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Infant and fetal mortality among a high fertility and mortality population in the Bolivian Amazon

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ABSTRACT

Indigenous populations experience higher rates of poverty, disease and mortality than non-indigenous populations. To gauge current and future risks among Tsimane Amerindians of Bolivia, I assess mortality rates and growth early in life, and changes in risks due to modernization, based on demographic interviews conducted Sept. 2002–July 2005. Tsimane have high fertility (total fertility rate = 9) and infant mortality (13%). Infections are the leading cause of infant death (55%). Infant mortality is greatest among women who are young, monolingual, space births close together, and live far from town. Infant mortality declined during the period 1990–2002, and a higher rate of reported miscarriages occurred during the 1950–1989 period. Infant deaths are more frequent among those born in the wet season. Infant stunting, underweight and wasting are common (34%, 15% and 12%, respectively) and greatest for low-weight mothers and high parity infants. Regression analysis of infant growth shows minimal regional differences in anthropometrics but greater stunting and underweight during the first two years of life. Males are more likely to be underweight, wasted, and spontaneously aborted. Whereas morbidity and stunting are prevalent in infancy, greater food availability later in life has not yet resulted in chronic diseases (e.g. hypertension, atherosclerosis and diabetes) in adulthood due to the relatively traditional Tsimane lifestyle.

Introduction

The selective environment of early life, with infant mortality ranging up to 25% in human populations, determines the representation of genes impacting viability, immune function and metabolism in a population. Survivors thus carry the stamp of early-life exposures with them throughout adulthood. The importance of infancy and the fetal period have gained renewed attention given the effects of early nutrition and morbidity on health outcomes in adulthood (e.g. Blackwell, Hayward, & Crimmins, 2001; Elo & Preston, 1992; Kuh & Ben-Shlomo, 1997; Painter et al., 2006). Indigenous populations worldwide suffer from the poorest nutrition and health, and therefore merit special attention. The persistence of poor infant and child health in indigenous populations can negatively impact cognitive development and human capital investments such as school attendance and performance, wage income and occupational status. It can also elevate risks for obesity, type 2 diabetes and cardiovascular disease if modernization leads to rapid "catch-up" growth, high energy intake and other lifestyle behavioral changes. These effects of early-life conditions on chronic disease in late adulthood are the basis of the "developmental origins of health and disease" (DOHaD) paradigm (Gluckman & Hanson, 2006; Kuzawa & Adair, 2003). Populations in the developing world with high morbidity and mortality suffer not only from high levels of infant and child sickness, malnutrition and growth stunting, but are also likely to show high rates of chronic ailments in the future when younger cohorts reach adulthood, lifestyles change and mortality levels decline (Finch & Crimmins, 2004). Children of parents under greater resource stress are also likely to show greater deficits themselves, thereby creating a legacy of poor health. The intergenerational inheritance of health risks is well established and a critical component of the DOHaD paradigm.

A first step to help gauge current and future risks of disadvantaged indigenous populations is to assess mortality and morbidity rates and their etiology early in life, and recent changes in risks due to modernization. Epidemiological transitions are experienced differently among poor sub-populations than those represented by national averages (Barrett, Kuzawa, McDade, & Armelagos, 1998; Gurven, Kaplan, & Zelada Supa, 2007). Vital registries and other demographic or medical surveys in developing countries are often incomplete or unrepresentative of indigenous populations who rate amongst the poorest in their respective home countries.

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Existing research, however, suggests that infant mortality rates (IMRs) are often 2–4 times greater among indigenous than among non-indigenous people (Gracey & King, 2009). Infant mortality is often used as a signature measure of population health, and disparities are often interpreted as evidence of societal inequality. The mosaic experience of modernization through changes in schooling, access to wage labor and experience with national culture can have both positive and negative impacts on health (Godoy, 2001). While greater market access provides opportunities to obtain vaccinations, purchase medicines and seek medical advice from health professionals and pharmacies, it can also lead to depleted wild game and fish, father absence due to migrant wage labor, alcoholism, sexually transmitted diseases and increased consumption of refined sugar and other unhealthy foods.

This paper examines infant mortality and miscarriage, and infant growth among indigenous Tsimane forager-horticulturalists inhabiting the neo-tropical forests of Bolivia. The populace of Bolivia is 50–70% indigenous (Hall & Patrinos, 2006). While most indigenous are of Aymara, Quechua or Guarani origin, Bolivia is also home to several dozen indigenous populations in the Amazonian lowlands. Bolivia is the second poorest country in South America, with anywhere from 59% to two-thirds living in poverty (per capita income $940 in 2005 – INE, 2001). Bolivia ranks 95 of 169 according to the Human Development Index (UN, 2010). In the Beni Department where the Tsimane reside, 76% of residents live below the national poverty line (Census 2001). Poverty rates are higher among indigenous than non-indigenous Bolivians and economic inequality has increased over time. Whereas non-indigenous poverty rates have declined over the past fifteen years, indigenous poverty rates have not (Hall & Patrinos, 2006).

Bolivia has not yet developed a system to record vital statistics, with under-registration of mortality as high as 63% (PAHO, 2011). National-level life expectancy at birth, e_0, is estimated to be 66.3 years and IMR to be 42.2 per 1000 live births in 2010, the worst in South and Central America (USAID, 2011). Bolivia's IMR remains one of the highest outside of sub-Saharan Africa despite having dropped by half over the past two decades, due in large part to new health programs. These health programs helped improve adult survivorship over the past two decades, but infant health, especially in remote areas, has improved little. Morbidity remains high in rural regions lacking suitable sanitation and clean water, where over 30% of Bolivia's population resides. Much of the populace continues to be affected by gastrointestinal diseases, measles, pertussis, pulmonary tuberculosis, Chagas disease, tetanus, malaria, yellow fever and other febrile illnesses (USAID, 2011). A study of mortality among the Tsimane showed that IMR from 1990 to 99 was about 130 per 1000 live births. This rate changed relatively little since 1950, despite the fact that IMR at the national level showed a consistent linear decline (Gurven et al., 2007).

Recently a growing presence of immunization campaigns, health outreach programs, NGOs and anthropologists have provided improved access to medical care for Tsimane, at the same time that market integration has been increasing. Health conditions are therefore likely to improve for younger cohorts. If younger cohorts reach adulthood under conditions of greater food and nutrient availability, they may also experience elevated risk of chronic non-communicable diseases due to environmental mismatch of improved conditions with a "thrifty phenotype" associated with restricted early-life growth and other metabolic changes under food-limited conditions (Gluckman, Hanson, & Beedle, 2007).

