others when they are sick, which assisted recovery and reduced mortality risk. According to this model, as hominid dietary reliance on high quality, difficult-to-acquire game resources increased, fitness benefits could be realized from lengthening the pre-reproductive period and, hence, the period of foraging skill acquisition. This led to the co-evolution of an increased flow of resources from older individuals to juveniles in order to support this period of learning. This development was problematic because the fitness benefits of an extended learning period would be reduced by the increased probability of mortality during this lengthened pre-reproductive stage (e.g. Horn, 1978; Kaplan et al., 2000; Pagel & Harvey, 1993; Pereira, 1993). However, if provisioning to weaned juveniles was extended across periods of illness and injury, it could have effectively reduced mortality risk during the pre-reproductive lifespan, and extended juvenile period and delayed reproduction could co-evolve (Kaplan et al., 2000).

To date, a number of studies have presented data on food-sharing, productivity, and life-history (Bird & Bliege Bird, 2002; Bliege Bird & Bird, 2002; Blurton Jones & Marlowe, 2002; Bock, 2002; Hill & Kaplan, 1999; Hill et al., 2001; Sugiyama, 2004; Walker et al., 2001), but systematic evidence regarding the occurrence and duration of injury, illness, and disability from this perspective is limited for forager and forager-horticulturalist populations living without regular access to Western medicine. Where there are reports, potentially disabling health insults are common (e.g. Bailey, 1991; Baksh & Johnson, 1990; Gurven et al., 2000; Hill & Hurtado, 1996; Howell, 1979; Kaplan et al., 2000; Sugiyama, 2004; Sugiyama & Chacon, 2000), and sometimes result in disability that lasts for prolonged periods (e.g. Gurven et al., 2000; Sugiyama, 2004; Sugiyama & Chacon, 2000). Besides the immediate problem of surviving a health crisis once it occurs, juveniles also face fitness costs from lowered nutritional intake when adult providers suffer disabling incidents that prevent them from foraging (Sugiyama & Chacon, 2000). This is particularly likely where high quality but difficult to acquire items such as game are key components of the diet, as they are for many human foragers, and where juveniles are dependent on adult provisioning for a significant portion of their diet (e.g. Kaplan et al., 2000; Kelly, 1995; Sugiyama & Chacon, 2000; Tooby & DeVore, 1987).

In a variety of primates (including humans) and other mammals, nutritional deficits are associated with a number of fitness costs, including shorter reproductive lifespan, fewer offspring, delay of menarche and onset of puberty, lower proportion of live births, lower infant body weight, and increased juvenile mortality (see e.g. Altmann, 1991; Fritch & McArthur, 1974; Green et al., 1986; Hill & Hurtado, 1996; Kohrs et al., 1976; Manocha & Long, 1977; Prentice et al., 1987; Riley et al., 1993; Schwartz et al., 1988). Among Yora foragers of Peru, prolonged recovery from injury to an average hunter resulted in an 18% reduction in average daily per capita protein intake in the village. Injury to the highest producing hunter would result in reduction of average daily per capita protein intake by approximately 37% (Sugiyama, 1996; Sugiyama & Chacon, 2000). Thus, in foraging contexts with high levels of food transfers, disability among adults may severely impact nutrition of not only those juveniles whose primary caretaker may be temporarily disabled, but also all juveniles within the sharing network (Sugiyama & Chacon, 2000).

Although these findings show clear costs to being sick and injured, and suggest that provisioning to sick and injured individuals could reduce juvenile mortality among people in small-scale, subsistence-based societies with little access to Western medical attention, systematic data on the occurrence and duration of illness and injury during the pre-reproductive lifespan are limited. If human delayed maturity and human longevity co-evolved with juvenile mortality reduction resulting from the extension of provisioning to times of health crisis, then the following are predicted to have characterized our recent evolutionary past: (1) health risk was a recurrent force during the pre-reproductive lifespan (even though risk-taking behavior may show facultative lifetime variation); (2) juveniles experienced health insults that would have been lethal without provisioning; (3) the probability and distribution of their occurrence was sufficiently great; that (4) provisioning during health crises effectively reduced juvenile mortality rates. Of course, paleopathological evidence can be used to test these assumptions, but doing so entails problems (e.g. Steckel et al., 2002; Sugiyama, 2004; Wood et al., 1992) that ethnobiological evidence can help alleviate (Sugiyama, 2004; Walker et al., 1998).

