Costs of reproduction and maternal depletion in a high fertility and mortality population

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Introduction

Sex differences in human mortality, health and well-being have been widely reported in both developed and developing countries (e.g. Gorman and Read 2006; McDonough and Walters 2001; Verbrugge 1989). Women typically live longer but experience higher morbidity, especially from non-fatal conditions such as depression and arthritis, while men suffer more from cardiovascular disease and other ailments (Case and Paxson 2005). Differences in risky behavior and lifestyle (e.g. smoking, drinking) explain some of the cross-country variability. To the extent that women and men lead more similar work and social lives, it is expected that health and survivorship should be more similar among women and men. However, even when controlling for differences in work-related behavior, smoking, obesity and other behaviors, marked sex differences in health and disability remain (Crimmins et al. 2011). Explanations that rely on biological factors such as hormonal changes suggest an obvious contender for further exploration. We posit that the costs of reproduction unique to women may be partly responsible for differential rates of health and physical decline in adulthood.

A life history framework argues that in all organisms, energy is limited and is allocated to competing physiological demands in ways that optimize biological fitness. It is therefore expected that energetic resources invested in reproduction should trade-off against those spent on somatic maintenance and survival (Stearns 1992). The additional caloric requirements of pregnancy and lactation are widely documented, as well as the effects of immune suppression and susceptibility to infection during pregnancy. In the 1960's, maternal depletion was identified as an important deterrent to women's health, based on research in Papua New Guinea (Jelliffe and Maddocks 1964). In the 1980's and 1990's, there were numerous attempts to test whether maternal depletion due to repeated bouts of reproduction negatively impacted maternal nutritional status (as assessed through anthropometrics). The evidence was largely mixed (Tracer 2002); however, most studies to date have been cross-sectional and rely on only a few anthropometric measures to assess health and nutritional status. Whether repeated pregnancies and lactation affect the health of malnourished women with high fertility has implications for policy recommendations about prolonged breastfeeding in the absence of nutritional supplementation.

In this paper, we present sex differences in adult health and physical condition among the Tsimane, a Bolivian natural fertility population of forager-horticulturalists, and test whether cumulative number of live births predicts variability in female health outcomes, independent of age and other confounding factors. We employ longitudinal data to examine change in weight, body mass index and body fat as a function of changes in parity, among women age 15-44. Among women age 45+, we test whether their completed fertility is associated with poorer anthropometric status over time. We also assess whether greater parity is associated with other health outcomes, including anemia, higher inflammation and cystocele (bladder prolapse).

Methods

The Tsimane are forager-horticulturalists (population ~13,000) living in the Beni Department of the Bolivian Amazon, dispersed in 90+ villages ranging in size from 40-550 inhabitants. Their diet remains largely traditional, based on horticulture (plantains, manioc, rice), fishing, hunting, and gathering fruits. There is no running water, electricity, plumbing or public sanitation. Fertility among Tsimane is high, with little evidence of any sustained decline in recent years. The average Tsimane woman has 9 births over her lifetime (McAllister et al. 2012), and effective contraceptive use is rare. Age at first birth is 18.3 yrs, and the average interbirth interval is 30 months (Gurven 2012).

We employ cross-sectional and longitudinal data collected from the Tsimane Health and Life History Project (www.unm.edu/~tsimane) over the period August 2002 to December 2012. A roving team of trained physicians, lab technicians and anthropologists visited 18 to 85 villages per wave, providing medical attention while collecting systematic clinical evaluations of the entire census population each visit. Evaluations include medical history, current symptoms and diagnoses, dental evaluation, anthropometrics, hematology, fecal and urine analysis. Reproductive histories and other demographic information were first collected in 2002-2005 (Gurven et al. 2007) and have been since updated in subsequent medical visits. PAP smears were also performed on a representative sample of women age 20+. Anthropometric indices include weight (kgs) and body fat (%) as measured by bioelectric impedance using a Tanita scale, and body mass index (kg/m^2). Height was measured using a portable stadiometer.