Organization of paper

This paper characterizes early-life condition among Tsimane. The first section documents mortality rates during the first year of life ($n = 2098$ births) in four regions that vary in proximity to town, market integration, schooling and access to healthcare. Second, I examine whether infant births ($n = 1758$) and deaths ($n = 107$) are more concentrated in the wet or dry season months. While many foods are available year-round to Tsimane, fish is more abundant in the dry season, hunted game and many fruits are more abundant in the wet season, and rice is sometimes scarce before the annual wet season harvest. Tsimane complain about contaminated water and sickness during the wet season months of December through April when flooding is common.

Third, I examine infant growth during the first two years of life ($n = 238$) to assess risk of stunting (short length-for-age) or wasting (small weight-for-length). Child height at age two may be the best predictor of future health status (Victora et al., 2008). I compare growth deficit by region and sex, and by two features of maternal condition—parity and weight. I test whether high parity infants and infants of low-weight mothers have compromised growth, as might be expected as a result of depleted maternal condition and resource stress.

The fourth section examines the profile of preterm fetal deaths ($n = 121$) (hereafter miscarriages). To my knowledge, miscarriage has never been investigated in an indigenous subsistence population. Whether an infectious environment and high fertility render Tsimane mothers more susceptible to miscarriages is an open question. Intrauterine bacterial infections can trigger cytokine cascades that lead to fetal damage, preterm delivery, and fetal death in extreme cases (Athayde et al., 2000; Romero et al., 1998). The frequency of miscarriage can provide indirect clues about whether infections or perinatal problems such as umbilical cord complications and uteroplacental insufficiency are sources of morbidity (Silver, 2007).

The fifth section explores risks experienced early in life by examining causes of infant mortality and miscarriage. Future initiatives designed to improve infant and maternal health, and to forecast adult health given early exposures, require such an analysis. Whether deaths are largely due to infectious disease, perinatal complications or trauma has different implications for prevention and for understanding risk of morbidity and mortality over the rest of the life course.

The final section links maternal condition with infant mortality and miscarriage. I test for effects of maternal age at pregnancy, maternal body size, parity, history of past infant deaths, and spacing between births on the probability of infant and fetal death. I predict that teenage and late-age mothers experience elevated risks. Offspring born to young mothers that are still growing are more likely to be low birthweight and are at higher risk of dying (Fraser, Brockert, & Ward, 1995). Similarly, older women have been shown to be more likely to deliver premature offspring that are at greater risk of dying (Wood, 1994). Younger and especially older mothers experience increased risk of miscarriage in developed nations (Andersen, Wohlfahrt, Christens, Olsen, & Melbye, 2000). I also expect shorter interbirth intervals (IBIs) to correlate with higher risk of infant death. The Tsimane have short IBIs (2–3 years), which coupled with their high fertility, may lead to maternal depletion that compromises high parity infant health (Tracer, 1991). I indirectly examine depletion effects by testing whether current maternal body size relates to rate of infant mortality and miscarriage. Lastly, I test whether women with more schooling and greater Spanish fluency are less likely to experience infant and fetal death. When greater human capital leads to lower infant mortality, women often respond by reducing their fertility, thereby leading to demographic transition.

Methods

Tsimane and infancy

The Tsimane inhabit small villages of extended family clusters in the Maniqui, Apere and Quiquibey River systems in the Ballivián and Yacuma provinces of Bolivia. Over 11,000 Tsimane inhabit ~90 villages in the forest and savanna regions east of the foothills of the Andes. Most of their diet still comes from subsistence activities. Tsimane cultivate plantains, rice, corn, and sweet manioc in small garden plots and regularly fish, hunt and gather fruits.

Although the Tsimane were exposed to Jesuit missionaries before the 17th century, they were never successfully settled in missions and remain relatively unacculturated (Chicchón, 1992). Rice and various citrus fruits were likely introduced by the Jesuits at this time. Other neighboring lowland groups such as the Mojeño and Yuracaré engaged in intensive agriculture and were more easily concentrated in centralized missions. Tsimane language is an isolate, sharing a similar vocabulary and grammar only with Mosetene, whose speakers inhabit the outskirts of Tsimane territory.

New mission posts in several villages were established in the 1950s, around the same time that roads connecting the region with the highlands were built. The greatest influence of the 35-year-old New Tribes Mission was to create a system of bilingual Spanish-Tsimane schools with trained Tsimane teachers. In 1989 a central representative organization, the *Gran Consejo Tsimane*, was founded with assistance from the New Tribes Mission. In 1990, the Mission also organized a small health clinic on the outskirts of San Borja, providing sporadic access to medicines in exchange for labor. Immunization campaigns are confined mostly to the past decade, and include *pentavalente* (diphtheria, tetanus, pertussis, hepatitis B, influenza B), yellow fever, measles, mumps and rubella. Coverage in Tsimane communities is sporadic, limited primarily to villages close to San Borja, during months of the year when travel is possible. Since 2002 the health insurance program *Seguro Universal Materno Infantil* (SUMI) has covered most expenses for prenatal and post-natal care (up to six months for mothers and 5 years for children). While Tsimane have benefited from SUMI, these benefits have been limited by poor management of funds, and because many Tsimane lack the photo identification card required to obtain coverage.

During pregnancy there are few taboos concerning diet and activity. Sexual intercourse with the mother is taboo (*micdyì*) during the last two trimesters up until about three months after the birth. Violation of the taboo is believed to make the infant sick and the father lazy. Tsimane women usually spend the first week of the infant's life maintaining direct contact, with both remaining exclusively inside a mosquito net in the house. It is considered taboo for a mother to leave the mosquito net during this time. Newborns are often painted with *bi* (*Genipa americanus*), a black dye common in tropical South America. It is believed that the blackness renders the baby invisible from malevolent spirits that might otherwise cause harm. It is common for infants to not receive proper names until about a year after birth. Children are breastfed exclusively for about four months; supplementary foods include plantains, fish, and meat. By about 16 months infants spend more time consuming solid foods than breastfeeding. The average IBI is 2.5 years and total fertility rate (TFR) is 9 live births (McAllister, Gurven, Kaplan, & Stieglitz, in press).