Here I report on the types, causes, and duration of injuries and illnesses suffered during the pre-reproductive lifespan of Shiwiar forager-horticulturalists of the Ecuadorian Amazon, based on physical evidence and reported occurrence of pathologies. I address the following questions: (1) what health insults do individuals in this population suffer from during the pre-reproductive lifespan? (2) With what frequency do these episodes occur? (3) With what frequency and duration do these cases cause disability severe enough to necessitate survival assistance during the pre-reproductive portion of the lifespan? and (4) What are the demographic and fitness effects of individuals having received long-term provisioning without which they are likely to have died?

STUDY POPULATION

The Shiwiar are a Jivaroan-speaking people who live in the southern Oriente (tropical forest) of Ecuador and northeastern Peru. Approximately 2000 Shiwiar occupy a region along the Corrientes River and its tributaries in the upper Amazon. Long-term direct contact with non-indigenous populations began in the later 1970s, when Shiwiar actively solicited missionary contact to reduce mortality from raiding and warfare. Mission contact also provided greater access to Western goods than previously used trade networks. Prior to this, Shiwiar lived in scattered households linked by marriage ties and the influence of powerful individuals (Descola, 1988). Unnavigable rivers, hostility toward outsiders, and border conflict between Ecuador and Peru have limited colonial incursions. Most Shiwiar villages have now cut small dirt airstrips in the forest, around which houses form loose clusters. These airstrips provide some access to medical and other facilities outside of Shiwiar territory via missionary light aircraft, although access is neither regular nor consistent. Shiwiar subsistence is based on foraging and horticulture, and internal politics are governed by traditional big-man, consanguine- and affine-based alliances.

Shiwiar access to Western medicine and medical supplies varies considerably across communities and through time. Emergency air flights can sometimes be arranged via a two-way radio. Villages also have health promoters trained to dispense first aid and medicine as best they can given a chronic shortage in supplies.

Nevertheless, in day-to-day life, the Shiwiar lifeway mirrors many aspects of our evolutionary past relevant to adaptations related to mortality reduction via provisioning during health crises. The Shiwiar live in small kin-based communities in which some foods, particularly game, are shared; they rely on hunting and fishing for most of their dietary fat and protein, and on gathered plant products for fruits, starch, construction, and tool material. They are closely related to most of the people with whom they have daily interaction, and come into repeated contact with relatively few people. They lack access to modern contraceptives, baby formula, and have limited access to Western medicine, but a detailed system of indigenous medical knowledge.

Shiwiar also grow at least 26 horticultural products (Descola, 1988). The predominant starch in the diet is manioc; other root crops (e.g. sweet potatoes, yams), and plantains are also important. Each female head of household has between two and four gardens at different stages of production, and on most mornings women go to the garden to harvest, replant, and weed. Gardens are larger than necessary for household consumption, even when the need to buffer the risk of losses due to animal and other pests is considered (Descola, 1988). Horticultural production provides a highly productive, reliable, and spatially concentrated patch of carbohydrate resources. Large-scale clearing is done via *mingas*, village-wide parties of cooperative labor exchange involving both men and women.

Both blowguns and muzzle-loading shotguns are used in hunting, although single-shot cartridge shotguns are increasingly used when cash is available for the relatively costly shells. A wide variety of small, medium and large game are taken. Hunting returns are relatively high, and the day-to-day risk of returning from a hunting trip without game is low (Sugiyama, 2000; Sugiyama & Chacon, 2000). Fishing is done either with hooks and line or by using *barbasco* fish poison (Sugiyama, 2000; Sugiyama & Chacon, 2000; Walker et al., 1998). Finally, the industrially produced machete is used ubiquitously as an all-purpose cutting, chopping, and digging tool. Metal pots, hooks, axes, and knives are also widely used.

Shiwiar life includes a number of health risks including lacerations from a variety of objects such as tools, branches, sticks, spines, logs, and falling trees. Local and parasitic infections, as well as diseases such as chicken pox, measles, and malaria are common. Animal and insect bites and stings are a ubiquitous problem. The threat from several species of venomous snake is serious (Sugiyama, 2004). Further, although jaguar predation is no longer a major concern because of shotgun use in hunting, informants state that in the past, when shot and powder were less available, jaguars were a real threat.

METHODS

Participant observation and interviews that recorded injuries and illness during the study periods provide the ethnographic context for Shiwiar reactions to injury.

Formal and informal interviews were conducted between 1993 and 1998 in four Shiwiar villages to gather genealogical and life history data. Physical examination of 19 male and 20 female Shiwiar individuals ranging in age from three to 50 years was conducted to document scars, broken bones, or other observable signs of past pathological events. An additional male was not examined during the study because he was not present in the village at the time. However, all critical information regarding a near-lethal snakebite was available for him from previous interviews, so it was included in the analysis (Sugiyama, 2004).