Results

Sex differences in health. Women show worse health than men on a variety of measures (Figure 1). They have higher rates of anemia, higher prevalence of hypertension, kidney dysfuntion, depression symptoms, more joint problems, greater tooth loss and greater functional disability. They also are more likely to have elevated white blood cells indicative of infection, between the ages 20-50 yrs, and elevated erythrocyte sedimentation rate, indicative of inflammation and infection, throughout adulthood. Women are also six times more likely to be obese than men, controlling for age, Spanish fluency, education and pregnancy status (OR=6.3, 95% CI=3.0, 13.1, $p<0.01$). Based on PAP smears (n=545) and follow-up colposcopies, Tsimane women also suffer high rates of cervical dysplasias (Figure 2). The prevalence of abnormal PAPs was 8.3%, and of low-grade and high-grade dysplasia as diagnosed upon follow-up is 1.3% and 2.9%, respectively.

Parity and nutritional status. We separate analyses among women still undergoing (ages 15-44) and those who have completed reproduction (age 45+).

Cross-sectional analyses controlling for age show no relationship between the number of live births (parity) and weight, BMI, fat-free mass or fat mass, in either group of women (n=1103 age 15-44, n=289 age 45+). There is a low positive correlation with body fat percentage that trends toward significance. Further analysis of other medical rounds shows a similar absence of any indication that greater parity associates with poorer nutritional status.

Longitudinal data on the same individuals are displayed in Figure 2, separated into three categories: women whose measurements were decreasing on average over time (by at least a mean 2 kg per round), remained relatively stable (within ±2 kg per round), and increasing over time (>2kg per round). The majority of women age 15-44 and 45+ were observed to have relatively stable weights and BMI. Only 10.7% of women age 15-44 and 13.7% age 45+ were categorized as having trajectories of weight loss over time.

Multilevel mixed-effects models are used to examine effects of changing parity on longitudinal changes in nutritional status, with random intercepts for each woman's starting measure (e.g. weight) and random slopes allowing women's rate of change to vary over time. Models control for age at baseline measurement, Spanish fluency, schooling, pregnancy status, age at first birth, cohort and time elapsed since last birth. Table 1 provides parameter estimates for four models: maternal weight (ages 15-44, 45+) and BMI (ages 15-44, 45+). In none of these models is parity a significant predictor of anthropometric status. Results only show that more educated, fluent Spanish speakers and younger cohorts are heavier. Similar results were also found in models of body fat percentage (not shown).

Parity and women's health. Whether parity affects the likelihood of having anemia, elevated white blood cells, or cystocele was also examined.

Controlling for age and BMI, we find that each additional live birth was associated with an 11.7% higher probability of having anemia among women age 45+ (p=0.0004, n=400). Among women of reproductive age, each additional live birth was associated with a 26% higher probability of having elevated white blood cell count (>10,000 units) (p=0.019, n=97) and a 32.4% higher probability of having elevated erythrocyte sedimentation rate (p=0.002, n=136).

The prevalence of advanced (grade 3+) cystocele is 9.7% (73/750 women examined). The parity of those with and without cystocele was 8.4 and 6.5, respectively (p<0.0001). Logistic regression analysis reveals that after controlling for age, each additional live birth increased the probability of having cystocele by 9% (p=0.05).

Discussion and Conclusion

We find no convincing evidence that greater parity leads to poorer nutritional outcomes, as measured by weight, BMI and body fat percentage. This was true in both cross-sectional analyses and longitudinal analyses that permit stronger inference by avoiding the self-selection problem that has plagued prior research on maternal depletion. The mixed effects models also controlled for timing of most recent birth, pregnancy status and other covariates, but still showed no effect of cumulative reproduction.

As daily energetic costs of lactation outweigh those of pregnancy, it could be argued that the number of live births is a poor measure of reproductive costs (Dufour and Sauther 2002). We do not have data on breastfeeding duration or intensity for the sample of women used in this study. Tsimane women tend to breastfeed exclusively for four months, then gradually introduce complementary foods, with weaning complete by nineteen months (Veile et al. In press). However, by including age at first birth and timing of previous interbirth intervals in our models, we indirectly account for the pace of reproduction. Another limitation is our reliance on relatively crude measures of anthropometric status: weight, BMI and body fat percentage. Even though these are routinely used in clinical settings to quickly assess chronic nutritional health and acute changes (Frisancho 1990), it is possible that greater reproductive costs lead to deficiencies in micronutrients such as iron, folate and zinc (King 2003).