The Tsimane territory for this paper is divided into four regions: riverine (8 villages), forest (7 villages), near town (2 villages) and mission (1 village). Riverine and forest villages are the most remote, located about 40 km from San Borja. In the dry season, it may take several days to reach the riverine villages located upstream on the Maniqui River from town. About 30 years ago, a logging company created a dirt road that then motivated forest communities to migrate closer to the road. In the wet season forest villages are largely unreachable along the logging road because the temporary bridges crossing the streams and small rivers are destroyed each year by the rains. The villages in close proximity to the market town of San Borja are referred to as "near town". The Mission village is located upstream at the confluence of the Maniqui and Chimanes Rivers. Despite its remote location, the presence of the Catholic Mission and the relatively reliable primary healthcare it provides merits its separation from the eight smaller riverine communities. Tsimane in all regions practice horticulture, fish, hunt and gather; although lifestyles are not dramatically different across Tsimane regions, villages near town have greater access to market foods, wage labor, cash cropping, schooling, immunizations and healthcare.

Demographic interviews: infant mortality and miscarriage

Infant mortality was derived from retrospective reproductive histories with all resident women over the age of 14 ($n = 363$ individuals from 18 villages) conducted from Sept. 2002 through July 2005. Details on age estimation are given elsewhere (Gurven et al., 2007). The outcome of each reported pregnancy was recorded as either ending in a live birth or terminating preterm (miscarriage). Tsimane identify an early birth (*jojoì nài*) where the infant is born dead as miscarriage (*jìshubudyè*), and so stillborns are likely counted as miscarriages. Age at death for miscarriages, when known, is reported by mothers as the number of moons that passed since they first recognized they were pregnant. The sex of the aborted fetus was also reported by the mother in 82/121 of cases. In consultation with a Tsimane Health and Life History Project (THLHP) physician (Dr. Daniel Eid Rodriguez), causes of death based on verbal autopsy interviews were assigned using the International Classification of Disease version 10 (ICD-10) (WHO, 1990). Verbal autopsy interviews used a combination of open-ended questions and directed questions oriented toward arriving at a clinical diagnosis. No cause could be determined for 16% of the 268 infant deaths in the sample, due more to a lack of information by informants than inexplicable symptoms. Our estimates of the percentages of deaths due to specific causes, and of cause-specific death rates, are underestimates of their true values because deaths with unknown causes are included in the denominator but never in the numerator. Cause-specific death rates were calculated by dividing the number of deaths due to specific causes by the appropriate number of risk years. A sample of 1763 individuals with known birthdates is used to investigate seasonal mortality patterns.

Infant growth and maternal body size

Height, length, and weight were measured on all individuals during annual village visits by the THLHP medical-anthropological team. Infant length is measured with the use of a Seca 210 Length Measuring Mat. Standing height for adults is measured using a Seca Road Rod 214 Portable Stadiometer. Weight and percentage body fat for adults are measured using either a Tanita BF680 Scale and Body Fat Monitor or estimated using the age- and sex-specific Durnin and Womersley (1974) equations that use subcutaneous fat skinfold measurements on the bicep, tricep, subscapular and suprailiac regions.

For a sample of 238 infants with exact birthdates, growth is examined in the first two years of life by region. Growth measurements for infants include z-scores of length-for-age (HAZ), weight-for-age (WAZ), weight-for-length (WHZ) and body mass index-for-age (BAZ) using the World Health Organization Multi-centre Growth Reference Study anthropometric standards for breastfed children (WHO, 2010). HAZ is usually interpreted as a measure of chronic stunting, WAZ as a measure of underweight, and WHZ and BAZ as measures of acute wasting (Frisancho, 1990).

Data analysis

Infant mortality curves over the first year of life are analyzed using Kaplan–Meier estimation with PROC LIFETEST in SAS 9.2.

Anthropometrics by region, age and sex are compared using chi-square tests and multiple linear regression (PROC GLM). Probabilities of infant death and miscarriage were modeled using generalized estimation equations (GEE) with PROC GENMOD. These mixed models use a logistic link function and account for the repeated pregnancies, births, or risk years from the same women.

Research was conducted with the approval of the Institutional Review Board of the University of California-Santa Barbara, and with approval from the Tsimane government (*Gran Consejo Tsimane*). Additional approval was granted during village meetings with leaders and residents, and by direct conversations with participants.

Results

Infant mortality

Fig. 1 shows survivorship (l_x, probability of surviving to age x) during the first year of life. 12.9% of Tsimane infants die in their first year. The riskiest period is the first two weeks, where 4% of infants die. 40% of infants that die in their first year do so in the first month of life. The neonatal mortality rate is thus 51.1/1000 live births. Mortality differs significantly by region (Wilcoxon test: chi-square = 18.94, p = 0.0003). It is highest in the riverine (IMR = 15.4%) and forest villages (15.3%), and lowest in the villages near town (8.1%). Greater distance from town positively correlates with IMR, varying three-fold from 8% to 26% (Fig. 2). Distance from town alone explains 25% of the inter-village variation in IMR. Forest villages show higher IMR than riverine villages, even after controlling for town distance ($\beta = 50.0$, $p = 0.021$, $R^2 = 0.484$).

Effect of seasonality on births and infant mortality

Fig. 3 shows the relative likelihood of births and deaths by month, and whether birth month affects the likelihood of infant death. December through April are wet season months, while May through August comprise the dry season. While heavy rains during the wet season can lead to flooding, poor water quality and crop loss, periodic spells of cold, southerly winds from the Argentine pampas (called *surazos*) are common during dry season months.

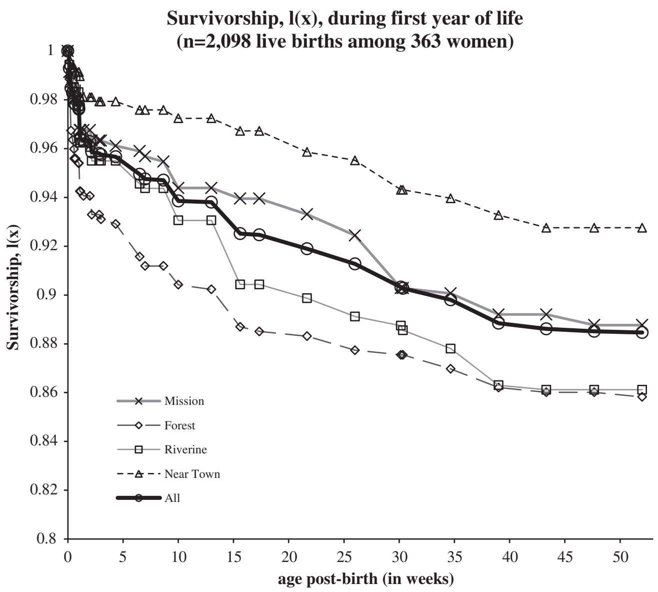

Fig. 1. Survivorship over the first year of life by geographical region. Sample includes 2098 live births among 363 women from time period 1950–2002.