The examination for evidence of injury or illness proceeded in a standardized way. Beginning with the right foot, the examination proceeded up the right leg as far as was comfortable for the informant, and then down the left leg. The left and right arm were then examined, followed by the front and then rear of the torso and neck, followed by the face and head. Scars and evidence of broken bones were noted on standardized forms depicting front and rear line drawing views of a human form, and enlarged views of the hands and feet. Each health insult recorded was coded as visible, reported (by the informant), current, or some combination of these in order to specify the evidence upon which the recording of each observation was based. For each scar or evidence of a broken bone observed, the subject was asked to provide information about the cause, activity engaged in at the time, and age at which the event occurred. Informants from one of the sample villages ($n = 17$) were also asked the duration of disability if applicable, and this information crosschecked with other informants. A standard set of questions about past illnesses, injuries, and treatment received (either from a shaman or Western medical practitioner) was then administered (Sugiyama, 2004). Disability duration gives a clearer indication of the proportion of health insults that would have been lethal without extended provisioning, and thus serves as a means by which juvenile mortality reduction via provisioning during health crises can be examined.

While the methods used provide systematic data collection on past and present illness and injury, they do entail problems. All scars on young individuals are easily observed, but older individuals have been subject to so many lacerations, abrasions, and infections that only the most prominent or most recent can be accurately recorded. Numbers of injuries recorded for older adults reported here thus primarily reflect the most recent or most serious injuries. For individuals under about 25 years of age, all health insults leaving visible evidence could be recorded. Methods used were time consuming however, and informants no doubt differed in levels of patience and quantity of details they were willing to supply. Although these problems could not be entirely solved, they were more likely to result in under-reporting than over-reporting. Independent means of crosschecking information suggest that overestimation or false reporting was highly likely to be exposed. The principle source of evidence was physical observation; reports of broken bones were verified both by tactile examination for evidence of a healed fracture and by corroboration by other informants. For information on both disability and health insults leaving no direct physical evidence, informant reports were crosschecked with others who were present at the time of the injury/illness or knowledgeable about the incident in question. Incidents causing significant disability were known by multiple informants, and the most significant were common knowledge.

On the other hand, infectious disease, pathogen load, and common illness are certainly underestimated by the methods used. Few infectious diseases leave visible traces, and intestinal parasitic infection is endemic, but is not visibly assessable. Only the most recent or severe are likely to have been recalled or recorded. I did not attempt to ask subjects about common colds or influenza, because while frequency was expected to be high, reported frequency was not expected to be accurate. Conversely, informants were asked if they had suffered from the following infectious diseases or parasitic infections known to occur in Shiwiar territory: measles, whooping cough (pertusis), tuberculosis, chicken pox (varicella), leishmaniasis, and malaria.

Finally, some health insults do not fit neatly into one category. As a guiding principle, I categorized illness or injury type according to the proximate cause of the condition with regard to its potential for causing disability. For instance, a health insult was recorded as laceration if the wound did not result in infection, but as infection if serious infection occurred, because for most lacerations observed, subsequent infection had greater potential to cause disability. That said however, severe lacerations were noted as such, and, subsequent infection was limited compared to what I expected based on previous observations (Sugiyama & Chacon, 2000). This may be because Shiwiar usually pack severe lacerations with masticated plant matter that appears to be an effective antibiotic. Similarly, insect bites that resulted in subsequent minor skin infection were recorded as infections, because such infections may become severe as other ectoparasites infect the wound. Finally, an incident was only recorded as pain when it occurred beyond simultaneous occurrence of another condition. For example, although snakebite causes extreme pain, at the time of the bite it is the venom and not the pain that poses the greatest threat of disability and death. Thus, pain of this type was recorded as snakebite. However, subsequent nerve or tissue damage can cause pain and limitations on mobility that can last long after the threat from venom is past. Accordingly, pain of this type was reported as pain, not snakebite.

RESULTS

Age/Sex Distribution of Sample

As of 1998, 410 Shiwiar living in six villages were in the core study area, with an additional 87 siblings or offspring of core area individuals living in surrounding villages. Usual resident population in the two villages from which data on health insults were collected was 63 and 103 persons, respectively. At the time of study in 1994–1995, long-term visitors were present in one village, while many residents from the other village were away visiting, such that there were 67 and 87 persons present in each village respectively. The sample of 40 individuals represents 24% of the usual resident population in these villages, and about 9.76% of the population of the core study area. The 17-person disability sample represents 16.5% of the population of the second village, and includes individuals from 10 of the 12 village households. Residents of the other households were not present when data were collected. A Kruskal-Wallis test shows no significant differences between the ages of males and females in the sample overall ($\chi^2 = 28.6$, df = 28, $p = 0.42$) or by 10-year age cohorts ($\chi^2 = 1.514$, df = 4, $p = 0.82$).