Despite not finding evidence that high fertility compromises overt nutritional status, we report findings illustrating the greater health risks facing Tsimane women compared to men. For a subset of conditions and health indicators, we also find that greater parity associates with higher morbidity, including higher risk of anemia, inflammation and infection. Cystocele is also a relatively important health problem. Patients complain of discomfort, painful urination, and cystocele may be partly responsible for repeated urinary tract and bladder infections, as well as the compromised kidney function that appears greater in Tsimane women than men (Figure 1b). Ongoing studies will examine in greater detail the types of ailments associated with greater parity, duration of sickness and quality of life based on self-reports of well-being.

It is possible that overt maternal depletion with repeated reproduction exists only under relatively extreme conditions of malnourishment and disease, as observed initially in Papua New Guinea in the 1960's. Although food-limited and physically active, Tsimane women on average are not malnourished. Indeed, the prevalence of underweight (BMI ≤ 18.5) among adult women age 20+ is very low (1.9%). Among women age 40+ it is only 3.8%. The high fertility and short inter-birth intervals is perhaps evidence of the favorable conditions of the Tsimane environment and their subsistence practices. Among Tsimane, horticulture provides a rich, fairly predictable and relatively easy-to-obtain source of abundant carbohydrates, whereas fishing and hunting provide adequate protein and fat (Martin et al. 2012).

That Tsimane women maintain their nutritional status over the course of their reproductive lifespan despite a rapid birth rate is a remarkable result that may be relatively unique to humans. Humans under natural fertility conditions maintain a birth rate that is roughly double that of chimpanzees, our nearest primate relatives (Kaplan et al. 2000). Extensive cooperation within and among families permits mothers to wean offspring earlier than expected given human body size. Whereas in other primates, such as baboons, mothers increase their work efforts to support the increased energetic costs of lactation, human mothers decrease their active physical labor and receive food and support from spouses, parents, in-laws, siblings and other group members. Most non-cooperative animals must rely on their own efforts for feeding and care, whereas humans depend on "pooled energy budgets" to subsidize rapid fertility and multiple dependent offspring simultaneously (Kramer and Ellison 2010). Family formation through marriage, and reliable social exchange and support networks among kin were critical human adaptations that allowed for both higher fertility in humans and a longer, healthier lifespan.

Figure 1. Sex differences in health: (a) hypertension prevalence, (b) microalbuminuria prevalence as indicator of kidney health, (c) depression symptoms, (d) joint problems as diagnosed by physician, (e) proportion of missing teeth by age, (f) erythrocyte sedimentation rate, (g) white blood cell (leukocyte) count.