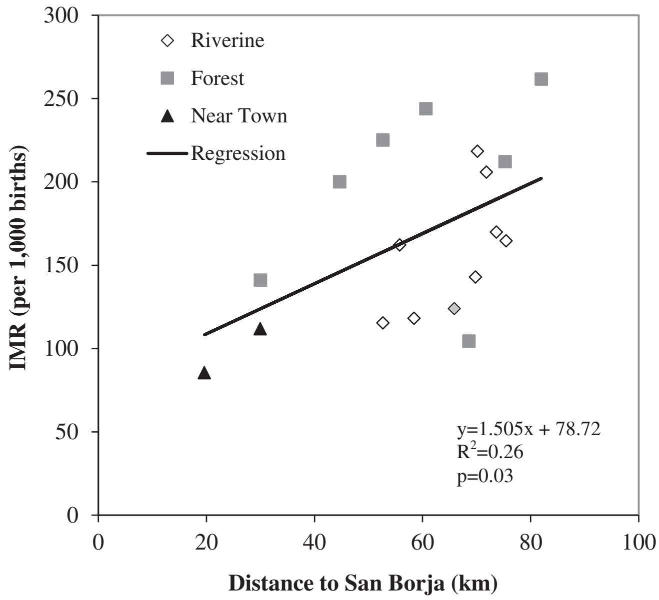

Fig. 2. Infant mortality rate (IMR) by proximity of villages to the town of San Borja.

There is no consistent pattern of birth timing throughout the year when considering the sample of pregnancies where birth month is known (n = 1758). Infant deaths, however, are more common during wet season months of February and March, and dry season months of May and August. Odds of infant death are 1.3–1.7 times greater during these months. Odds of infant death are lowest in the dry season month of July, the wet season month of January, and the transitional months, September and October. During these low risk months, infant deaths are 36–71% lower than expected by chance. Infant death rates, however, are correlated with monthly birth rates ($r = 0.67$, $p < 0.05$); after controlling for birth rates, the residual death rates only trend toward significantly mirroring the patterns in Fig. 3 ($p = 0.073$, binomial test).

I next examined whether infants were more likely to die in the first year of life if born in certain months (solid line in Fig. 3). IMR was 1.38 times greater than average for infants born during peak wet season months (February and March), compared with 0.91 for the rest of the year (chi-square = 4.49, $p = 0.034$). IMR was slightly elevated for births in August and November. In contrast, birth in the early dry season months was associated with significantly lower likelihood of death (35–64% lower than average). When controlling for monthly birth rates, the relationship between likelihood of death and month born remains significant ($p < 0.001$, binomial test).

Infant growth

Table S1 (Electronic supplementary material) reports the prevalence of stunting, underweight and wasting. 32% of infants show moderate to severe stunting, 15% show a similar level of underweight, and 13% show wasting. These levels correspond to a high severity of stunting and wasting according to World Health Organization criteria (Blossner & de Onis, 2005). There is a higher prevalence of (1) stunting among older infants, (2) underweight among males, older infants and infants farther from town, and (3) wasting in the riverine villages (Table S1). Regression of anthropometric z-scores on region, sex and age confirms these results, although regional differences in wasting are no longer significant after controlling for sex and age (Table 1). Regression models in Table 1 explain at most only 9% of the variation in infant anthropometrics.

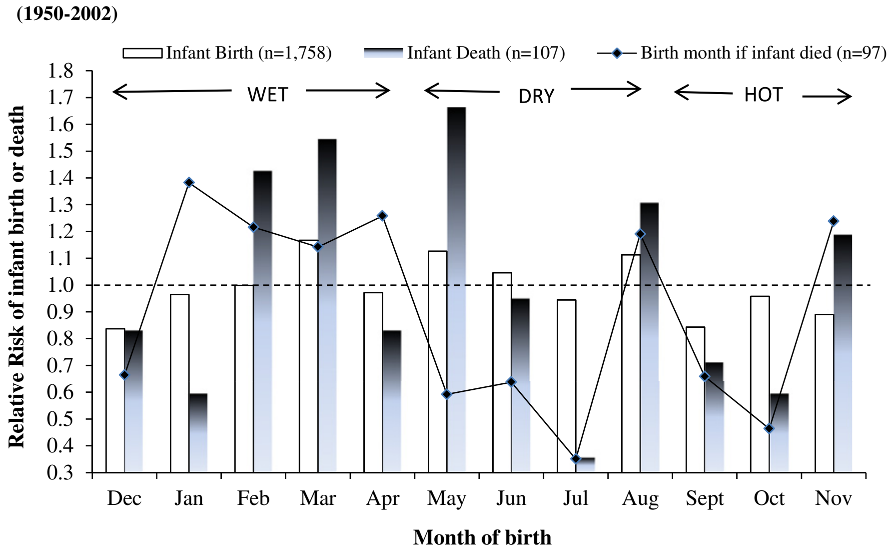

Fig. 3. Seasonality in infant births and deaths, relative risk of (a) birth by birth month, (b) death by month, (c) death in first year of life by birth month.

Infant stunting and underweight varies by maternal weight, maternal age and birth order. Maternal age and birth order are highly correlated ($r = 0.85$, $p < 0.0001$), and so I report analysis based on birth order, as it is a more robust predictor than maternal age. Mean ± SD birth order is 4.8 ± 3.1, mean ± SD maternal age is 28.3 ± 7.2, and mean ± SD maternal weight is 52.7 ± 7.0 kg. Fig. 4 shows predicted *z*-scores of HAZ and WAZ for the ±1 SD unit range in maternal weight (45–60 kg) and ±1 SD unit range in birth order (2–8), controlling for infant age and sex. High parity infants of underweight mothers show the lowest *z*-scores for HAZ and WAZ, while low parity infants of overweight mothers show the highest. Parity and maternal weight effects are greater for HAZ ($\beta_{parity} = -0.185$, $\beta_{maternal\ weight} = 0.077$) than for WAZ ($\beta_{parity} = -0.076$, $\beta_{maternal\ weight} = 0.049$). Neither maternal weight, maternal age, nor birth order are significant in multiple regressions of wasting (WHZ and BAZ) after controlling for infant age and sex.