Health Insults Suffered

A total of 678 injuries and illnesses were recorded for the 40 individuals examined. The most commonly observed incidents were lacerations, followed by infections (including infectious disease), bites and stings, puncture wounds, abrasions, pain (either chronic or periodic), broken bones, and burns. Sugiyama (2004) provides detailed analysis of occurrence, definition, and distribution of pathologies by type, cause, and sex of victim across the lifespan. Data on health insults suffered during the pre-reproductive lifespan were extracted from this sample in two ways. Twenty-two sample individuals, 10 females and 12 males (aged 3–25), were pre-reproductive and all health insults they suffered were therefore included. Eighteen individuals, nine females and nine males, had begun reproduction by the time of the study. For these adults, health insults for which an age of occurrence or phase of lifetime (e.g. childhood or after first child) were reported, were examined for cases occurring prior to the individuals' age at first reproduction. Together, these yielded 456 health insults occurring prior to first reproduction. Data analysis presented below is based on these incidents. The Kruskal-Wallis test indicates no significant age difference between the sexes within this sub-sample ($\chi^2 = 15.546$, df = 14; $p = 0.34$).

Table 1. Number of Shiwiar Health Insults Prior to First Reproduction.

Health Insult Type	Observed	Residual	Percent
Laceration	152[a]	114.0	33.3
Bite/Sting	118[a,b]	80.0	25.9
Infection	99[b,c]	61.0	21.7
Puncture	30[c]	−8.0	6.6
Abrasion	22	−16.0	4.8
Scars unknown	10	−28.0	2.2
Fracture	9	−29.0	2.0
Burn	6	−32.0	1.3
Contusion	4	−34.0	0.9
Pain	4	−34.0	0.9
Blisters	1	−37.0	0.2
Irritation	1	−37.0	0.2
Total	456		100.0

Pl. provide note for a, b and c.

As expected, significant differences were observed in the relative frequencies with which different types of health insults were observed (Table 1). Lacerations were the most frequently observed health insults, and were observed significantly more often than bites and stings, the second leading cause. Although the number of bites/stings and infections (the third leading cause of health insults) observed do not significantly differ, both were significantly more common than puncture wounds. Thus, infections were observed significantly more often than all remaining types of health insults: i.e. abrasions, scars of unknown type, fractures, burns, contusions, pain, blisters, and irritated skin in descending order observed (Table 1).

Sex Differences in Health Insults Suffered

Males generally suffer disproportionately more illness and injury than females, a fact attributable both to higher male behavioral risk-taking, aggression, and susceptibility to health problems (e.g. Dabbs & Dabbs, 2000; Daly & Wilson, 1988; Kraemer, 2000). As expected, Shiwiar males suffer significantly more health insults than females in the pre-reproductive years (Table 2). Analysis by type indicates that prior to age at first reproduction males were more frequent victims of laceration, infection, bites/stings, and puncture wounds than females. Males and females did not differ in number of abrasions or scars of unknown cause. Contusions, fractures, and pain did not occur with sufficient frequency for statistical tests to be meaningfully performed. In addition, only males suffered burns.

Table 2. Sex Differences in Shiwiar Health Insults Prior to First Reproduction.

Health Insult	Male		Female		Total	χ^2	df	*p*-Value
	Observed	Expected	Observed	Expected				
Abrasion	15	11.0	7	11.0	22	2.91	1	0.088
Bite/Sting	82	59.0	36	59.0	118	17.93	1	0.000
Blisters	1		0		1	[a,b]		
Burn	6	6.0	0	0	6	[a,b]		
Contusion	3		1		4	[b]		
Fracture	5		4			[b]		
Infection	67	49.5	32	49.5	99	12.37	1	0.000
Irritation	0		1		1	[a]		
Laceration	111	76.0	41	76.0	152	32.24	1	0.000
Pain	2	2.0	2	2.0	4	[b]		
Puncture	23	15.0	7	15.0	30	8.53	1	0.003
Scars	5	5.0	5	5.0	10	0.00	1	1.00
Total	319	228.0	135	228.0	456	44.24	1	0.000

[a] This variable is constant. Chi-Square test cannot be performed.
[b] Expected cell frequency less than 5. Chi-square test not performed.

