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RESEARCH PAPER

Sibling composition and children's anthropometric indicators of nutritional status: Evidence from native Amazonians in Bolivia

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***Background*: Siblings compete for parental resources. Little is known about how sibling composition (older sisters, older brothers, younger sisters, younger brothers) might affect child anthropometric indicators of nutritional status.**

***Aim*: This study evaluates the associations between sibling composition and child anthropometry using panel data from a native Amazonian society (Tsimane').**

***Methods*: Anthropometry of ~168 girls and 169 boys aged 2–9 years were measured annually during 2002–2007 (2360 observations). Children's weight-for-height *Z*-score (WHZ), mid-upper arm circumference (MUAC), mid-upper arm muscle area (AMA) and triceps skin-fold thickness (TST) were regressed separately against all of the sibling composition variables while controlling for child's age and survey year. Multivariate panel linear regressions were used with individual, village, survey year and village-year fixed-effects, clustering by household.**

***Results*: Among girls, an additional older brother was associated with a 1.4% decrease in MUAC ($p < 0.01$) and a 4.3% decrease in AMA ($p < 0.01$); an additional younger sister was associated with a 6.3% decrease in TST ($p < 0.01$). The association between sibling composition and arm anthropometry was robust to various model specifications.**

***Conclusion*: Older brothers and younger sisters were negatively associated with arm measures in girls. This finding may help improve policy interventions that aim to address children's nutritional health and long-term well-being.**

Keywords: Sibling, anthropometrics, nutrition, children, Bolivia

INTRODUCTION

Interest in how the socio-demographic profile of a household is associated with individual outcomes has a long history. Researchers in fields as diverse as economics (Butcher and Case 1994; Steelman et al. 2002; Dayioğlu et al. 2009), anthropology (Hrdy 1992; Borgerhoff-Mulder 1998; Hagen and Barrett 2009; Kramer 2010) and evolutionary biology (Trivers 1972, 1974; Daly and Wilson 1984, 1988; Zeller 1987; Clutton-Brock 1991) have posed questions about how major life events such as the number of children in a household, age of first reproduction or level of parental investment (PI) shape the evolution of human families. Together, these studies constitute life-history research.

Parental investment theory, a sub-set of life-history theory, deals specifically with parental investment decisions about producing and raising offspring. Evolutionary-minded researchers argue that, when food, time or other resources are constrained, parents will invest these resources differentially between offspring depending on offspring's sex, age, health and likely relatedness to the parent (Trivers 1972, 1974; Daly and Wilson 1984, 1988; Clutton-Brock 1991; Hrdy 1992). Parents are inclined to divide resources equally between all their children (Fisher 1930), but they will likely favour the offspring, whom they believe will be the most successful reproductively as a result of a resource investment. We might then expect that, for a given child, having siblings who are more favoured might dilute household resources, with potentially negative consequences for that child.

Previous researchers have reported a relation between a child's birth order and well-being indicators, such as intellectual ability (Belmont and Marolla 1973; Steelman et al. 1980, 2002; Downey 1995, 2001; Kristensen and

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Bjerkedal 2007), educational attainment (Butcher and Case 1994; Steelman et al. 2002; Dayioğlu et al. 2009) and health among young children (Horton 1986; Rosenzweig 1986; Das Gupta 1987; Behrman 1988; Amin 1990; Pande 2003). However, less attention has been paid to the role of *sibling composition*, or how the specific number of older or younger sisters and older or younger brothers might affect these outcomes.

Examining the relation between a child's nutritional status and sibling composition is important because it might add insights into household dynamics that may have short- and long-term health and economic impacts on household members. Our objective is to shed light on apparent trade-offs and competition between siblings within households, and their association with children's nutritional status. Trade-offs and competition are probably shaped by adaptive evolutionary propensities as well as by specific social and economic conditions that could help us understand human families. Understanding these associations might help improve health policy interventions such as household planning and nutritional programmes that are aimed at, for example, addressing children's nutritional and health status by identifying the most vulnerable children in a household. It might also help explain fertility patterns such as the total number of children in resource-constrained environments.

For the empirical analysis we used panel data collected among the Tsimane' (2002–2007), a foraging and horticultural society of native Amazonians in Bolivia who are in the early stages of continual exposure to the market economy (Leonard and Godoy 2008). While our study takes place in a very specific setting, our data and study are unique in two ways. First, the use of panel data allows us to remove confounders plaguing cross-sectional estimates. Second, using data from a remote, low-income rural society allows us to assess whether findings from industrial societies hold in a very different socioeconomic setting and can be generalized beyond the industrial world. We hypothesize that sibling effects will be more apparent in a resource-constrained society such as the Tsimane'; if household resources were ample, all children receiving resources would have had ample nutrition even if one sibling obtained more resources than another.

In this study, we tested the PI theory that parents experiencing resource constraints would invest differentially in offspring such that having an additional sibling of one type vs another has a differential association with a child's anthropometric indicators of nutritional status. Specifically, we focused on children aged 2–9 years (inclusive) to explore the relation between sibling composition (having an additional younger or older sister or younger or older brother) and a range of anthropometric measures of nutritional status including weight-for-height *Z*-score (WHZ), mid-upper-arm circumference (MUAC), mid-upper arm muscle area (AMA) and triceps skin-fold thickness (TST).