Frequency of miscarriage

The rate of fetal death is 55.1/1000 pregnancies (based on a sample of 121 miscarriages from 2195 pregnancies by 363 women). 59% of Miscarriages were reported as having occurred within the first several months after last menses (first trimester), 22% during second trimester and 19% during third trimester. There was no difference in overall miscarriage rate before 1990 (54.2/1000) and from 1990 to 2002 (66.8/1000) (chi-square = 1.13, $p = 0.288$) although this result changes in the multiple regression analysis reported in Table 3. Miscarriage rates varied by region (Forest: 90.1/1,000, Near Town: 44.9/1,000, River: 45.2/1,000, Mission: 37.9/1000; chi-square = 17.2, $p < 0.001$). They also varied by maternal age, such that youngest and oldest mothers were at increased risk of miscarriage (Fig. 5, chi-square = 14.49, $p = 0.013$). Odds of miscarriage for women aged 15–20 are 2.7 times greater than women aged 25–30; odds of miscarriage for women age 40+ are 5.4 times greater using the same reference group.

Causes of infant and fetal death

Causes of infant mortality are clustered into macro-categories like gastrointestinal (e.g. diarrhea, gut obstruction), respiratory infection (e.g. pneumonia, influenza), other infection (e.g. measles, whooping cough, fever), violence/accidents (e.g. falls, drowning, infanticide, neglect), and congenital (perinatal complications).

Table 1
Multiple regression of nutritional status variables (HAZ, WAZ, WHZ, BAZ) on infant sex, age and region of residence. Parameters in bold refer to $p < 0.05$, italics $p < 0.10$.

Parameter	HAZ		WAZ		WHZ		BAZ	
	β	*p*-Value	β	*p*-Value	β	*p*-Value	β	*p*-Value
Intercept	−0.761	0.014	−0.651	0.003	−0.120	0.652	−0.299	0.260
Sex (female)	0.185	0.443	**0.402**	0.020	**0.446**	0.033	**0.424**	0.043
Region								
Near town (vs. river)	0.488	0.118	**0.580**	0.010	0.360	0.183	0.424	0.116
Forest (vs. river)	0.242	0.550	0.345	0.234	0.255	0.466	0.306	0.380
Mission (vs. river)	0.224	0.479	0.088	0.696	−0.133	0.628	−0.117	0.667
Age group								
18–24 mos (vs. <6 mos)	**−1.200**	0.004	**−0.577**	0.050	−0.225	0.531	0.266	0.459
12–18 mos (vs. <6 mos)	**−0.844**	0.011	**−0.476**	0.043	−0.265	0.353	0.092	0.745
6–12 mos (vs. <6 mos)	−0.473	0.114	*−0.393*	0.065	−0.248	0.339	−0.146	0.572
R^2	0.062		0.086		0.043		0.043	
F	2.11		3.04		1.41		1.44	
p-Value	0.043		0.005		0.203		0.190	

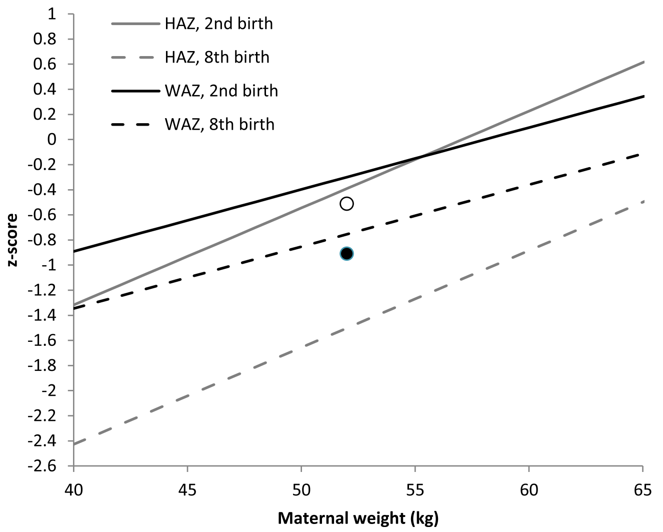

Fig. 4. Regressions of height-for-age (HAZ) and weight-for-age (WAZ) *z*-scores as a function of infant birth order and maternal weight, controlling for infant age and sex ($n = 84$). For HAZ regression, $\beta_{\text{maternal weight}} = 0.077$, $p = 0.020$, $\beta_{\text{birth order}} = -0.185$, $p = 0.012$; WAZ: $\beta_{\text{maternal weight}} = 0.049$, $p = 0.019$, $\beta_{\text{birth order}} = -0.076$, $p = 0.098$. Lines are plotted at sample averages for infant age and sex. Solid (open) circle refers to sample mean HAZ (WAZ). Stunting (underweight) reflects HAZ (WAZ) *z*-score < -2.

Distribution of causes by infant age is shown in Fig. 6. Overall, 55% of infant deaths are due to infection (29% respiratory, 15% gastrointestinal, 11% other). 13.6% of deaths are due to violence and accidents. Infanticide alone accounts for 8.7% of infant deaths. Including deaths from the larger demographic sample based on kin reproductive histories yields 26 infanticides: 10 as a consequence of infidelity, 5 "unwanted" infants, 2 born with deformities and 2 born "too soon" after the previous infant.

Deaths by violence, accidents and infection are less common in the 1990–2002 time period than in 1950–1989 (Table S2, Electronic supplementary material). Villages near town also show the lowest IMR from congenital problems, respiratory infection and violence/accidents. Mission IMR is similar to forest and riverine, except the Mission shows lower risk of death by gastrointestinal infection and by violence and accidents.