Causes of Health Insults Suffered in the Pre-reproductive Years

The specific cause of each type of health insult was recorded at the time of data collection. Table 3 shows the frequency with which the 37 specific causes of observed health insult occurred during the pre-reproductive lifespan. There are significant differences in the frequency with which different kinds of health insults occurred. The four most frequently observed were bites from vampire bats ($n = 98$), followed by machete wounds ($n = 75$), lacerations, contusions, abrasions, and broken limbs from being hit by, or running into spines, branches, or logs ($n = 70$), and insects (mostly ectoparasites [$n = 60$]). Together these account for 66.4% of all health insults observed. Although each of these causes occur significantly more often than expected by chance, they also differ significantly from one another in relative frequency with which they are observed due to the difference between the highest frequency cause – vampire bat bites – and the least frequent – insects. Falls, lance wounds, chicken pox, snake bites, malaria, axe wounds, leishmaniasis (a tropical protozoaic infection), and burns from cooking fires occur repeatedly but significantly less frequently than the first set of causes (Table 3).

Of particular interest when considering health risks in evolutionary perspective is the comparison of incidents caused by introduced technology and those that arise from non-introduced causes. Study results would be problematic if most health insults were due to the direct influence of Western technology. This does not

Table 3. Causes of Shiwiar Health Insults Prior to First Reproduction.[a]

Cause	Observed	Residual	Percent
Bat	98[a,b]	86.0	21.5
Machete	75[a]	63.0	16.4
Plant	70[a]	57.7	15.3
Insect	60[a,b,c]	48.0	13.2
Unknown	49	37.0	10.7
Fall	13[c]	1.0	2.9
Lance	11	−1.0	2.4
Varicella	11	−1.0	2.4
Snake	8	−4.0	1.8
Malaria	7	−5.0	1.5
Axe	6	−6.0	1.3
Leishmaniasis	6	−6.0	1.3
Fire	5	−7.0	1.1
Injection	4	−8.0	0.9
Hit	3	−9.0	0.7
Knife	3	–9.0	0.7
Measles	3	–9.0	0.7
Assault	2	−10.0	0.4
Fingernail	2	−10.0	0.4
Pertusis	2	−10.0	0.4
Scorpion	2	−10.0	0.4
Amoebae	1	−11.0	0.2
Ant	1	−11.0	0.2
Bee	1	−11.0	0.2
Blisters	1	−11.0	0.2
Bot fly	1	−11.0	0.2
Collision	1	−11.0	0.2
Dog	1	−11.0	0.2
Ear piercing	1	−11.0	0.2
Fight	1	−11.0	0.2
Fish spine	1	−11.0	0.2
Harpoon	1	−11.0	0.2
Howler monkey	1	−11.0	0.2
Onchersoriasis	1	−11.0	0.2
Person	1	−11.0	0.2
Pirana	1	−11.0	0.2
Shotgun	1	−11.0	0.2
Total	456		100.0

Pl. provide note for b and c.

[a] For each cause, expected = 12.

appear to be the case. Although machete cuts are highly prevalent, chi-square tests reveal that when introduced causes of injury (i.e. wounds by machete, axe, knife, injection, and shotgun) are compared to all other types of health insults, the latter occur significantly more often than the former ($\chi^2 = 128.85$, df = 1, $p = 0.000$). It is possible that the significantly higher frequency of insults caused by natural or local versus introduced agents is a reflection of limited contact with modern products because 32 of the 37 observed causes of health insult were not directly related to introduced tools. Moreover, when expected frequencies are adjusted to account for this fact (86.5% of 407 = 352.06 for natural or local and 13.5% of 407 = 54.95 for introduced, respectively), natural causes of injury and illness are still more frequently observed than ones attributable to introduced technologies ($\chi^2 = 24.40$, df = 1, $p < 0.000$).

Within health insult type, some causes are more frequently observed than others are. Vampire bats are by far the most common of the nine types of animal bites and stings observed ($\chi^2 = 621.68$, df = 8, $p < 0.000$), accounting for 98 of the total 118 bites and stings. Fifteen different causes of local, parasitic, and contagious infections were recorded, again differing significantly in how often they caused infection ($\chi^2 = 381.76$, df = 14, $p < 0.000$), with mild skin infections from insect bites that are scratched open most common. Chicken pox, leishmaniasis, and malaria were observed significantly less often. Sources of lacerations also differ significantly in how often they caused lacerations ($\chi^2 = 339.86$, df = 10, $p < 0.000$). Among these, machetes caused significantly more lacerations than the next most common, plants (i.e. running into logs, branches, sticks [$\chi^2 = 16.96$, df = 1, $p < 0.000$]), unknown causes or lance wounds ($\chi^2 = 13.56$, df = 1, $p < 0.000$). All other causes – axes, falls, knifes, being hit, lacerated by a howler monkey, and assaults – occurred only a few times each. Puncture wounds, were most often caused by plants ($\chi^2 = 29.27$, df = 6, $p < 0.000$).