Sibling composition and the role of local ecology

To understand the dynamics of intra-household trade-off and competition between siblings, it is important to examine the role of local ecology in parental decisions to allocate resources. If a given society has an economy that favours having boys over girls, resource-constrained parents might invest more in the well-being of boys (e.g. through providing boys with more or nutritious food, leisure time activities or healthcare). Indeed, many studies have examined sex-biased parenting in humans (for reviews, see James 1987; Sieff 1990; Cronk 1991) and the gendered allocation of child work (Ember 1973; Zeller 1987; Blair 1992). For example, Borgerhoff-Mulder (1998) found that low-income Kipsigis families in Kenya invested preferentially in their daughters' education more than did richer families. Among Kipsigis, daughters were seen as less costly, indeed an economic asset to parents since they left the household, and brought bridewealth upon marriage (Borgerhoff-Mulder 1998). Thus, for low-income Kipsigis families, investing in their daughters' education meant an increase in the chances of their daughters marrying more educated and richer men, which in turn would provide greater access to resources and enhance reproductive fitness. A similar phenomenon was observed by Cronk (2004) among the Mukugodo in Kenya concerning girls' anthropometric indicators of nutritional status. Cronk posited that Mukugodo parents were unintentionally investing more in the health of girls because, unlike boys, girls could marry into a higher socioeconomic status with their neighbouring Maasai tribe.

Local ecology may also determine whether parents are inclined to invest in a sibling of one relative age over another (i.e. older vs younger) so as to bring greater fitness returns. In a setting with low healthcare availability and utilization and high disease prevalence and mortality rates, resource constrained parents might favour older children or first-borns since these children will have already survived the riskiest stage of their lives health-wise and are closer in age to begin contributing economically to the household; this may include caring for younger siblings (Weisner and Gallimore 1977; Henry et al. 2005; Kramer 2005). Conversely, parents might skew investment toward vulnerable, younger siblings if they perceive that older siblings are likely to survive even if investment in them is reduced (Daly and Wilson 1984, 1988; Hagen et al. 2001). Parents may choose not to favour younger children, however, if they perceive that these children are less likely to survive in any case.

A society's wealth inheritance pattern can also shape parental decisions to allocate resources such that there are significant long-term consequences for the health and well-being of some household members. For example, in Ethiopia, farmers with older brothers tended to have poorer marital and reproductive prospects only in a system whereby land was inherited through parents (Gibson and Gurmu 2011). A comparable group of farmers who had acquired land through government redistribution did not experience the same effects (Gibson and Gurmu 2011). A similar finding was observed in Kenya where men with older brothers tended to have smaller initial bridewealth, later age at marriage (Mace 1996; Borgerhoff-Mulder 1998), smaller plots of land (Borgerhoff-Mulder 1998) and fewer offspring surviving to age 5 (Borgerhoff-Mulder 1998).

Sibling composition and children's anthropometric indicators of nutritional status in developing nations

In developing countries a few studies have examined the relation between sibling composition and children's anthropometric indicators of nutritional status. Using data from 2458 children (age < 7 years) from the 1988–1989 Ghana Living Standards Survey, Garg and Morduch (1998) examined the impact of sibling composition on children's height-for-age, weight-for-age and weight-for-height. Holding sibling size constant, they found that both boys and girls benefitted from having more sisters, independent of birth order. In shifting from having all brothers to all sisters, anthropometric indicators improved by as much as 25–40 percentile points. The role of resource constraints was less clear. One possible explanation for the negative effect of older brothers on younger siblings' anthropometric indicators might pertain to the maternal foetal environment following the birth of a boy. Older brothers were associated with reduced birth-weight of younger siblings of either sex, partly due to a shorter gestation period (Nielsen et al., 2008). Poor recovery of maternal somatic resources and a greater dilution of the intense care required in the first years of life following the birth of a boy may also contribute to the negative impact.

Among adolescent Ecuadorian Shuar children, Hagen and Barrett (2009) found that girls, as opposed to boys, were associated with reduced growth and development in their younger siblings. The authors posited that the higher energy needs of adolescent girls' reproductive physiology may have led to a re-direction of resources away from younger siblings or that the earlier age of marriage of adolescent girls caused adolescent boys to stay home longer, providing alloparental care to their younger siblings (Hagen and Barrett 2009).

In societies where pro-male bias is pronounced, a child's gender and relative age may have detrimental effects on health outcomes. Studies from Bangladesh and India found that children with same-sex older siblings had a higher probability of dying and this was worse for girls than for boys (Das Gupta 1987; Muhuri and Preston 1991). There was a preference for daughters only when parents had at least one son (Rahman and Davanzo 1993; Chaudhuri 2008). In India, Jayachandran and Kuziemko (2011) found that breastfeeding duration was shorter for older siblings, particularly older daughters and children without older brothers because of parents trying again for a son.

Overall, research on the relation between sibling composition and child health from developing countries suggests that having brothers of any relative age is negatively associated with child growth indicators, while having sisters has a positive association. Sibling gender can play a significant role in determining child health outcomes, particularly in economies with marked pro-male biases. There is no consistent evidence concerning the role of resource constraints, although one study from Bangladesh found that boys adversely affected their siblings' nutritional status as measured by height only in households facing greater resource constraints (Chaudhuri 2008).