Emic views for why infants die often depart from clinical diagnoses. For a sample of 48 infant deaths where emic views were expressed, it was reported that infants died because of husbands having sex with other women ($n = 19$), and because of sorcery from angered spirits (*jäjäba* or *òpito*) due to norm violations ($n = 20$). Accusations regarding a husband's philandering are also common when infants get sick, as threats of men disinvesting from the family are viewed as harmful. Infant sickness is often linked to

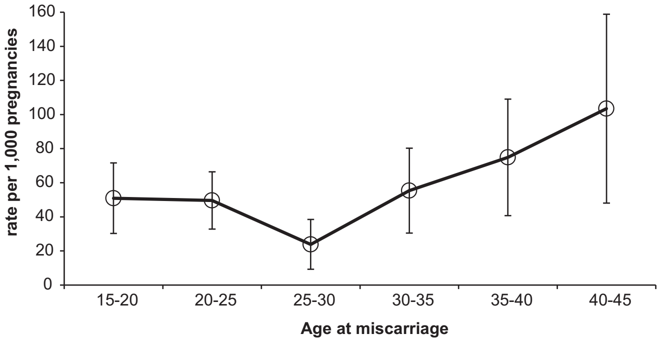

Fig. 5. Fetal death rate by trimester of pregnancy and maternal age.

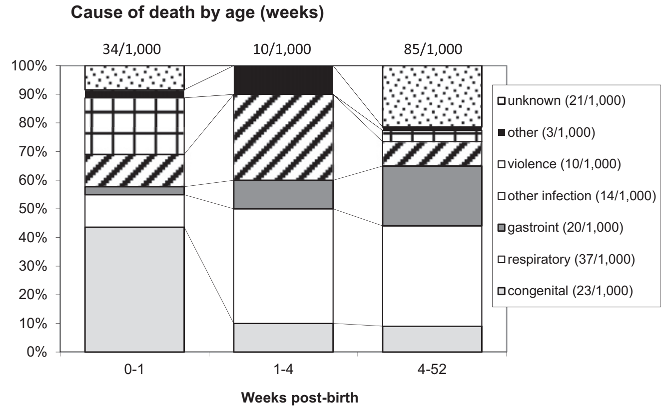

Fig. 6. Causes of infant death in first year of life.

norm violations, such as violating food, menstrual, or hunting taboos, as well as angering other people believed to be sorcerers.

Our "verbal autopsy" approach is to be interpreted with caution, especially for fetal deaths. Even with modern medical facilities, it has been estimated that as many as 12–50% of stillbirths and miscarriages have no identifiable etiology (Incerpi et al., 1998). Placental abruption and other clinical diagnoses were not possible here. Causes of miscarriage as reported by women fall into several categories: 39% of miscarriages ($n = 100$) occurred as a result of falling, often on one's stomach, usually in the context of hauling water, firewood, clothes or food, 18% from "working too hard" (includes heat exhaustion), 13% were self-induced (reportedly by beating and pressing one's stomach with force), and 10% from maternal sickness.

Predicting infant and fetal death

Tables 2 and 3 model the probability of infant death up to age two, and the probability of miscarriage, respectively. Predictors in the base model include infant age and sex, region, and maternal age. Consistent with Fig. 2, I find that infant mortality is about 50–100% higher in forest and riverine regions than near town. Consistent with Table S2, infant deaths are 25–50% more likely in the recent past (1950–1989) than during the 1990–2002 period.

Additional predictors added to the base model include maternal anthropometric variables measured concurrently with the demographic interview (controlling for the time difference between risk year and anthropometric measurement), maternal socioeconomic variables (maternal education and Spanish fluency) and demographic variables (birth order, and IBIs from the previous birth to the current, and from the current to the next).

Women who were heavier (greater WAZ) were about 40% more likely to have experienced an infant death. An obese woman ($\text{BMI} \geq 30$) was almost 3 times as likely to have experienced an infant death in the past compared to a woman in the normal BMI range (<25). Larger women may have had greater completed fertility and experienced greater infant mortality as a consequence, but even after controlling for fertility, the effect of women's current obesity is significant (reducing OR to 2.52, $p = 0.05$). Women who do not speak any Spanish are about 50% more likely to have had an infant die than those who are fluent, whereas maternal education shows no significant effect.

Short IBIs are highly predictive of infant death. Waiting an additional year after the birth of the previous child is associated with a 25% lower chance of the next infant dying, whereas an additional year before the next infant's birth is associated with a 32% lower chance of the previous infant dying. Birth order shows no effect on infant death when added to the baseline model.

Table 2
Probability of infant death in first two years of life, using generalized estimating equations (GEE) with a logistic link function (243 deaths across 3498 person-years for 419 women). Parameters in bold refer to $p < 0.05$, italics $p < 0.10$.

Variable	Model 1: baseline		Model 2: maternal anthropometrics		Model 3: maternal human capital		Model 4: demography	
	Odds ratio	*p*-Value	Odds ratio	*p*-Value	Odds ratio	*p*-Value	Odds ratio	*p*-Value
Age of infant (yr)	**0.162**	<0.0001	**0.157**	<0.0001	**0.150**	<0.0001	**0.134**	<0.0001
Sex (ref = male)	1.062	0.656	1.052	0.727	1.082	0.597	1.234	0.244
Region								
Mission (vs. near town)	1.316	0.220	1.402	0.196	1.351	0.202	*1.588*	0.060
Forest (vs. near town)	*1.531*	0.093	*1.636*	0.091	1.413	0.132	**1.718**	0.023
River (vs. near town)	**1.781**	0.014	**1.935**	0.014	**1.849**	0.004	1.322	0.260
Period 1950–1989 (vs. 1990–2002)	**1.385**	0.048	**1.520**	0.023	*1.291*	0.112	1.256	0.270
Maternal age								
35+ (vs. 20–34)	0.983	0.946	1.051	0.855	0.765	0.247	0.987	0.975
<20 (vs. 20–34)	*1.340*	0.094	1.291	0.182	1.255	0.219	0.796	0.481
Mother height-for-age *z*-score			0.914	0.286				
Mother weight-for-age *z*-score			**1.418**	0.010				
Mother body mass index								
Obese (vs. normal)			**2.650**	0.034				
Overweight (vs. normal)			1.116	0.665				
Mother body fat (%)			1.005	0.714				
Mother Spanish								
None (vs. fluent)					*1.553*	0.099		
Moderate (vs. fluent)					1.354	0.293		
Mother education								
None vs. (3rd grade+)					1.345	0.291		
1st–2nd Grade (vs. 3rd grade+)					1.401	0.254		
Birth order							0.984	0.729
Interbirth interval (pre-birth)							**0.748**	0.002
Interbirth interval (post-birth)							**0.675**	0.002

I performed a similar analysis for the probability that a woman has a miscarriage (Table 3). Male fetuses were about twice as likely as female fetuses to be aborted. Miscarriages were about twice as likely to be reported in the more recent period 1990–2002. Mothers under age 20 were about 50% more likely to have a miscarriage than prime reproductive age women (20–34 yrs) in two of the four models where statistical significance was only marginal (see also Fig. 5). The only other maternal variable that predicted miscarriages was mother's education. Women with no education were over 5 times as likely to miscarry (or report a miscarriage) as women with at least a third grade education level. One to two years of education was marginally associated with a three-fold greater likelihood of miscarriage than at least a third grade education.