Disabling Health Insults

Informants from one sample village were asked about the duration of disability associated with each reported pathological condition. This information was then crosschecked with other informants. Disability was defined as a condition that prevented the informant from leaving the house or engaging in foraging or garden work. The Kruskal-Wallis test indicates that the sex composition of this sub-sample, including eight males and nine females, does not differ significantly from the rest of the larger sample ($\chi^2 = 0.100$, df = 1, $p = 0.725$) although it does contain an older age cohort ($\chi^2 = 14.31$, df = 1, $p = 0.000$), ranging from seven to 50 years of age. This means that they have more pre-reproductive life experience than the sample as a whole. It includes more individuals having survived their entire juvenile lifespan, and thus provides a more complete picture of how likely one is to encounter disability severe enough to demand provisioning for survival. Shiwiar place high value on vigorous work and industriousness, therefore reports of disability reflect conditions that physically precluded subsistence work or the mobility necessary for subsistence work (Sugiyama, 2004). Informants usually reported disability duration estimates in even units of days, weeks, and months; these were converted to number of days for comparison.

I could determine either the age of occurrence, or whether an incident occurred before or after first reproduction, for 131 of the 215 conditions recorded in the subsample. Fifty-nine of these were cases in which disability was observed. Comparing the age at which the disability occurred with genealogical data allows calculation of the probable effects of disability on mortality and reproduction. Thirty-three of 59 (55.9%) cases of disability affected individuals prior to first reproduction (Table 4). Duration of these disabilities ranged from one day to one year, with 12 of the 33 cases (22%) causing disability of one month or longer. These 12 incidents were distributed among 10 of the 17 individuals (58.82%) for whom data were available.

Table 4. Frequency of Shiwiar Disability by Duration and Lifestage.

Disability Duration (Days)	Juvenile Period or Age During Adulthood															Total
	Juvenile	21	22	23	24	25	26	27	28	30	35	37	39	41	43	
1	4							1								5
2	1															1
3			1										1			2
4				1												1
6	1															1
7	6				1		1		1		1			1		11
10															1	1
14	2	2					1			1					1	7
15	3	1														4
17	1															1
20	1															1
21	2			1												3
30	7						1		1			1			1	11
45	2		1													3
60	1			1		1						1				4
90	1															1
180			1													1
365	1															1
Total	33	3	3	3	1	1	3	1	2	1	1	2	1	1	3	59

Table 5. Frequency of Disability by Individual, Duration, and Reproductive Success.

ID	Age	Sex	Disability Duration (Days)				RS (Descending Generations)				Descendants (% Population)	
			Total	7–13	14–29	30<	1st	2nd	Total	In Village	% Village	% Tot. Pop
8	16	f	2	1	1	0	0	0	0	0	0	0
5[a]	**18**	**f**	**8**	**2**	**3**	**2**	**0**	**0**	**0**	**0**	**0**	**0**
10[a,b]	**18**	**f**	**3**	**0**	**1**	**1**	**2**	**0**	**2**	**2**	**1.94**	**0.40**
6[a]	**25**	**f**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**
16[a,b,c]	**27**	**f**	**6**	**0**	**1**	**3**	**2**	**0**	**2**	**2**	**1.94**	**0.40**
12[a,b,c]	**29**	**f**	**14**	**1**	**1**	**4**	**8**[e]	**0**	**8**	**8**[e]	**7.78**	**1.61**
11[a,b]	**37**	**f**	**4**	**1**	**0**	**3**	**9**[d]	**5**[f]	**14**	**7**[d]	**6.80**	**2.82**
2[a,b,c]	**43**	**f**	**10**	**2**	**3**	**5**	**10**	**8**	**18**	**15**	**14.56**	**3.6**
17	7	m	2	0	2	0	0	0	0	0	0	0
15[a]	**15**	**m**	**5**	**0**	**3**	**2**	**0**	**0**	**0**	**0**	**0**	**0**
1[a,b]	**22**	**m**	**4**	**2**	**0**	**2**	**2**	**0**	**2**	**2**	**1.94**	**0.40**
7[b]	24	m	7	1	5	0	3	0	3	3	2.91	6.0
14[b]	34	m	1	0	0	0	9[e]	0	9	9[e]	8.74	1.81
3[b,c]	36	m	1	na	na	1	3	0	3	3	2.91	0.60
4[b]	37	m	3	2	1	0	5	1	6	6	5.83	1.20
9[b]	43	m	3	2	0	0	9[d]	5[f]	14	7[d]	6.80	2.82
13[a,b]	**50**	**m**	**8**	**1**	**1**	**3**	**11**	**14**	**25**	**24**	**23.30**	**5.03**
LLWPJ subtotal							44[g]	27[g]	71[g]	60[g]	58.25[g]	14.63[g]
Total			82	15	22	27	54[g]	28[g]	82[g]	73[g]	70.87[g]	16.49[g]