In fields as diverse as economics and anthropology, researchers have attempted to answer questions about what factors shape human families and how parents make decisions about producing and raising offspring. What kind of social, cultural and economic environment determines the advantages (or disadvantages) associated with being a sibling of a certain sex and relative age, particularly in a resource-constrained household? Studies suggest that, in cases where there is disparity in well-being indicators, the children who are advantaged, whether in health or in the number of offspring that they will eventually have, are those who will potentially bring greater reproductive fitness by uplifting the socioeconomic status of themselves and of their households as a result of being of a specific gender and relative age. These findings underline the need to study sibling composition in terms of the combined effect of a sibling's sex and relative age on child well-being, which studies examining only the effect of birth order or of the number of sisters vs brothers fail to identify.

This study adds new knowledge to the research on sibling composition as well as advances the literature methodologically by examining the separate effects of sibling dyads (number of younger sisters, number of older sisters, number of younger brothers, number of older brothers) on children's anthropometric indicators of nutritional status using data from a low-income foraging and farming society in the Bolivian Amazon.

Hypotheses

We draw on PI theory to test the following three hypotheses:

First, for the pooled sample, we hypothesize that sibling composition will affect anthropometric indicators of children's nutritional status because of sibling rivalry for finite household resources, rivalry that should be marked and more readily visible in a resource-constrained society such as the Tsimane'.

Second, we hypothesize that the effect will not differ by the sex of the sibling or of the child. Ethnographic evidence suggested some level of sex-typing in the allocation of household work among Tsimane' children (e.g., boys learn to hunt early), however, prior research based on a short panel ($\sim$4–5 consecutive quarters, 2002–2003) among Tsimane' suggested little evidence of girl–boy disparities in a wide range of well-being indicators (Godoy et al. 2006, 2007), including intestinal parasitic infections (Tanner et al. 2009) and anthropometric measures of short-run and long-run nutritional status (Godoy et al. 2006).

Third, while Tsimane' society is relatively egalitarian, we hypothesize that the effects of sibling composition on a child's nutritional status will be stronger among households with lower income and wealth than among more affluent households. Income and wealth grant households access to goods that directly affect health and nutrition (e.g. food, medicine) or indirectly, through, for example, the expansion of hunting and gathering abilities (e.g. canoes, rifles, and fishing hooks; Godoy et al. 2010a). The effect of sibling composition on a child's nutritional status will be less marked among more affluent households.

METHODS

Materials

Tsimane' live mainly in the Department of Beni in Bolivia. They number ~15 000 people and reside in ~120 villages. Like many native Amazonian societies, Tsimane' practice hunting, fishing, plant foraging, slash-and-burn farming and increasingly wage labour. Tsimane' live in small villages with an average of 19.32 households/village (SD = 11.80). Recent publications contain descriptions of the geographic setting, history and ethnography of the Tsimane' (Huanca 2008; Ringhofer 2010).

We collected annual panel data during June–September 2002–2007 (inclusive) from all Tsimane' in 13 Tsimane' villages along the Maniqui River located in the Department of Beni (the complete data and documentation, along with publications from the Tsimane' Amazonian Panel Study TAPS project are available for public use at http://www.tsimane.org). The 13 villages were selected to capture variation in proximity to the market town of San Borja (mean village-to-town distance using GPS = 25.96 kilometres; SD = 16.70), the only town along the Maniqui River. Village-to-town distance captures variation in market exposure or modernization, which likely affects child health, as communities closer to market towns may have greater access to modern healthcare and also be more affluent. The panel includes 345 households with ~1500 people, but we limit the analysis to children between the ages of 2–9 years to ensure that puberty does not affect the estimates of growth rates, particularly in height. In previous studies, we found that children may enter a pre-pubertal growth spurt as early as 10–12 years of age (Byron 2003; Godoy et al. 2010a). Depending on the anthropometric data, we have annual data, on average, for 196 girls and 197 boys (ages 2–9 years), which resulted in a total sample size of 2360 observations over the 6 years of the study.

A team of Bolivian university graduates did the surveys, aided by bilingual Tsimane' who translated survey questions from Spanish to Tsimane'. The first language of the surveyors was Spanish. The surveys took place at the participant's home, but anthropometric measures were taken at the schoolhouse when available, or at a central courtyard in the village.

Variables

Table I contains definitions of the variables used in the analyses with their descriptive statistics. Per capita household income had a much wider variation (36.171 ± 76.871) compared with per capita household wealth (425.325 ± 357.027). Wealth and income were measured in bolivianos (1 USD = ~7 bolivianos).

Dependent variables. We used several anthropometric indicators for the dependent variables because they capture different aspects of a child's nutritional status. The rationale for the use of the different anthropometric indicators is described below.