Discussion

Infant mortality among Tsimane Amerindians is high, and is greatest in remote regions lacking access to modern healthcare facilities. Infections account for over half of all infant deaths. While pathogen exposure may vary by geographical proximity to town, it is likely that infant deaths are instead more preventable close to town due to greater medical access, prenatal care and vaccinations. Medical attention during critical periods, such as during the wet season and peak *surazo* dry season, could help reduce IMR.

Infant stunting is prevalent, affecting a third of infants, but underweight and wasting are less frequent. Stunting is greatest among older infants close to weaning age (18–24 months) and far from town, while underweight affects boys more than girls. The high fertility of Tsimane women is a key factor, as later born infants are at greatest risk of being small for their age. Small mothers are also more likely to have small infants. Whether small infants show evidence of catch-up growth or are more likely to die has not yet been determined among Tsimane. Nonetheless, small infants are likely to be at higher risk of morbidity and death.

Despite frequent stunting (overall 34% prevalence), however, there was less evidence of wasting (12%). In a compilation of 37 studies in Latin America, Victora (1992) found the median prevalence of child stunting to also be 34% but was only 3% for wasting. A higher stunting prevalence (47%) but similar wasting prevalence (5%) was found among Tsimane children under age 9 (Foster et al., 2005). Based on low prevalence of wasting and of low muscularity, Foster et al. (2005) concluded that Tsimane children do not suffer severe acute protein-energy malnutrition. As adults, Tsimane are taller than the mean for 42 lowland Amerindian populations, but are still below the 5th percentile for height among U.S. adults, and shorter than pre-modern Europeans from the 18th and 19th century (Godoy et al., 2006). There is also no evidence for secular changes in adult Tsimane height over the past seven decades, suggesting that increasing market integration and healthcare has not yet had a steady, continuous impact on chronic well-being (Godoy et al., 2006). Consistent with the lack of secular change is the relative lack of regional variability in infant and child anthropometrics reported here. Only weight-for-age was higher in villages near town, whereas stunting and wasting did not vary

Table 3
Probability of miscarriage, using generalized estimating equations (GEE) with a logistic link function (61 miscarriages in 1934 person-years on 394 women). Parameters in bold refer to $p < 0.05$, italics $p < 0.10$.

Variable	Model 1: baseline		Model 2: maternal anthropometrics		Model 3: maternal human capital		Model 4: demography	
	Odds ratio	*p*-Value	Odds ratio	*p*-Value	Odds ratio	*p*-Value	Odds ratio	*p*-Value
Sex (ref = male)	**0.459**	0.006	**0.499**	0.014	**0.463**	0.009	**0.459**	0.006
Region								
Mission (vs. near town)	0.483	0.119	0.542	0.214	0.704	0.462	0.484	0.126
Forest (vs. near town)	1.432	0.398	1.369	0.482	1.380	0.414	1.433	0.409
River (vs. near town)	1.182	0.670	1.109	0.806	1.375	0.421	1.181	0.677
Period 1950–1989 (vs. 1990–2002)	**0.529**	0.041	*0.591*	0.096	**0.495**	0.016	**0.528**	0.041
Maternal age								
35+ (vs. 20–34)	1.274	0.512	1.151	0.720	0.750	0.502	1.340	0.555
<20 (vs. 20–34)	1.620	0.103	1.525	0.152	*1.677*	0.100	1.571	0.209
Mother height-for-age *z*-score			0.969	0.845				
Mother weight-for-age *z*-score			0.729	0.171				
Mother body mass index								
Obese (vs. normal)			0.342	0.311				
Overweight (vs. normal)			0.913	0.833				
Mother body fat (%)			1.023	0.339				
Mother Spanish								
None (vs. fluent)					0.516	0.190		
Moderate (vs. fluent)					0.822	0.692		
Mother education								
None vs. (3rd grade+)					**5.236**	0.018		
1st–2nd Grade (vs. 3rd grade+)					3.088	0.103		
Birth order							0.990	0.879

regionally. Overall, stunting and slow growth reduces energetic support costs for Tsimane parents who wean early. High fertility in natural fertility populations like the Tsimane results in women having multiple dependent offspring simultaneously, thereby requiring energetic subsidies from spouses and other kin (Gurven & Walker, 2006).

The higher wasting prevalences I report for infants suggest greater risk in the first several years of life than in later childhood. Infants are protected by exclusive breastfeeding for about four to six months, then supplemented with other foods to accommodate demands of infant growth. The prevalence of moderate to severe stunting increased during the period of food supplementation and weaning. Greater pathogen exposure from unhygienic feeding practices and poor nutrient absorption from infectious disease, immature dentition and inefficient digestion may contribute to the increase in stunting over this period (McDade & Worthman, 1998). Indeed, body fatness, as assessed in the Foster et al. study, was most compromised between ages 1–3. The higher level of underweight and wasting among boys also merits further attention. Parents anecdotally report a preference for sons, due to perceptions about the value of their future economic contributions. However, male infants may be costlier to raise as they require more calories than females (estimated 32 cals/day for 1 year olds, 145 cals/day for 2 year olds using Oxford equations (Henry, 2005)). Godoy et al. (2006) also report that wealth among Tsimane mothers is more likely to be associated with greater BMI among daughters but not sons.

Population comparisons of miscarriage rates are complicated by different operational definitions, detection ability and reporting bias. For this reason clinical miscarriages (those occurring after the 10th week since the woman's last menses) are often used in epidemiological studies. The preliminary Tsimane data on reported miscarriages suggests that Tsimane women show similar risk of fetal loss as other documented populations (Fig. S1, electronic Supplementary material). This is surprising given their high fertility, infectious exposure and relative lack of prenatal care. Accidents, self-induced trauma and sickness were reported as the main causes of fetal death among Tsimane. While trauma can lead to placental separation, reasonable trauma does not usually lead to fetal loss; criteria used to establish a causal link are often not met (Ribe, Teggatz, & Harvey, 1993). However, deliberate violence may induce abruption. Intimate partner violence has been associated with greater likelihood of prenatal hemorrhage, intrauterine growth restriction and fetal death (Janssen et al., 2003). Tsimane women report a high level of domestic violence (Stieglitz, Kaplan, Gurven, Winking, & Tayo, 2011). While pregnancy reduces the likelihood that a Tsimane woman experienced physical abuse by 19%, women nonetheless experienced abuse during 33.5% of their pregnancies (243/725, $n = 1600$ risk years on 110 women) (J. Stieglitz, pers. comm.).