[a] Bold: individuals who suffered health insult likely to be lethal without provisioning during juvenile period (LLWPJ).
[b] Individuals who had started reproduction by time of the study.
[c] Individuals who suffered health insult likely to be lethal without provisioning after age of first reproduction.
[d] Represents same individuals: Offspring of a married couple both included in the sample.
[e] Eight of these nine are same individuals: offspring of a married couple both included in the sample.
[f] Represents same individuals.
[g] Totals calculated based on descendants of a couple both of whom are included in the subsample only once.

For humans, death from dehydration occurs within about three–seven days in temperate environments (Egland, 2002) and, depending on a number of variables, hunger strikers have died from starvation after an average of 55 days if no food is taken, but medical attention, water, and salt are available (Beresford, 1987). Recent examples suggest that when sick or injured, a person can survive without care for about 30 days with water and a little food before death (Krakauer, 1996). Younger juveniles succumb more rapidly (Egland, 2002; see discussion below). I assume here that sick and injured individuals could acquire water and salt, but would be unable to forage. Because food deprivation during periods of illness or injury significantly hinder recovery, I therefore assume that 30 days without food under these circumstances would likely prove lethal. Ten of the 17 people in the second village sub-sample suffered an illness or injury of this severity during their juvenile years. Of these, seven had begun reproduction by the time of the study. If provisioning was required for individuals to survive disability of 30 days or longer, then without provisioning, over half of the sub-sample would have died sometime during their pre-reproductive years.

Fifty-four offspring and 28 grandchildren were born to individuals in the second village sample (children/grandchildren born to parents/grandparents who are both in the sample were counted only once), although only two members of the sample had completed or were approaching probable completed fertility. Provisioning during health crises can have large effects on individual fitness. Of the living descendants of individuals in the second village sample, 44 out of the 54 (81.5%) first descending generation, and 27 out of 28 (96.4%) of the second descending generation were born after a direct ancestor in the sample survived a juvenile health crisis likely to be fatal without provisioning. In other words, 71 of the 82 individuals born to members of the subsample, were either the child or grandchild of an individual who would not have survived to reproduce had s/he not received extended provisioning during a juvenile health crisis. Further, three individuals (ID numbers 2, 11, and 13) who survived juvenile health crises likely to be lethal without provisioning, are either the parent or grandparent of 27 second-generation descendants. Together, these three individuals are either parent or grandparent of 11.5% of the Shiwiar population in the study area, and 45% of sub-sample village residents. One (ID number 13), is the parent or grandparent of 5% of the Shiwiar population block and 23% of the people in their village. Another (ID number 2) is the direct ancestor of 3.6% of the population and 14.5% of the people in their village (Table 5).

DISCUSSION AND CONCLUSION

To date, suggestive evidence indicated that provisioning during health-care crises could reduce juvenile mortality in forager and forager-horticulturalist societies.

No systematic data have been available on the overall degree to which individuals in such societies suffer injury/illness of sufficient duration to interfere with subsistence. Data presented in this paper address these questions more directly. As expected, health insults represent a significant hazard during the pre-reproductive lifespan in the sample population. Illness and injury are frequently encountered and widely distributed across individuals. Over half the sample individuals in the second study village suffered juvenile health crises expected to be lethal without extended care from others, indicating that provisioning effectively reduces juvenile mortality.

Further, it is clear that individual Shiwiar fitness is predicated on the existence of provisioning to temporarily disabled individuals. Of 54 offspring born to informants in the sub-sample, over 80% were born after a parent included in the sample suffered injury or illness likely to be fatal without extended provisioning. Of 28 individuals in the second descending generation of informants in the sub-sample, over 95% were born after a direct ancestor in the sample survived an incident likely to be fatal without provisioning. Additional work must be done to extend these findings, particularly through increasing sample size and constructing life history and mortality tables for the Shiwiar, so that the degree of mortality reduction via health-care provisioning can be estimated. Comparative studies among extant foraging and forager-horticulturalist societies living with little access to Western medical care are also critical.