- *Weight-for-height Z-score (WHZ)*. WHZ is used to assess wasting and mortality risk. We used National Centre for Health Statistics (NCHS) standards rather than the World Health Organization (WHO) growth standard because the latter apply only to children less than 5 years old; beyond 5 years, the recommendations are to continue to use the NCHS data (Hamill et al. 1979; WHO 1995). Children with Z-scores ≤ -2.0 are considered nutritionally at risk or 'wasted' (WHO 1995, 2006; Onyango et al. 2007). Because WHZ does not account for variability in muscle and fat mass and can therefore misclassify tall and lean children as having low WHZ (Frisancho 1990), we also included arm anthropometric measures of muscle and fat content to better assess nutritional status.
- *Mid-upper arm circumference (MUAC)*. MUAC measures the diameter of the upper arm and assesses both fat stores (source of energy) and muscle mass (source of protein or amino acids) in the body. Studies suggest that MUAC can predict mortality among young children independent of WHZ and other weight or height-based measures (Briend et al. 1989; Van den Broeck et al. 1998; Berkley et al. 2005; Akinbami et al. 2010). MUAC is used to capture muscularity and fatness, both of which represent tissues that are energy reserves for supporting vital functions during infection or starvation. The measure of MUAC is easy and yields more accurate values while assessing malnutrition among children, particularly in resource-limited settings (de Onis et al. 1997).
- *Arm-muscle area (AMA)*. AMA is a measure of muscle content (Saito et al. 2010) and of protein reserves, as most of the protein in fat-free mass is stored in muscle (Frisancho 1990). The calculation of AMA was derived using MUAC and triceps skin-fold thickness (TST) (Frisancho 1990, Table I)
- *Triceps skinfold thickness (TST)*. TST measures subcutaneous adipose tissue thickness and is an indicator of total body fat and energy reserves (Frisancho 1990; Jebb et al. 1993; Pecoraro et al. 2003). High fat content is associated with high calorie intake or low energy expenditure (Frisancho 1990). Fat assessment has an added advantage in that fat changes relatively little among children aged 1–7 years old (Gurney 1969). We transformed MUAC, AMA and TST into natural logarithms to ease the interpretation of regression coefficients.

The use of muscle and fat measures was of primary interest because these components are severely affected by nutritional disorders (Holliday 1978; Briend et al. 1989). We did not include height, weight and body mass index (BMI) as outcome variables. These measures approximately estimate children's long- and short-term growth and nutritional status, but do not measure children's body muscle mass and body fatness. BMI is widely used to

Table I. Description and summary statistics of outcome variables and control variables used in models: Tsimane' girls and boys aged 2–9 years, inclusive, surveyed annually during 2002–2007.

Name	Definition	Obs	$M \pm$ SD
Outcome variables			
WHZ	Weight-for-height *Z*-score. Standing physical stature was recorded to the nearest millimetre using a portable stadiometer. Participants were asked to stand against a vertical board on a flat board without shoes. Body weight was measured to the nearest 0.2 kg using a standing scale.	2360	0.470 ± 0.719
MUAC (cm)*	Mid-upper arm circumference was measured to the nearest millimetre at the mid-point of the upper arm between the shoulder and the elbow and on the skin surface with the arm relaxed using a plastic measuring tape.	2360	16.314 ± 1.510
AMA (cm^2)*	Arm muscle area was calculated from MUAC and TST. AMA = $(\text{MUAC} - 0.1\ \pi\text{TST})^2/4\pi$	2360	15.802 ± 3.539
TST (mm)*	Triceps skin-fold thickness was measured to the nearest millimetre on the back of the arm at the same point where the MUAC was taken using a Lange caliper.	2277	7.345 ± 2.230
Control variables			
Age	Child's age in years	2360	5.463 ± 2.060
Morbidity	Sum of the total number of reported days ill or bed-ridden in the last 2 weeks	2316	4.816 ± 6.776
Per capita household wealth*,‡	Total real monetary value of modern and traditional assets and domesticated animals owned by the entire household in bolivianos divided by household size	2360	425.325 ± 357.027
Per capita household income*,‡	Total monetary income earned by the entire household from wage labour and the sale of goods in the last 2 weeks divided by household size, in bolivianos	2360	36.171 ± 76.871

Notes: Other control variables included a full set of village and survey year dummy variables and a year–village interaction term; * In regressions, values were transformed into natural logarithms to ease the interpretation of coefficients in terms of a constant percentage change in the outcome that is associated with a one unit change in the explanatory variable; † Reported by child's principal caretaker, usually the mother; ‡ 1 USA dollar = ~7 bolivianos.

assess older children and adults as underweight, overweight and obese (Onyango et al. 2007); however, it is less accurate at predicting body fat compared with skin-fold thickness measures (Sarria et al. 1998) and is problematic in young children, especially children with failed linear growth (Duggan 2010). We did not include other skin-fold measures of body fat because of the small number of observations, and because sub-scapular skin-fold thickness is generally higher in girls than in boys (Akinbami et al. 2010).

Explanatory variable: Sibling composition. We created four variables for the following types of siblings: number of older sisters, number of older brothers, number of younger sisters and number of younger brothers. A younger or older sister or brother was any child $\leq$ 16 years of age living in the household at the time of the annual surveys who was either above or below the age of the target child. For example, the variable older brother included the total number of boys $\leq$ 16 years of age who were older than the target child. Older brother included full and half siblings on the side of the mother or father and also included more distantly related children living in the household. We used 16 years as a cut-off to define adulthood because at that age Tsimane' set up their households and stop attending school. The definition of sibling relationships in terms of co-resident as opposed to consanguineal children may be a potential limitation of the study. However, during 2009, we did a survey of 496 households in 40 Tsimane' villages outside of the panel study and found that most of the households with children were nuclear, and ~10% included grandchildren, step children or other more distantly related younger kin; in these households, field observations suggested that the household heads in these families did not treat unrelated children living in their household differently than own offspring.