It is likely that miscarriages in the first trimester were underreported or undetected. Premature stillbirths may have also been misclassified as infant deaths, and gestational ages were probably imprecise. It has been estimated that stillbirth rates are usually about 20% of IMR (Knodel, 1974), which would be roughly 26 per 1000 live births; however, the Tsimane stillbirth rate is 14.5. Both rates are much higher than those reported in high-income countries (3.1 per 1000 births in 2009) but similar to those found in other world regions (Cousens et al., 2011). A study of over 14,000 fetal deaths in hospitals in Latin America found that the lack of prenatal care was associated with a fourfold increase in likelihood of miscarriage; fetuses small for gestational age, high parity and maternal age (≥35 yrs) were also important factors (Conde-Agudelo, Belizán, & Díaz-Rossello, 2000). Other factors include smoking, obesity, maternal and gestational diabetes and maternal hypertension (Flenady et al., 2011). Tsimane women of reproductive age rarely smoke, few are obese, hypertension is rare and diabetes is almost non-existent. On average, a woman has 2.58 births after age 35 and 1.15 after age 40. Miscarriage is most common in younger and older mothers (Fig. 5). However, given the young age structure of the Tsimane population, only 5.7% of pregnancies are among women over age 40.

There was mixed evidence that a woman's human capital affected the likelihood of infant or fetal death. Mothers unable to speak Spanish are only marginally more likely to experience an infant death, and those with no schooling a greater probability of fetal loss. These effects were independent of region and maternal age. Neither father's education nor Spanish fluency bore a relationship with infant or fetal death (analysis not shown). These findings are noteworthy because they contradict a consensus view that maternal education is the most important predictor of offspring mortality (Gakidou, Cowling, Lozano, & Murray, 2010).

Other patterns found among Tsimane mirror those observed elsewhere. First, short interbirth intervals were associated with a higher risk of infant death. Post-birth interval might correlate with infant death because of the rapid post-death resumption of ovulation, rather than from being weaned too soon. However, short pre-birth spacing may lead to subsequent infant death due to the compromised growth, nutrition and health of these infants. Short spacing might not allow mothers enough time to replete energetic reserves to support the next pregnancy (Tracer, 1991). Similar effects between birth spacing and infant mortality were found among Bolivian mothers using Demographic and Health Survey data (Forste, 1994). Second, death rates were higher for male fetuses. It has been postulated that premature rupturing of membranes is more common with preterm male fetuses that are typically greater mass at lower gestational age (Di Renzo, Rosati, Sarti, Cruciani, & Cutuli, 2007), suggesting that males may be more fragile or more costly to bring to term (Kraemer, 2000). Third, obese women were more likely to have experienced infant death. The prevalence of obesity in Tsimane women aged 20–39 is only 5.1%. In the U.S., obese women experience more neonatal mortality, regardless of weight gain during pregnancy, due to more pregnancy complications related to short gestation and low birthweight, preeclampsia and prolonged labor (Chen, Feresu, Fernandez, & Rogan, 2009). There was no support for greater likelihood of infant death for underweight women.

Despite the evidence presented here on compromised early-life conditions, Tsimane remain relatively lean as adults and do not currently experience high levels of chronic disease. Peripheral arterial disease, atherosclerosis and type 2 diabetes are absent, while hypertension, obesity and other cardiovascular risk factors are minimal (Gurven et al., 2009). Chronic disease accounts for relatively few deaths, whereas infections are responsible for the majority of adult deaths (Gurven et al., 2007). In Bolivian cities, however, diabetes, hypertension and obesity are increasingly prevalent, and are rising public health threats, as has already been shown in other Latin American countries (Barceló & Rajpathak, 2001). Lifestyle changes associated with modernization have impacted diet and physical activity and reduced pathogen exposure at the national and regional level, thereby increasing risk factors for chronic disease. Obesity, insulin resistance and type 2 diabetes, heart and renal disease and stroke are likely to increase if Tsimane diet, activity and other lifestyle behaviors change with rapid modernization, as they have for North Amerindians, Australian aborigines and other indigenous populations (Dressler, 1982; Herrera & Rodríguez-Iturbe, 2003; Leonard, Snodgrass, & Sorenson, 2005; Narva, 2003; Shephard & Rode, 1996; Spencer, Silva, Snelling, & Hoy, 1998). Whereas the effects of modernization on anthropometrics and Tsimane lifestyle are not yet substantial, changes in fertility and health may be on the horizon, consistent with the decrease in infant and child mortality observed only after 1990 (Gurven et al., 2007; McAllister et al., in press). Recent cohorts may be particularly susceptible to adult chronic disease in the coming decades due to the "mismatch" between the legacy of maternal effects and "thrifty phenotype" associated with past, poor environments and the improved health and nutritional conditions of the imminent future (Gluckman et al., 2007). During the future epidemiological transition, reduced activity and changed diet, but with high levels of inflammation from infection, could lead to a rise in adult chronic disease. In conclusion, this paper provides a glimpse into past and present conditions among a population of indigenous South Amerindians in socioeconomic and epidemiological transition. Infant health, growth and survivorship are tied to maternal condition, and to access to traditional and novel resources. While Tsimane subsistence efforts may be currently sufficient to support the caloric demands of high fertility, infants nonetheless suffer the costs of short birth intervals through higher mortality and compromised growth.

The main limitation of this paper is that it is based largely on retrospective demographic interviews requiring recall of past information. More precise information (e.g. exact interbirth interval), and proper covariates (e.g. infant birthweight, pre-birth maternal anthropometrics) are more appropriately measured in longitudinal study. Longitudinal study will also be required to link variation in nutrition, growth and health early in life to health outcomes later in life. This study, based on demographic records and baseline measures collected during the first three years of the THLHP, forms the foundation for these prospective studies of the effects of early conditions on health outcomes in late childhood, adolescence and adulthood.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.socscimed.2012.09.030.

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