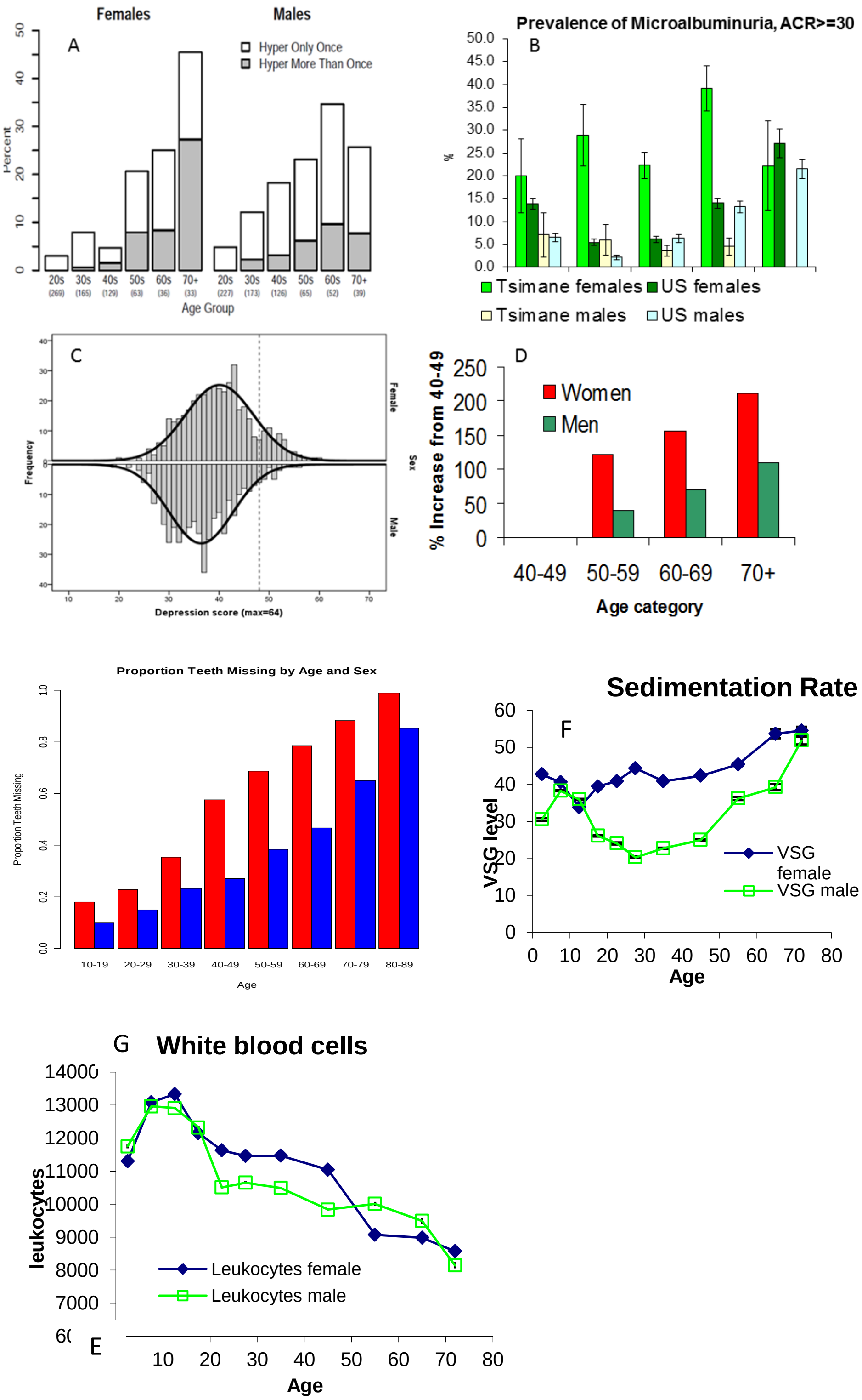

Figure 2. Longitudinal trajectories of weight among women age 20-44 (top row) and 45+ (bottom row). Left (right) column refers to women whose weight decreased (increased) by at least 2 kgs per year. Middle column refers to women whose weight remained relatively constant over time.