Control variables. In all models, we controlled for morbidity incidences as measured by the sum of the number of days with illnesses or the number of days in bed. By doing so, we controlled for the possibility of infectious diseases and diarrhoea as these influence young children's anthropometric indicators by impairing the absorption of nutrients (Black 1991; WHO 1995; Scrimshaw and SanGiovanni 1997; Wilson et al. 1999). All models were controlled for child's age because of the association between age and child growth.

In additional specifications, we controlled for per capita household wealth or per capita household income. We ran separate regressions for wealth and income because they capture different aspects of household resources: income was based on the monetary earnings from wage-labour and sale of forest and farm goods. Thus, it was subject to greater fluctuation from year-to-year, and also differed from wealth because it was less accessible to others, or less prone to sharing with other households (Godoy et al. 2004). Wealth was based on the total real (inflation-adjusted) monetary value of a basket of physical assets owned by individuals at the time of the survey and provided a more stable measure of socioeconomic status than income. Wealth included 22 physical assets owned by individuals in the households, including traditional (e.g. canoes, bows) and modern assets (e.g. radios, axes) and domesticated animals (chickens, ducks, pigs, cattle). Based on ethnographic knowledge of the Tsimane' (Huanca 2008; Martínez-Rodríguez 2009), we included assets typically owned by females (e.g. bags, pots) and males (e.g. guns, cattle) and that capture significant wealth differences in the sample. We estimated total wealth

Table II. Descriptive statistics showing means and standard deviations of anthropometric indicators of nutritional status (outcome variables) among Tsimane' girls and boys aged 2–9 years, inclusive, surveyed annually during 2002–2007.

Anthropometry	Girls		Boys		
	Obs.	$M \pm SD$	Obs.	$M \pm SD$	t-statistic*
1. Weight-for-Height Z-score (WHZ)	1175	0.467 ± 0.698	1185	0.473 ± 0.739	−0.218
2. Mid-Upper Arm Circumference (MUAC, cm)	1175	16.347 ± 1.516	1185	16.282 ± 1.504	1.049
3. Arm-Muscle Area (AMA, cm^2)	1175	15.567 ± 3.455	1185	16.034 ± 3.608	−3.210**
4. Triceps Skin-fold Thickness (TST, mm)	1132	7.785 ± 2.296	1145	6.910 ± 2.075	9.545**

Notes: Significance level: * $p \leq 0.05$, ** $p \leq 0.01$; * Results of 2-sided t-test for the equality of means between girls and boys.

using the selling price of the assets in the village and aggregated the value by household.

Analytic procedures

In all models, we used multivariate panel linear regressions with individual, village, survey year and village-year fixed-effects with robust standard errors, while clustering by household. This approach allows for removing the effect of household level variables that might modify the association between sibling composition and child health outcomes, including household attributes such as sibling size (Desai 1995; Hagen et al. 2001), mother's health (Gabler and Voland 1994; Sear et al. 2001) and genetically inherited anthropometric traits such as parental height or weight. We also included a full set of dummy variables for survey year to remove attributes of the year that might affect child growth (e.g., abundant harvest in particular years) and a full set of dummy variables for villages to remove the effect of fixed attributes of the village that might affect child health but that remain stable during the study period (e.g. wealth inequality, proximity to health centres) (Marmot 2005). Also, a full set of interaction dummy variables between year and village was included to remove the role of year-village fixed attributes, such as food prices.

Further, we controlled for per capita household wealth or per capita household income in two additional model specifications: (1) model with wealth or income as a control and (2) model with wealth or income interacted with sibling composition. We included these specifications because we expected that household resource availability will modify the association between sibling composition and children's nutritional status (i.e. we expected significant interaction terms between sibling composition and these economic indicators). Because of inter-household and year-to-year differences in socioeconomic status, we summed the monetary value of income or assets separately, first by household, then by survey-year.

In all models, we analysed girls and boys separately. Stata for Windows, version 9 (Stata Corporation, College Station, TX) was used for the statistical analysis.

RESULTS

Description of study participants

Tsimane' children aged 2–9 years old had on average 4.07 (SD = 2.05) siblings under the age of 16 years (≤16). The average child had 1.29 (SD = 1.23) older brothers, 1.08 (SD = 1.09) older sisters, 0.84 (SD = 0.93) younger brothers and 0.80 (SD = 0.85) younger sisters.

Table II presents descriptive statistics of the anthropometric measures used in the analyses. As shown in rows 1–4, across the six survey years, boys had a significantly higher AMA ($16.03\,cm^2$) than girls ($15.57\,cm^2$; $t = -3.21$, $p \leq 0.01$) and girls had a significantly higher TST (7.78 mm, SD = 2.30) than boys (6.91 mm, SD = 2.07; $t = 9.54$, $p \leq 0.01$). When compared with US children, Tsimane' girls and boys had 0.47 higher WHZ (row 1).

Multivariate analysis

Main effects. Table III presents information on the associations between sibling composition and children's anthropometric indicators of nutritional status. In the main model (columns 4, 7), we found a consistent and significant association between an additional older brother and reduced MUAC and AMA in girls. As shown in row I-d, an additional older brother was associated with a 1.4% decrease in MUAC ($t = -2.74$; $p \leq 0.01$) (column 4) and a 4.3% decrease in AMA ($t = -2.79$; $p \leq 0.01$) (column 7). Among girls, an additional younger sister was associated with an average of 6.3% decrease in TST ($t = -2.55$; $p \leq 0.01$) (row I-a, column 10). Sibling composition was not significantly associated with anthropometric indicators in boys. In addition, siblings did not affect the WHZ of girls or boys.