My use of 30 days as an estimate of probable mortality without provisioning is rather crude, but I believe it is nevertheless reasonable. Outdoor survival guides report that adults can live for from three to seven days with no water, but here I conservatively assumed that even among those individuals who are temporarily disabled all but the most seriously sick or injured individuals could access water. However, chicken pox, measles, influenza, malaria, or other disease resulting in high fever, diarrhea and/or vomiting are such that dehydration, volume depletion, and poor nutrition can lead to rapid death. Food provisioning is critical in such cases, because even with access to water, volume depletion can lead to seizures, cerebral edema, or cardiovascular collapse when water but not sodium and other solutes are replaced (i.e. hyponotremic volume depletion; Egland, 2002). In the United States, about 5% of hospital admissions for children are the result of volume depletion. Worldwide, diarrheal illness is the third leading cause of death across all age groups (following respiratory and cardiac disease, and in developing countries volume depletion from diarrhea causes approximately 5 million deaths of children under the age of five each year (Egland, 2002). This means that the data presented here probably underestimate the effects of provisioning on mortality rates, and that the criteria for disability – defined here as a condition that prevented an informant from leaving the house or engaging in foraging or garden work – that would be lethal without provisioning is conservative for such illnesses. Even though people can survive starvation alone for longer periods, and death from dehydration and volume depletion can occur much more quickly, particularly among juveniles, 30 days seems a reasonable estimate of the time by which a condition causing disability severe enough to prevent foraging would be lethal without protection and provisioning. With large-bodied predators around, the time could well be shorter.

Although data supporting each component of the Kaplan et al. (2000) co-evolutionary model of human life-history evolution exist, other adaptationist explanations for elements of human life-history evolution have been proposed. These include Hawkes' and colleagues (1998, 2000) "grandmother" hypothesis, which posits that the dietary transition to high quality plant foods led to offspring provisioning, long lifespan, and with this extension the juvenile period was also drawn out (see though Kennedy, 2003; Peccei, 2001). The social intelligence hypothesis posits that the evolution of large brains and high intelligence is a consequence of an increasing intra-specific arms race for social intelligence (e.g. Alexander, 1989; Byrne & Whiten, 1997; Flinn et al., manuscript) which occurred after evolution of ecological foraging dominance (e.g. Flinn et al., manuscript). Finally, Miller's (2000) hypothesis is that increased human intelligence is largely the consequence of runaway sexual selection.

Blurton Jones and Marlowe (2002) challenge the assumption that adult foraging competence requires an extended period of learning, arguing that the reason Hadza children do not achieve adult levels of foraging competence is that they have insufficient size and/or strength to do so. Among Miriam Island foragers, children are reported to achieve adult foraging rates for some skill-intensive fishing techniques well before they achieve adult rates for techniques requiring less skill but greater size, speed or strength (Bird & Bliege Bird, 2002; Bliege Bird & Bird, 2002; Bliege Bird et al., 1995). Although each of these hypotheses appears to have valid elements, uni-dimensional theories are unlikely to explain the complex complement of human traits ultimately at issue: (1) long pre-reproductive period and lifespan; (2) high levels of social and technical intelligence; (3) cultivation of a foraging niche based on acquisition of difficult-to-acquire, high-quality foods; (4) extended investment in offspring and in the learning of complex social and foraging strategies; and (5) conspecific provisioning of injured/ill individuals and of females and their offspring. Co-evolutionary models positing multiple sequential and/or simultaneous interacting evolutionary pressures appear necessary to explain these intersecting phenomena (e.g. Alexander, 1989; Flinn et al., manuscript; Kaplan et al., 2000).

Regardless of one's position with regard to these theories, the data reported here illustrate a clear point. If illness, injury and disability risk among the Shiwiar are within the normal range of those associated with a foraging lifeway, then whichever explanation of these phenomena one wishes to advance, the evolution of mortality risk reduction via provisioning during health crises appears to be a necessary feature that must be incorporated into one's model, either as a pre-adaptation or co-evolutionary condition for the emergence of these features of the human "cognitive niche" (Tooby & DeVore, 1987). Once juvenile provisioning evolved and was provided during health crises, selection would be expected to favor strategies for garnering strategic health-care provisioning during adulthood as well (e.g. Gurven et al., 2000; Sugiyama, 1996, 2004; Sugiyama & Chacon, 2000). Without provisioning during health crises, features of the human lifeway associated with long juvenile period, long lifespan, and long period of cognitive development are unlikely to have evolved, because the fitness costs of extending the pre-reproductive lifespan in the absence of extended juvenile provisioning during health crises are overwhelmingly great.

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Uncited reference

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