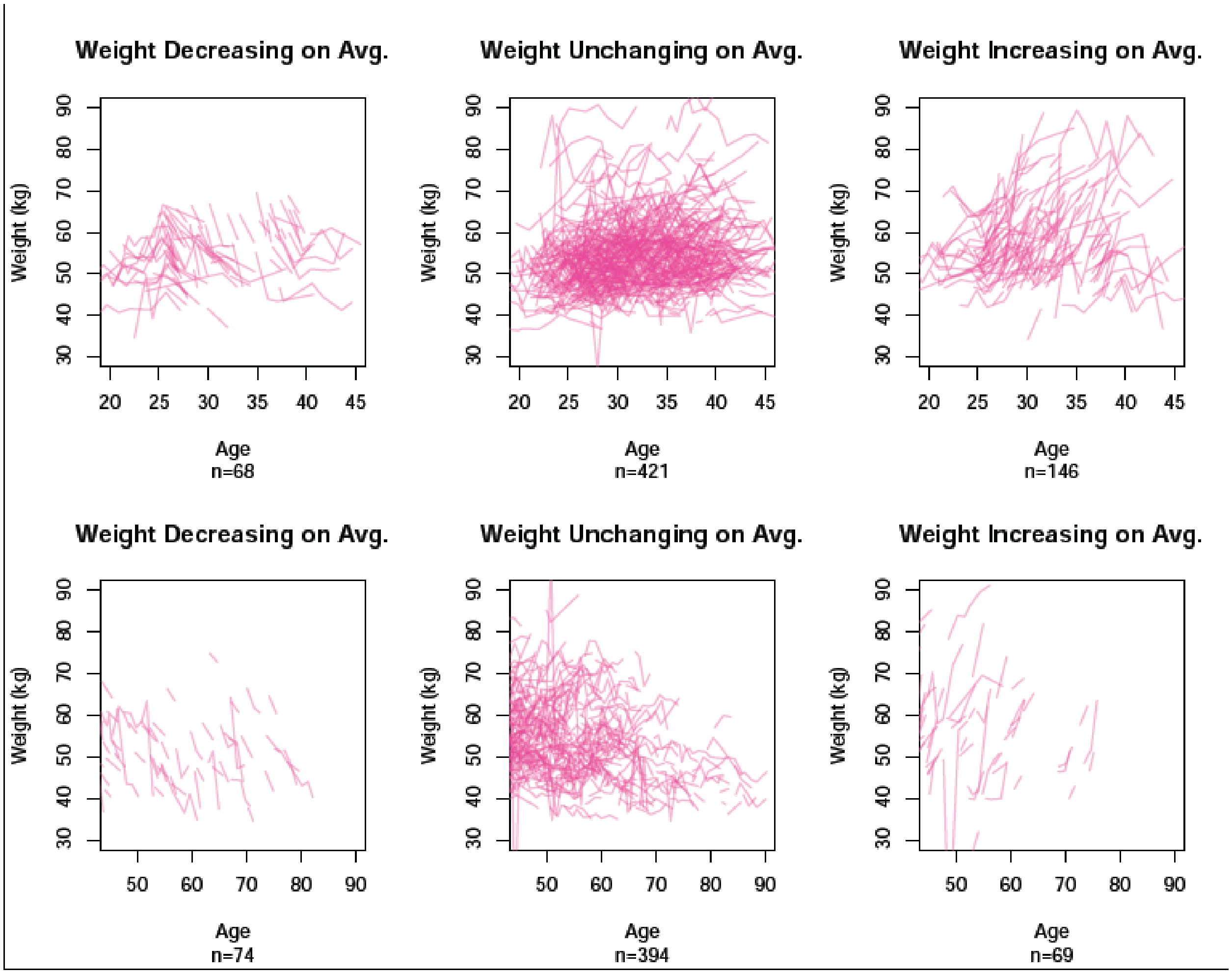

Table 1. Mixed effects model of Maternal Weight and BMI for women age 15-44, and ages 45+. Random effects terms are included for intercepts and slopes.

	Weight: Ages 15-44		**BMI: Ages 15-44**		**Weight: Ages 45+**		**BMI: Ages 45+**	
Predictor Variables	β	P	β	P	β	P	β	P
Age at first measurement	0.483	0.000	0.185	0.000	0.049	0.747	0.069	0.283
Age at first birth	0.214	0.157	0.060	0.313	0.197	0.256	0.058	0.427
Days since last birth	0.000	0.798	0.000	0.825	0.000	0.817	0.000	0.749
Parity at measurement	0.047	0.847	0.027	0.782	0.086	0.760	0.005	0.964
Length of previous IBI	0.000	0.538	0.000	0.633	0.000	0.471	0.000	0.684
Highest grade completed	-0.245	0.218	-0.127	0.099	2.672	0.017	0.895	0.054
Spanish ability	2.479	0.000	0.865	0.000	1.892	0.077	0.920	0.041
Year of birth (cohort)	0.304	0.000	0.132	0.000	0.198	0.032	0.066	0.094
Pregnant at measurement	0.579	0.005	0.233	0.010	-0.121	0.771	-0.110	0.553
	N=1,993 obs, 533 women				N=719 obs, 220 women			

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