Controlling for household wealth and income. Table III also presents information on the main effects model adjusted for per capita household wealth or income. We tested whether the significant associations between an additional younger sister and girls' TST and between an additional older brother and girls' MUAC and AMA still held after controlling for household resources. As shown in Table III (columns 5–6, 8–9 and 11–12), the size effect and level of statistical significance of the sibling composition variables did not vary much from the direct effects reported in columns 4, 7 and 10: controlling for income increased the size effect on MUAC and AMA by 0.1% (row I-d, column 6) and 0.2% (row I-d, column 9), respectively; controlling for wealth decreased the size effect by 0.2% (row I-a, column 11). In all other cases, the main effect results did not change after adjustment.

Interaction between sibling composition and household wealth and income. Table IV presents information on the associations between sibling composition and children's arm anthropometric indicators of nutritional status with

Table III. Association between child anthropometric indicators of nutritional status (outcome variables) and sibling composition among Tsimane' girls and boys aged 2–9 years, inclusive, surveyed annually during 2002–2007: Results of multivariate individual and village fixed-effects panel linear regressions.*

	Outcome variables: anthropometry											
	WHZ			MUAC, log			AMA, log			TST, log		
Explanatory variables	Main Model [1]	Wealth [2]	Income [3]	Main Model [4]	Wealth [5]	Income [6]	Main Model [7]	Wealth [8]	Income [9]	Main Model [10]	Wealth [11]	Income [12]
I. Girls, # of:												
a. Younger sisters	−0.068	−0.068	−0.069	−0.003	−0.003	−0.003	0.015	0.013	0.015	−0.063*	−0.061*	−0.063*
b. Older sisters	0.019	0.019	0.013	−0.002	−0.002	−0.003	−0.002	−0.006	−0.005	0.004	0.011	0.005
c. Younger brothers	0.001	0.001	0.003	−0.007	−0.007	−0.006	−0.009	−0.012	−0.008	−0.023	−0.018	−0.023
d. Older brothers	−0.035	−0.035	−0.039	−0.014**	−0.014**	−0.015**	−0.043**	−0.043**	−0.045**	0.035	0.036	0.035
II. Resources: wealth	^	0.000	^	^	0.000	^	^	0.004	^	^	−0.007	^
III. Resources: income	^	^	0.011	^	^	0.001	^	^	0.005	^	^	−0.001
Adjusted R^2	0.41	0.41	0.41	0.56	0.56	0.56	0.59	0.59	0.59	0.29	0.29	0.29
n	1158	1158	1158	1158	1158	1158	1158	1158	1158	1116	1116	1116
IV. Boys, # of:												
a. Younger sisters	0.017	0.013	0.019	−0.006	−0.006	−0.006	−0.030	−0.032	−0.029	0.035	0.037	0.033
b. Older sisters	0.006	0.003	0.005	0.002	0.002	0.002	0.000	−0.001	0.000	−0.003	−0.001	−0.001
c. Younger brothers	−0.001	−0.005	−0.000	−0.010	−0.010	−0.010	−0.022	−0.024	−0.021	−0.016	−0.013	−0.017
d. Older brothers	−0.052	−0.054	−0.053	−0.002	−0.002	−0.002	−0.006	−0.006	−0.006	0.005	0.006	0.006
V. Resources: wealth	^	0.004	^	^	0.000	^	^	0.003	^	^	−0.003	^
VI. Resources: income	^	^	0.004	^	^	0.000	^	^	0.002	^	^	−0.006
Adjusted R^2	0.38	0.38	0.38	0.49	0.49	0.49	0.53	0.54	0.53	0.34	0.34	0.34
n	1158	1158	1158	1158	1158	1158	1158	1158	1158	1118	1118	1118

Notes: Significance level: * $p \leq 0.05$, ** $p \leq 0.01$. ^ variable intentionally left out.; * Results of panel linear regressions with individual, village, year and village-year fixed-effects with clustering by household. Regressions included child's age, morbidity incidences, robust standard errors, full set of village ($n = 13$) and survey-year dummy variables ($n = 6$), year–village interaction term and constant; these are not shown.

Table IV. Association between sibling composition and arm anthropometry (outcome variables) among Tsimane' girls and boys aged 2–9 years, inclusive, surveyed annually during 2002–2007: interaction effects with per capita household *wealth* and *income*.*

	Outcome variables: arm anthropometry					
	MUAC, log		AMA, log		TST, log	
Explanatory variables	Interaction: Wealth [1]	Interaction: Income [2]	Interaction: Wealth [3]	Interaction: Income [4]	Interaction: Wealth [5]	Interaction: Income [6]
I. Girls, # of:						
a. Younger sisters	−0.015	−0.004	0.007	0.015	−0.108	−0.072*
b. Older sisters	0.005	−0.008	−0.015	−0.016	0.057	−0.013
c. Younger brothers	−0.008	0.000	−0.015	0.008	−0.003	−0.020
d. Older brothers	−0.021*	−0.010	−0.077**	−0.040*	0.078	0.054
II. Resources: wealth	−0.001	^	−0.002	^	0.001	^
III. Resources: income	^	0.002	^	0.007	^	−0.002
IV. Interaction						
a. Younger sisters*Resources	0.001	0.000	0.000	−0.001	0.004	0.003
b. Older sisters*Resources	0.000	0.002	0.001	0.003	−0.004	0.005
c. Younger brothers* Resources	0.000	−0.001	0.000	−0.004	−0.001	0.000
d. Older brothers* Resources	0.001	−0.001	0.003	−0.001	−0.004	−0.005
Adjusted R^2	0.56	0.56	0.59	0.59	0.29	0.29
n	1158	1158	1158	1158	1116	1116
V. Results of *F*-test for the statistical significance of the joint null hypothesis: *F* statistic shown						
a. Younger sisters & Younger sisters*Resources	1.14	0.17	0.26	0.33	2.74	2.99
b. Older sisters & Older sisters*Resources	0.16	1.13	0.09	0.60	0.55	0.65
c. Younger brothers & Younger brothers*Resources	1.23	0.91	0.55	0.64	0.27	0.22
d. Older brothers & Older brothers*Resources	4.51*	3.65*	5.63*	3.53*	1.44	1.70
VI. Boys,- # of:						
a. Younger sisters	−0.016	−0.005	−0.055	−0.035	0.031	0.048
b. Older sisters	−0.011	0.001	−0.062	−0.009	0.099	0.028
c. Younger brothers	−0.019	−0.010	−0.046	−0.017	0.011	−0.028
d. Older brothers	−0.007	−0.003	−0.011	−0.012	−0.043	0.007
VII. Resources: wealth	0.000	^	−0.010	^	0.000	^
VIII. Resources: income	^	0.000	^	0.000	^	0.000
IX. Interaction						
a. Younger sisters* Resources	0.001	0.000	0.001	0.001	0.001	−0.003
b. Older sisters* Resources	0.001	0.000	0.004	0.002	−0.007	−0.006
c. Younger brothers* Resources	0.001	0.000	0.001	−0.001	−0.002	0.002
d. Older brothers* Resources	0.000	0.000	0.001	0.001	0.003	−0.001
Adjusted R^2	0.49	0.49	0.54	0.53	0.34	0.34
n	1158	1158	1158	1158	1118	1118
X. Results of *F*-test for the statistical significance of the joint null hypothesis: *F* statistic shown						
a. Younger sisters & Younger sisters*Resources	0.45	0.47	2.17	1.76	0.98	0.78
b. Older sisters & Older sisters*Resources	0.66	0.13	1.67	0.49	1.41	1.92
c. Younger brothers & Younger brothers*Resources	1.02	0.96	0.98	0.66	0.25	0.31
d. Older brothers & Older brothers*Resources	0.19	0.07	0.08	0.21	0.29	0.03

Notes: Significance level: * $p \leq 0.05$, ** $p \leq 0.01$; * Same notes as in Table III. 'Resources' are household wealth or income per capita in natural logarithms.

tests for interaction effects between siblings with household resources. As shown, the interaction terms were not statistically significant and the main effects for the most part did not vary by household wealth or income. The *F*-test for the significance of the joint effects of older brother and older brother*resources on girls' MUAC and AMA were significant and are reported in row V-d, columns 1–4 ($p \leq 0.05$). The *F*-tests results further suggest that there is a significant negative correlation between the number of older brothers and girls' MUAC and AMA that is independent of household resources (row V-d, columns 1–4).

Robustness analysis

In robustness analyses, we performed a Box-Cox test on all models to assess whether using raw or log transformed dependent variables influenced the results. A significant test indicates that the model specification influences the results. The tests were significant for all models except for the ones in which TST was the dependent variable. Since the specification mattered for most models, we re-ran the regressions using the raw dependent variables. We found that the direction of associations and significance level remained the same between both specifications. Therefore, to remain consistent throughout the analyses, we used only the results from the log-transformed dependent variables. For brevity, the additional regressions are not shown. Last, to ensure that our results did not hinge on the type of anthropometric indicator used, we compared two different measures of adiposity, TST and Arm-Fat Area (calculated as $(MUAC^2/4\pi) - AMA$) (Van den Broeck et al. 1998) and found that TST provided the same regression estimates as Arm-Fat Area (data not shown).

DISCUSSION

No study to date has investigated the relation between sibling composition (number of younger sisters or brothers, number of older sisters or brothers) and children's anthropometric indicators of nutritional status. In our hypotheses, we predicted that sibling composition would be associated with anthropometric indicators of a child's nutritional status because of sibling rivalry for household resources and we expected that the associations would not differ by the sex of the sibling or child. We found support for the first prediction, but not for the second. Among girls, older brothers were associated with reduced MUAC and AMA and younger sisters were associated with reduced TST. Although the effect sizes were small, the implications of reduced arm anthropometric measures are significant. Studies in developing countries showed that MUAC is an independent indicator of malnutrition and short-term mortality (Briend et al. 1986, 1989; Pelletier 1994; Vella et al. 1994; Van den Broeck et al. 1996; Akinbami et al. 2010). For example, in a study of young children in Congo, low fatness and muscularity scores were associated with excess 3-month mortality among normal-weight children, even after controlling for sex, age, season and weight-for-age (Van den Broeck et al. 1998). Among children 1–5 years old admitted to a hospital in Nigeria for various infections, a one-unit increase in MUAC was associated with as much as a 200% increase (OR = 2.02; $p \leq 0.01$) in the odds of survival (Akinbami et al. 2010).

We predicted that controlling for per capita household wealth or income would modify the association between sibling composition and children's anthropometry, possibly attenuating the associations. We found that household resources did not mediate the association. The main effects remained mostly significant after controlling for resources and the interaction effects of sibling categories with household wealth or income were not significant, suggesting that siblings likely affect Tsimane' girls' nutritional indicators through other paths besides resource availability. Thus, the underlying mechanism may go beyond resource constraints, perhaps having more to do with unique inter-sibling behavioural dynamics.

Our findings raise several issues. First, sibling composition was associated with arm anthropometry rather than with measures based on weight or height (e.g. WHZ). A possible explanation is that weight and height are highly variable in young children during this growth-spurt period, while arm measures provide a more consistent, less age-dependent measure of a child's nutritional background (Jelliffe and Jelliffe 1969, 1971; Frisancho 1990). Arm anthropometric indicators, particularly MUAC, were found to be stronger predictors of malnutrition and short-term mortality among poor young children, while wasting and stunting thresholds, which are based on weight and height, under-estimated the prevalence of malnutrition and thereby of mortality (Briend et al. 1989; Van den Broeck et al. 1998; Akinbami et al. 2010).

Second, only older brothers were associated with reduced AMA, but only among girls. One possibility is that an older brother may prevent the development of arm muscle in younger sisters if older brothers take on chores which require greater strength, such as heavy lifting. This would be consistent with sex-typing in the allocation of household work to children (Ember 1973; Blair 1992), through, for example, the assignment of roles or imitation of parents. Previous research among the Tsimane' suggested that ~50% of all work activities are highly segregated by sex. Men's activities mostly included hunting and heavy farm labour, while women's activities were primarily food preparation and cooking (Gurven et al. 2009). It is also possible that older brothers consume more protein-rich foods as a result of, for example, game sharing during hunting trips (Gurven et al. 2006), or have a more balanced diet than their younger sisters. Biomedical mechanisms may also underlie this association. It is well documented in both animal and human studies that male offspring are more costly to mothers (Clutton-Brock et al. 1981; Tamimi et al. 2003). Older brothers were associated with a delayed age at menarche in younger sisters (Milne and Judge 2011). A study from Denmark found that, after adjusting for important determinants of low birth-weight, older brothers were associated with reduced birth-weight of younger siblings of either sex, due in part to a shorter gestation period (Nielsen et al. 2008). The maternal immune reaction against male-specific H-Y antigens initiated after a pregnancy with a boy may cause inflammatory processes leading to insufficient placental function and consequently low-birth weight (Bartha et al. 2003; Nielsen et al. 2008). In turn, low-birth weight has been associated with lower AMA at birth, reduced grip strength and reduced fat mass in young children (Fewtrell et al. 2004; Barr et al. 2010). Yet others suggest that morbidity and socioeconomic factors rather than birth-weight are greater determinants of children's arm anthropometrics (Lima et al. 2011).

Third, younger sisters were associated with reduced arm adiposity in their older sisters, suggesting a drawdown on their energy reserves. A possible explanation is that, among Tsimane', an older sister has the responsibility of caring for her younger siblings, including feeding, cleaning and comforting the younger sibling and will relinquish this role only after she has her own children (Zeng et al. 2012). The alloparenting role of girls is well-documented in many societies (for a review, see Sear and Mace 2008). Thus, it is possible that in older sisters the physical and mental effort of care-giving, particularly of their younger sisters, translated into increased energy expenditure. Older sisters with care-giving responsibilities may also have less time and opportunities to eat frequently.

Fourth, household resource had no modifying or interactive effect on these associations. One possible explanation may pertain to the fact that Tsimane' are severely resource-constrained compared with people in industrial societies, but they also live in a more egalitarian society (Undurraga et al. 2010). Tsimane' are linked by a wide kinship network marked by ubiquitous sharing and reciprocity. It is possible that household material resources do not affect child anthropometry because any negative effect is attenuated by the sharing of food and caretaking responsibilities for children. Our observational field studies suggest that Tsimane' households typically maintain open access to food both inside and outside the house (e.g. fields, home gardens, open-kitchens) and that even young children do not have problems accessing food on their own. We found no significant role for childhood household resources in another recent study examining the association between sibling composition and adult blood pressure (Zeng et al. 2012).

Our findings suggest that there is a significant association between sibling composition and children's anthropometric indicators of nutritional status that is independent of household resources in this small-scale society. The underlying mechanism is unclear and may be explained by factors beyond lack of material resources such as adaptive evolutionary propensities and local social and economic conditions. Future studies should more closely examine the specific dynamics between different types of siblings. The different associations between sibling types and children's anthropometry highlight the value of using disaggregated sibling categories to gain a firmer grasp of how intra-household dynamics might affect child well-being. Furthermore, our findings may help inform health policy interventions by improving our understanding of the impact of additional children and of sibling composition on children's nutritional status and, ultimately, incorporating household dynamics in the design of policies that focus on vulnerable children.

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